KSIT BANGLORE

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

COURSE FILE

NAME OF THE STAFF	:	Pooja S.
SUBJECT CODE/NAME	:	17EC81/Wireless Cellular & 4G LTE Broadband
SEMESTER/YEAR	:	8^{th} Sem/4^{th} Year
ACADEMIC YEAR	:	2020 – 2021
BRANCH	:	ECE

COURSE IN-CHARGE

HOD

K. S. INSTITUTE OF TECHNOLOGY

VISION

"To impart quality technical education with ethical values, employable skills and research to achieve excellence".

MISSION

- **To attract and retain highly qualified, experienced & committed faculty.**
- **To create relevant infrastructure.**
- **Network with industry & premier institutions to encourage emergence of new ideas by providing research & development facilities to strive for academic excellence.**
- **To inculcate the professional & ethical values among young students with employable skills & knowledge acquired to transform the society.**

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

VISION

"To achieve excellence in academics and research in Electronics & Communication Engineering to meet societal need".

MISSION

- To impart quality technical education with the relevant technologies to produce industry ready engineers with ethical values.
- To enrich experiential learning through active involvement in professional clubs & societies.
- To promote industry-institute collaborations for research & development.

K.S. INSTITUTE OF TECHNOLOGY
Department: Electronics and Communication Engg.

PROGRAM EDUCATIONAL OBJECTIVES (PEO'S)

- Excel in professional career by acquiring domain knowledge.
- Motivation to pursue higher Education & research by adopting technological innovations by continuous learning through professional bodies and clubs.
- To inculcate effective communication skills, team work, ethics and leadership qualities.

PROGRAM SPECIFIC OUTCOMES (PSO'S)

PSO1: Graduate should be able to understand the fundamentals in the field of Electronics & Communication and apply the same to various areas like Signal processing, embedded systems, Communication & Semiconductor technology.

PSO2: Graduate will demonstrate the ability to design, develop solutions for Problems in Electronics & Communication Engineering using hardware and software tools with social concerns.

PO: PROGRAM OUTCOME

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

K. S. INSTITUTE OF TECHNOLOGY

#14, Raghuvanahalli, Kanakapura Main Road, Bengaluru-5600109

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Course: Wireless Cellular and LTE 4G Broadband			
Course In-Charge: Dr. Sangappa, Mrs.Pooja S			
Type: Core		**Course Code:**17EC81	
No of Hours per week			
Theory (Lecture Class)	Practical/Field Work/Allied Activities	Total/Week	Total teaching hours
4	0	4	50
Marks			
Internal Assessment	Examination	Total	Credits
40	60	100	4

Aim/Objective of the Course:

- Understand the basics of LTE standardization phases and specifications.
- Explain the system architecture of LTE and E-UTRAN, the layer of LTE, based on the use of OFDMA and SC-FDMA principles.
- Analyze the role of LTE radio interface protocols to set up, reconfigure and release the Radio Bearer, for transferring the EPS bearer.
- Analyze the main factors affecting LTE performance including mobile speed and transmission bandwidth.

Course Learning Outcomes:

After completing the course, the students will be able to,

CO1	Make use of the system architecture and the functional standard specified in LTE 4G.	Applying (K3)
CO2	Identify the role of the layer of LTE radio interface protocols and EPS Data convergence protocols to set up, reconfigure and release data and voice from users.	Applying (K3)
CO3	Establish the UTRAN and EPS handling processes from set up to release including mobility management for a variety of data call scenarios.	Applying (K3)
CO4	Identify the difference between uplink , down link and the physical layer procedures that provide the services to upper layers.	Applying (K3)
CO5	Evaluate the Performance of resource management and packet data processing and transport algorithms.	Applying (K3)

Syllabus Content:	
Module 1: Key Enablers for LTE features: OFDM, Single carrier FDMA, Single carrier FDE, Channel Dependent Multiuser Resource Scheduling, Multi antenna Techniques, IP based Flat network Architecture, LTE Network Architecture. Wireless Fundamentals: Cellular concept, Broadband wireless channel (BWC), Fading in BWC, Modeling BWC – Empirical and Statistical models, Mitigation of Narrow band and Broadband Fading. LO: At the end of this session the student will be able to, 1. Understand the LTE Architecture. 2. Explain the cellular concepts and broadband fading techniques.	CO1 CO4 10hrs PO1-3 PO2-1 PO3-1 PO4 – 1 PO5 – 1 PO6 – 1 PO9-2 PO10 -2 PO12 -1

Module 2: Multicarrier Modulation: OFDM basics, OFDM in LTE, Timing and Frequency Synchronization, PAR, SC-FDE (Sec 3.2 – 3.6 of Text). OFDMA and SC-FDMA:OFDM with FDMA,TDMA,CDMA, OFDMA, SC-FDMA, OFDMA and SC-FDMA in LTE (Sec 4.1 – 4.3, 4.5 of Text). Multiple Antenna Transmission and Reception: Spatial Diversity overview, Receive Diversity, Transmit Diversity, Interference cancellation and signal enhancement, Spatial Multiplexing, Choice between Diversity, Interference suppression and Spatial Multiplexing. LO: At the end of this session the student will be able to, 1. Explain the concepts of multicarrier modulation. 2. Classify different types of multiple access techniques. 3. Understand the diversity techniques used in antennas.	CO2 10hrs. PO1-3 PO2-2 PO3-1 PO4 – 1 PO5 – 1 PO6 – 1 PO9-2 PO10 -2 PO12 -1

Module 3 Overview and Channel Structure of LTE: Introduction to LTE, Channel Structure of LTE, Downlink OFDMA Radio Resource, Uplink SC-FDMA Radio Resource. Downlink Transport Channel Processing: Overview, Downlink shared channels, Downlink Control Channels, Broadcast channels, Multicast channels, Downlink physical channels, H-ARQ on Downlink. LO: At the end of this session the student will be able to, 1. Establish the relation between uplink and downlink channels. 2. Understand the various radio resources used in OFDMA.	CO3 CO5 10hrs PO1-3 PO2-2 PO3-2 PO4 – 1 PO5 – 1 PO6 – 1 PO9-2 PO10 -2 PO12 -1
Module 4: Uplink Channel Transport Processing: Overview, Uplink shared channels, Uplink Control Information, Uplink Reference signals, Random Access Channels, H-ARQ on uplink. Physical Layer Procedures: Hybrid – ARQ procedures, Channel Quality Indicator CQI feedback, Precoder for closed loop MIMO Operations, Uplink channel sounding, Buffer status Reporting in uplink, Scheduling and Resource Allocation, Cell Search, Random Access Procedures, Power Control in uplink. LO: At the end of this session the student will be able to, 1. Understand the physical layer procedures used in LTE system. 2. Identify the uplink transport channel processing signals. 3. Evaluate the precoder used for MIMO techniques.	CO4 10hrs PO1-3 PO2-2 PO3-2 PO4 – 1 PO5 – 1 PO6 – 1 PO9-2 PO10 -2 PO12 -1
Module 5: Radio Resource Management and Mobility Management: PDCP overview, MAC/RLC overview, RRC overview, Mobility Management, Inter-cell Interference Coordination LO: At the end of this session the student will be able to, 1. Understand the purpose of MAC and RLC layers. 2. Explain the intercell Interfernce Coordination. 3. Identify the RAN procedures for Mobility.	CO5 10hrs PO1-3 PO2-1 PO4 – 1 PO6 – 1 PO9-2 PO10 -2 PO12 -1

Text Books: - (specify minimum two foreign authors text books)

Arunabha Ghosh, Jan Zhang, Jefferey Andrews, Riaz Mohammed, 'Fundamentals of LTE', Prentice Hall, Communications Engg. and Emerging Technologies.

Reference Books:

1. LTE for UMTS Evolution to LTE-Advanced' Harri Holma and Antti Toskala, Second Edition - 2011, John Wiley & Sons, Ltd. Print ISBN: 9780470660003.

2. 'EVOLVED PACKET SYSTEM (EPS) ; THE LTE AND SAE EVOLUTION OF 3G UMTS' by Pierre Lescuyer and Thierry Lucidarme, 2008, John Wiley & Sons, Ltd. Print ISBN:978-0-470-05976-0.

3. 'LTE – The UMTS Long Term Evolution ; From Theory to Practice' by Stefania Sesia, Issam Toufik, and Matthew Baker, 2009 John Wiley & Sons Ltd, ISBN 978-0-470-69716-0.

Useful Websites

- https://www.youtube.com/watch?v=1JZG9x_VOwA
- https://www.youtube.com/watch?v=iS8jmhVAfoQ
- https://www.youtube.com/watch?v=qNSaaRRkEnQ

Useful Journals

- Journal of Electronics and Communication system.
- Journal of Analog and Digital Communication system.

Teaching and Learning Methods:

1. Lecture class: 50 hrs.
2. Self-study: 4hrs.

Assessment:

Type of test/examination: Written examination
Continuous Internal Evaluation(CIE) : 20 marks (Average of best two of total three tests will be considered)

Semester End Exam(SEE) : 80 marks (students have to answer all main questions)
Test duration: 1 :30 hr
Examination duration: 3 hrs

CO to PO Mapping

PO1: Science and engineering Knowledge **PO2:** Problem Analysis **PO3:** Design & Development **PO4:** Investigations of Complex Problems **PO5:** Modern Tool Usage **PO6:** Engineer & Society	**PO7:** Environment and Society **PO8:** Ethics **PO9:** Individual & Team Work **PO10:** Communication **PO11:** Project Mngmt & Finance **PO12:** Lifelong Learning

PSO1: Graduate should be able to understand the fundamentals in the field of Electronics and Communication and apply the same to various like signal processing, embedded systems, communication and semi-conductor technology.

PSO2: Graduate will demonstrate the ability to design, develop solutions for problems in electronics and Communication engineering using hardware and software tools with social concerns.

COURSE NAME- WIRELESS CELLULAR & LTE 4G BROADBAND COURSE CODE-17EC81

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
17EC81.1	3	2	–	–	–	–	–	–	–	–	–	–
17EC81.2	3	2	–	–	–	–	–	–	–	–	–	–
17EC81.3	3	2	–	–	–	–	–	–	–	–	–	–
17EC81.4	3	2	–	–	–	–	–	–	–	–	–	–
17EC81.5	3	2	–	–	–	–	–	–	–	–	–	–
17EC81	3	2	–	–	–	–	–	–	–	–	–	–

CO – PSO Mapping

CO	PSO1	PSO2
17EC81.1	3	2
17EC81.2	3	2
17EC81.3	3	2
17EC81.4	3	2
17EC81.5	3	2
17EC81	3	2

Course In-charge | Module Coordinator | HOD

K. S INSTITUTE OF TECHNOLOGY, BENGALURU-560109

TENTATIVE CALENDAR OF EVENTS: EVEN SEMESTER (2020-2021)

SESSION: APR 2021 - AUG2021

Week No.	Month	Day						Days	Activities
		Mon	Tue	Wed	Thu	Fri	Sat		
1	APR	19 *	20	21	22	23	24	6	19*-Commencement of Higher Semester 24 Wednersday Time Table
2	APR/MAY	26	27	28	29	30	1	5	1 May Day
3	MAY	3	4	5	6	7	8	6	8 Monday Time Table
4	MAY	10	11	12	13	14	15DH	3	13 Idul Fitr 14 Basava Jayanti
5	MAY	17	18	19	20	21	22TA	6	22 Tuesday Time Table
6	MAY	24 T1	25T1	26T1	27	28	29DH	5	
7	MAY/JUN	31	1	2	3	4	5ASD	6	5 Wednersday Tme Table
8	JUN	7	8	9	10	11	12DH	5	
9	JUN	14	15	16	17	18	19	6	19 Monday Time Table
10	JUN	21	22	23	24	25TA	26DH	5	
11	JUN/JUL	28 T2	29T2	30T2	1	2	3	6	3 Thursday time Table
12	JUL	5	6	7	8	9ASD	10DH	5	
13	JUL	12	13	14	15	16	17	6	17 Tuesday Time Table
14	JUL	19 T3(VIII)	20 * T3(VIII)	21	22	23	24DH	4	20 *VIII Sem Last working day 21 Bakrid / Eid al Adha
15	JUL	26	27	28TA	29	30	31	6	
16	AUG	2	3	4	5 T3	6 T3	7*T3	6	7 Wednersday Tme Table
17	AUG	9	10LT	11LT	12LT	13LT	14LT	6	14* IV &VI Last working day

Total No of Working Days : 92

Total Number of working days (Excluding holidays and Tests)=79

H	Holiday
T1,T2, T3	Tests 1,2, 3
ASD	Attendance & Sessional Display
DH	Declared Holiday
LT	Lab Test
TA	Test attendance

Monday	16
Tuesday	16
Wednesday	16
Thursday	16
Friday	15
Total	**79**

PRINCIPAL
K.S. INSTITUTE OF TECHNOLOGY
BENGALURU - 560 109.

K. S INSTITUTE OF TECHNOLOGY, BENGALURU-560109

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

TENTATIVE CALENDAR OF EVENTS: EVEN SEMESTER (2020-2021)

SESSION: APR 2021 - AUG2021

Week No.	Month	Day						Days	Activities	Department Activities Tentative Dates
		Mon	Tue	Wed	Thu	Fri	Sat			
1	APR	19 *	20	21	22	23	24	6	19*-Commencement of Higher Semester 24 Wednesday Time Table	
2	APR/MAY	26	27	28	29	30	[redacted]	5	1 May Day	
3	MAY	3	4	5	6	7	8	6	8 Monday Time Table	3rd - 8th May AICTE - ISTE Induction / Refresher programme (FDP)
4	MAY	10	11	12	[redacted]	[redacted]	15DH	3	13 Idul Fitr 14 Basava Jayanti	
5	MAY	17	18	19	20	21	22TA	6	22 Tuesday Time Table	
6	MAY	24 T1	25T1	26T1	27	28	29DH	5		24th - 29th May AICTE - ISTE Induction / Refresher programme (FDP)
7	MAY/JUN	31	1	2	3	4	5ASD	6	5 Wednersday Tme Table	5th June IEEE KSIT SB Digital Siganal Processing Applications using MATLAB
8	JUN	7	8	9	10	11	12DH	5		11th June IETE Webinar, 11th June IEEE Power of Positive Thoughts Webinar
9	JUN	14	15	16	17	18	19	6	19 Monday Time Table	14th June Internet Communication and Networking Webinar 15th June IEEE KSIT SB CREAT WIE TI Inter college Art Competation
10	JUN	21	22	23	24	25TA	26DH	5		
11	JUN/JUL	28 T2	29T2	30T2	1	2	3	6	3 Thursday time Table	2nd July IETE Webinar
12	JUL	5	6	7	8	9ASD	10DH	5		
13	JUL	12	13	14	15	16	17	6	17 Tuesday Time Table	14th July ASH in association with IEEE-WIE Webinar
14	JUL	19 T3(VIII)	20 * T3(VIII)	[redacted]	22	23	24DH	4	20 *VIII Sem Last working day 21 Bakrid / Eid al Adha	19th July IEEE KSIT SB FOUS FLOW Webinar
15	JUL	26	27	28TA	29	30	31	6		29,30,31 Practice Lab
16	AUG	2	3	4	5 T3	6 T3	7*T3	6	7 Wednersday Tme Table	2,3,4 Practice Lab
17	AUG	9	10LT	11LT	12LT	13LT	14LT	6	14* IV &VI Last working day	10,11,12,13,14, 1st &2nd Lab Internals

Total No of Working Days : 92

Total Number of working days (Excluding holidays and Tests)=79

H	Holiday
T1,T2, T3	Tests 1,2, 3
ASD	Attendance & Sessional
DH	Declared Holiday
LT	Lab Test
TA	Test attendance

Monday	16
Tuesday	16
Wednesday	16
Thursday	16
Friday	15
Total	**79**

Kumar

7/8/2021

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE -109

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

INDIVIDUAL TIME TABLE FOR THE YEAR - 2021 (EVEN SEMESTER)

W.E.F. : 19/4/2021

ONLINE TIME TABLE

NAME OF THE FACULTY : Mrs. POOJA S

DESIGNATION: ASSISTANT PROFESSOR

PERIOD	1	2		3	4		5	6
TIME / DAY	9.00 AM 10.00 AM	10.00 AM 11.00 AM	11.00 AM 11.15 AM	11.15 AM 12.15 PM	12.15 PM 1.15 PM	1.15 PM 1.45 PM	1.45 PM 2.45 PM	2.45 PM 3.45 PM
MON		WC (17EC81)	TEA BREAK	RE (17EC833)	WC (17EC81)	LUNCH BREAK	SEMINAR B	
TUE	RE (17EC833)			WC (17EC81)			SEMINAR A	
WED	RE (17EC833)	WC (17EC81)			RE (17EC833)			
THU								
FRI								

	Subject Code	Subject Name	Sem	Section	Work Load
Subject 1	17EC81	Wireless Cellular and LTE 4G Broadband	VIII	B	4
Subject 2	17EC833	Radar Engineering	VIII	A&B	4
MiniProject	18ECMP68	Mini-Project (Coordinator)	VI	A&B	2
Internship	17EC84	Internship/Professional Practice	VIII		2
Project	17ECP85	Project Work	VIII		2
Seminar	17ECS86	Seminar	VIII	A&B	3
ADDITIONAL WORK: MENTORING AND OTHERS					
TOTAL LOAD= 17 Hrs/Week					

Time Table Co-ordinator

HOD 19/4

HEAD OF THE DEPARTMENT
Dept. of Electronics & Communication Engg
K.S. Institute of Technology
Bengaluru - 560 109

Principal

PRINCIPAL
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DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

VIII SEMESTER TIME TABLE FOR THE YEAR 2021 (EVEN SEMESTER)

W.E.F. : 19/04/2021 **ONLINE TIME TABLE** **CLASS TEACHER : Mrs. Pooja S**

SEC : 'B'

PERIOD	1	2		3	4		5	6
TIME / DAY	9.00 AM 10.00 AM	10.00 AM 11.00 AM	11.00 AM 11.15 AM	11.15 AM 12.15 PM	12.15 PM 1.15 PM	1.15 PM 1.45 PM	1.45 PM 2.45 PM	2.45 PM 3.45 PM
MON	FON (17EC82)	WC (17EC81)	TEA BREAK	RE(17EC833) / NCS(17EC835)	WC (17EC81)	LUNCH BREAK	INTERNSHIP (17EC84)	
TUE	RE(17EC833) / NCS(17EC835)	FON (17EC82)		WC (17EC81)	FON (17EC82)		SEMINAR (17ECS86)	
WED	RE(17EC833) / NCS(17EC835)	WC (17EC81)		FON (17EC82)	RE(17EC833) / NCS(17EC835)			
THU				PROJECT WORK				
FRI				PROJECT WORK				

Sub-Code	Subject Name	Faculty Name
17EC81	Wireless Cellular and LTE 4G Broadband	Mrs. Pooja S
17EC82	Fiber Optics & Networks	Mr. Saleem S Tevaramani
17EC833	Radar Engineering (Professional Elective-5)	Mrs. Pooja S
17EC835	Network and Cyber Security (Professional Elective-5)	Dr. B Surekha
17EC84	Internship/Professional Practice	Mr. Praveen . A , Mr. Saleem S Tevaramani
17ECP85	Project Work	Dr.B.Sudharshan , Mrs. Pooja S
17ECS86	Seminar	Dr. B Surekha, Mrs. Pooja S

V. S

Time Table Co-ordinator

HOD
F/C

Principal

B.E E&C EIGTH SEMESTER SYLLABUS

WIRELESS CELLULAR and LTE 4G BROADBAND B.E., VIII Semester, Electronics &Communication Engineering/ Telecommunication Engineering [As per Choice Based Credit System (CBCS) Scheme]			
Course Code	**17EC81**	**CIE Marks**	**40**
Number of Lecture	**04**	**SEE Marks**	**60**
Total Number	**50 (10 Hours / Module)**	**Exam Hours**	**03**
CREDITS – 04			

Course Objectives: This course will enable students to:

- Understand the basics of LTE standardization phases and specifications.
- Explain the system architecture of LTE and E-UTRAN, the layer of LTE, based on the use of OFDMA and SC-FDMA principles.
- Analyze the role of LTE radio interface protocols to set up, reconfigure and release the Radio Bearer, for transferring the EPS bearer.
- Analyze the main factors affecting LTE performance including mobile speed and transmission bandwidth.

Module – 1

Key Enablers for LTE features: OFDM, Single carrier FDMA, Single carrier FDE, Channel Dependent Multiuser Resource Scheduling, Multi antenna Techniques, IP based Flat network Architecture, LTE Network Architecture. (Sec 1.4- 1.5 of Text).

Wireless Fundamentals: Cellular concept, Broadband wireless channel (BWC), Fading in BWC, Modeling BWC – Empirical and Statistical models, Mitigation of Narrow band and Broadband Fading (Sec 2.2 – 2.7of Text). **L1, L2**

Module – 2

Multicarrier Modulation: OFDM basics, OFDM in LTE, Timing and Frequency Synchronization, PAR, SC-FDE (Sec 3.2 – 3.6 of Text).

OFDMA and SC-FDMA:OFDM with FDMA,TDMA,CDMA, OFDMA, SC-FDMA, OFDMA and SC-FDMA in LTE (Sec 4.1 – 4.3, 4.5 of Text).

Multiple Antenna Transmission and Reception: Spatial Diversity overview, Receive Diversity, Transmit Diversity, Interference cancellation and signal enhancement, Spatial Multiplexing, Choice between Diversity, Interference suppression and Spatial Multiplexing (Sec 5.1 – 5.6 of Text). **L1, L2**

Module – 3

Overview and Channel Structure of LTE: Introduction to LTE, Channel Structure of LTE, Downlink OFDMA Radio Resource, Uplink SC-FDMA Radio Resource(Sec 6.1 – 6.4 of Text).

Downlink Transport Channel Processing: Overview, Downlink shared

channels, Downlink Control Channels, Broadcast channels, Multicast channels, Downlink physical channels, H-ARQ on Downlink(Sec 7.1 – 7.7 of Text). L1, L2
Module – 4
Uplink Channel Transport Processing: Overview, Uplink shared channels, Uplink Control Information, Uplink Reference signals, Random Access Channels, H-ARQ on uplink (Sec 8.1 – 8.6 of Text). **Physical Layer Procedures: Hybrid – ARQ procedures, Channel Quality Indicator CQI feedback, Precoder for closed loop MIMO Operations, Uplink channel sounding, Buffer status Reporting in uplink, Scheduling and Resource Allocation, Cell Search, Random Access Procedures, Power Control in uplink(Sec 9.1- 9.6, 9.8, 9.9, 9.10 Text). L1, L2**
Module – 5
Radio Resource Management and Mobility Management: PDCP overview, MAC/RLC overview, RRC overview, Mobility Management, Inter-cell Interference Coordination (Sec 10.1 – 10.5 of Text). **L1, L2**
Course Outcomes: At the end of the course, students will be able to: • Understand the system architecture and the functional standard specified in LTE 4G. • Analyze the role of LTE radio interface protocols and EPS Data convergence protocols to set up, reconfigure and release data and voice from users. • Demonstrate the UTRAN and EPS handling processes from set up to release including mobility management for a variety of data call scenarios. • Test and Evaluate the Performance of resource management and packet data processing and transport algorithms.
Text Book:
Arunabha Ghosh, Jan Zhang, Jefferey Andrews, Riaz Mohammed, 'Fundamentals of LTE', Prentice Hall, Communications Engg. and Emerging Technologies.
Reference Books: 1. LTE for UMTS Evolution to LTE-Advanced' Harri Holma and Antti Toskala, Second Edition - 2011, John Wiley & Sons, Ltd. Print ISBN: 9780470660003. 2. 'EVOLVED PACKET SYSTEM (EPS) ; THE LTE AND SAE EVOLUTION OF 3G UMTS' by Pierre Lescuyer and Thierry Lucidarme, 2008, John Wiley & Sons, Ltd. Print ISBN:978-0-470-05976-0. 3. 'LTE – The UMTS Long Term Evolution ; From Theory to Practice' by Stefania Sesia, Issam Toufik, and Matthew Baker, 2009 John Wiley & Sons Ltd, ISBN 978-0-470-69716-0.

K S INSTITUTE OF TECHNOLOGY BANGALORE
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COURSE PLAN EVEN SEM-2020-21

NAME OF THE STAFF : **Mrs. POOJA S**

SUBJECT CODE/NAME : **17EC81/WIRELESS CELLULAR AND LTE 4G BROADBAND**

SEMESTER/SEC : **VIII SEM /B**

ACADEMIC YEAR : **2020-2021**

Sl. No.	Topic to be covered	Mode of Delivery	Teaching Aid	No. of Periods	Cumulative No. of Periods	Proposed Date
	Module -1: Key Enablers for LTE & Wireless Fundamentals					
1	Introduction to Wireless Communication	L+AV	LCD	1	1	19/4/2021
2	Key Enablers for LTE features: OFDM	L+ D	LCD+BB	1	2	19/4/2021
3	Single carrier FDMA, Single carrier FDE	L+ D	LCD+BB	1	3	20/4/2021
4	Channel Dependent Multiuser Resource Scheduling, Multiantenna Techniques	L+D	LCD+BB	1	4	21/4/2021
5	IP based Flat network Architecture, LTE Network Architecture	L+D	LCD+BB	1	5	26/4/2021
6	Wireless Fundamentals:Cellular concept,	L+D	LCD+BB	1	6	26/4/2021
7	Broadband wireless channel (BWC),	L+D	LCD+BB	1	7	27/4/2021
8	Fading in BWC,	L+D	LCD+BB	1	8	28/4/2021
9	Modeling BWC- Empirical and Statistical models	L+D	BB	1	9	03/5/2021
10	Mitigation of Narrow band and Broadband Fading	L+D	BB	1	10	03/5/2021
11	**Quiz and class test**	L+D	BB	1	11	04/5/2021
	Module -2: Multicarrier Modulation & Multiple Antenna Transmission and Reception					
12	Multicarrier Modulation:OFDM basics	L+ D	BB	1	12	05/5/2021

13	OFDM in LTE	L+D	BB	1	13	10/5/2021
14	Timing and Frequency Synchronization	L+D, PS	BB	1	14	10/5/2021
15	Peak-to-Average Ratio, SC-FDE	L+D, PS	BB	1	15	11/5/2021
16	OFDM with FDMA,TDMA,CDMA, OFDMA,	L+D, PS	BB	1	16	12/5/2021
17	SC-FDMA, OFDMA and SC-FDMA in LTE	L+D, PS	BB	1	17	17/5/2021
17	Multiple Antenna Transmission and Reception:	L+D, PS	BB	1	18	17/5/2021
18	Spatial Diversity overview, Receive Diversity, Transmit Diversity	L+D	BB	1	19	18/5/2021
19	Interference cancellation and signal enhancement	L+D	BB	1	20	19/5/2021
20	Spatial Multiplexing	L+D	BB	1	21	31/5/2021
21	**Quiz and class test**			1	22	31/5/2021
	Module - 3: Channel Structure of LTE&Downlink Transport Channel Processing					
23	Introduction to LTE	L+D	BB	1	23	01/6/2021
24	Channel Structure of LTE	L+D	BB	1	24	02/6/2021
25	Downlink OFDMA Radio Resource	L+D	BB	1	25	07/6/2021
26	Uplink SC-FDMA Radio Resource	L+D	BB	1	26	07/6/2021
27	Downlink Transport Channel Processing:Overview,	L+D	BB	1	27	08/6/2021
28	Downlink shared channels, Downlink Control Channels	L+D	BB	1	28	09/6/2021
29	Broadcast channels	L+D	BB	1	29	14/6/2021
30	Multicast channels	L+D	BB	1	30	14/6/2021
31	Downlink physical channels	L+D	BB	1	31	15/6/2021
32	H-ARQ on Downlink	L+D	BB	1	32	16/6/2021
	Module -4: Uplink Channel Transport Processing & Physical Layer Procedures					
33	Uplink Channel Transport Processing: Overview	L+AV	LCD	1	33	21/6/2021
34	Uplink shared channels	L+D	BB	1	34	21/6/2021
35	Uplink Control Information	L+D	BB	1	35	22/6/2021
36	Uplink Reference signals	L+D	BB	1	36	23/6/2021
37	Random Access Channels	L+D	BB	1	37	05/7/2021
38	H-ARQ on uplink, Hybrid – ARQ procedures	L+D	BB	1	38	05/7/2021
39	Channel Quality Indicator CQI feedback	L+D	BB	1	39	06/7/2021
40	Precoder for closed loop MIMO Operations	L+D	BB	1	40	07/7/2021
41	Uplink channel sounding, Buffer status Reporting in uplink	L+D	BB	1	41	12/7/2021
42	Scheduling and Resource Allocation	L+D	BB	1	42	12/7/2021

43	Cell Search, Random Access Procedures, Power control in the uplink	L+D	BB	1	43	13/7/2021
Module -5: Radio Resource Management & Mobility Management						
44	PDCP overview	L+AV	LCD	1	44	14/7/2021
45	MAC overview	L+D	BB	1	45	19/7/2021
46	RLC overview	L+D	BB	1	46	19/7/2021
47	RRC overview	L+D	BB	1	47	20/7/2021
48	Mobility Management	L+D	BB	1	48	26/7/2021
49	Mobility Management Techniques	L+D	BB	1	49	26/7/2021
50	Interference	L+D	BB	1	50	27/7/2021
51	Inter-cell Interference Coordination	L+D	BB	1	51	28/7/2021
52	Quiz	L+D	BB	1	52	2/8/2021
53	Revision	L+D	BB	1	53	3/8/2021
54	Revision	L+D	BB	1	54	4/8/2021

Text Book:

Arunabha Ghosh, Jan Zhang, Jefferey Andrews, Riaz Mohammed, 'Fundamentals of LTE', Prentice Hall, Communications Engg and Emerging Technologies.

Reference Books:

1. 'LTE for UMTS Evolution to LTE-Advanced' Harri Holma and Antti Toskala, Second Edition - 2011, John Wiley & Sons, Ltd. Print ISBN:9780470660003.
2. 'EVOLVED PACKET SYSTEM (EPS) ; THE LTE AND SAE EVOLUTION OF 3G UMTS' by Pierre Lescuyer and Thierry Lucidarme, 2008, John Wiley & Sons, Ltd. Print ISBN:978-0-470-05976-0.
3. 'LTE – The UMTS Long Term Evolution ; From Theory to Practice' by Stefania Sesia, Issam Toufik, and Matthew Baker, 2009 John Wiley & Sons Ltd, ISBN 978-0-470-69716-0.

Course in charge **Module Coordinator** **ECE - HOD**

K.S. Institute of Technology, Bangalore

DEPARTMENT OF
ELECTRONICS & COMMUNICATION ENGINEERING

ASSIGNMENT QUESTIONS

Academic Year	2020-21		
Batch	2017-2021		
Year/Semester/section	IV/VIII/ A & B		
Course Code-Title	17EC81-Wireless Cellular & LTE 4G Broadband		
Name of the Instructor	Pooja S	Dept	ECE

Assignment No: 1 **Total marks:10**
Date of Issue: 17/5/2021 **Date of Submission: 23/5/2021**

Sl.No	Assignment Questions	K Level	CO	Marks
1.	**Identify** the advantages of OFDM in LTE.	K3 [Applying]	1	1
2.	**Identify** the key enabling technologies and features of LTE.	K3 [Applying]	1	1
3.	**Establish** why the IP based network architecture is called flat and discuss its working in detail. **Identify** the different techniques used for tuning Adaptive Modulation and Coding.	K3 [Applying]	1	1
4.	**Identify** the different multi-antenna techniques used in LTE. Elaborate Fading in a Broadband Wireless Channel.	K3 [Applying]	1	1
5.	**Identify** the new nodes in the Evolved Packet Core network architecture and elaborate their working in it.	K3 [Applying]	1	1
6.	**Identify** the mathematical equations representing Pathloss and Shadowing in an LTE system and elaborate its effect in the LTE system	K3 [Applying]	1	1
7.	**Distinguish** the effect of a) Delay Spread and Coherence Bandwidth b) Doppler Spread and Coherence Time in an LTE system with the necessary equations.	K3 [Applying]	2	1
8.	**Identify** the different blocks in an OFDM Communication System and explain with the help of a neat block diagram.	K3 [Applying]	2	1
9.	Write the block diagram of an OFDMA downlink transmitter and **explain** its operation	K2 [Understanding]	2	1
10.	Write the block diagram of an SCFDMA uplink transmitter and **explain** its operation	K2 [Understanding]	2	1

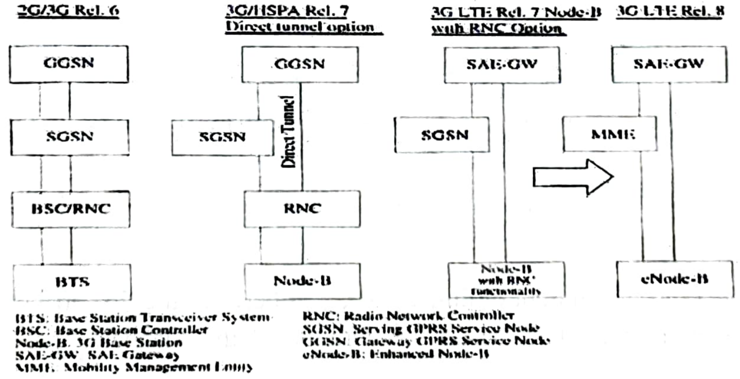
Course In charge HOD

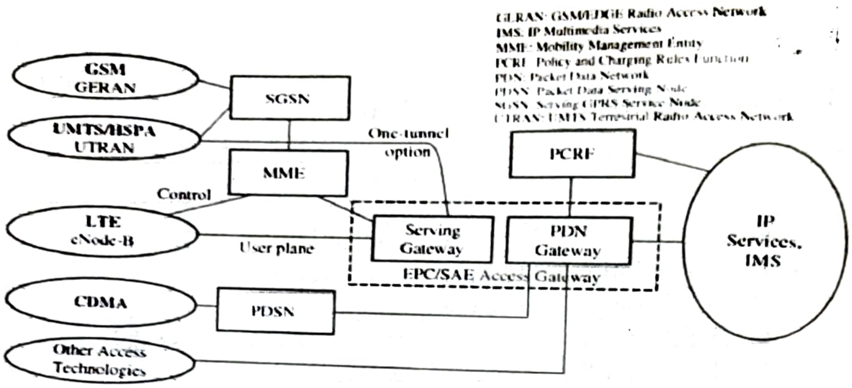
K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

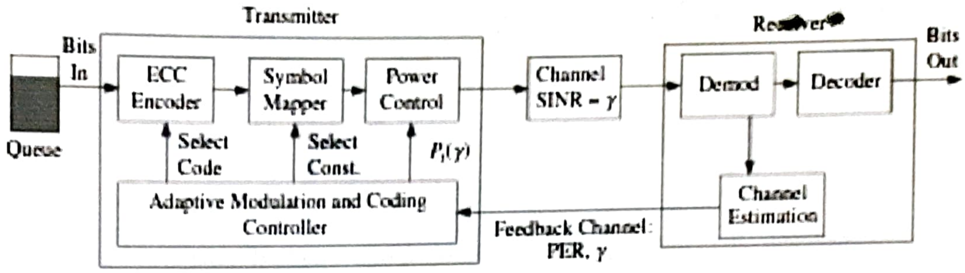
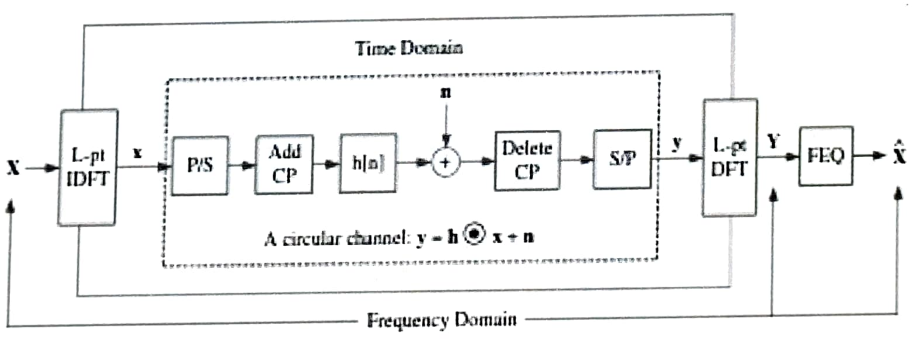
ASSIGNMENT - I 2020 – 21 EVEN SEMESTER

SCHEME AND SOLUTION

Degree: B.E. **Semester: VIII**
Branch: ECE **Course Code:17EC81**
Course Title: Wireless Cellular & LTE 4G Broadband

Q No.	Points	Marks
1.	The following advantages of OFDM led to its selection for LTE: – Elegant solution to multipath interference. – Reduced computational complexity. – Graceful degradation of performance under excess delay. – Exploitation of frequency diversity. – Enables efficient multi-access scheme. – Robust against narrowband interference – Suitable for coherent demodulation – Facilitates use of MIMO. – Efficient support of broadcast services.	1M
2.	To meet its service and performance requirements, LTE design incorporates several important enabling radio & core network technologies. They are: 1. Orthogonal Frequency Division Multiplexing (OFDM) 2. Single Carrier Frequency Domain Equalization (SC-FDE) and SC-FDMA 3. Channel Dependent Multi-user Resource Scheduling 4. Multi antenna Techniques 5. IP - Based Flat Network Architecture	1M
3.	Flat here denotes reduced number of nodes. Explanation of the nodes along with their working  Fig1: IP-based Flat network architecture	
4.	Multi-antenna Techniques:- – Transmit diversity – Beam forming – Spatial multiplexing – Multi-user MIMO	1M

		Fading: fading is caused by the reception of multiple versions of the same signal. The multiple received versions are caused by reflections that are referred to as *multipath*.	1M
5.		 Fig 2: EPC Network Architecture Four new nodes of EPC 1. Serving Gateway (SGW) 2. Packet Data Network Gateway (PGW) 3. Mobility Management Entity (MME) 4. Policy & Charging Rules Function (PCRF) Explanation of the nodes	
6.		The *free space path loss formula* or **Friis formula**, is given more precisely as $$P_r = P_t \frac{\lambda^2 G_t G_r}{(4\pi d)^2}$$ where P_r and P_t are the received & transmitted powers and λ is the wavelength. As observed in Friis formula, $P_r \propto \lambda^2$, which means that $P_r \propto \frac{1}{f_c^2}$ With shadowing, the empirical path loss formula becomes $$P_r = P_t P_0 \chi (\frac{d_0}{d})^{\alpha}$$ where χ is a sample of the shadowing random process. The shadowing value χ is typically modeled as a lognormal random variable, that is $$\chi = 10^{x/10}, where x \sim N(0, \sigma_s^2)$$ where $N(0, \sigma_s^2)$ is a Gaussian (Normal) distribution with mean 0 and variance σ_s^2	1M
7.		Delay Spread: is the amount of time that elapses between the first arriving path and the last arriving path. It specifies the duration of the channel impulse response h(τ,t) τ_{max} = maximum delay spread, intuitively gives the measure of the width or spread of the channel response in time. Coherence Bandwidth B_c: is the frequency domain dual of the channel delay spread. It gives the rough measure for the maximum separation between frequency f_1 & frequency f_2	1M

8.	$$\|f_1 - f_2\| \le B_c \Rightarrow H(f_1) \approx H(f_2)$$ $$\|f_1 - f_2\| > B_c \Rightarrow H(f_1) \text{ and } H(f_2) \text{ are uncorrelated}$$ $$B_c \approx \frac{1}{5\tau_{rms}} \approx \frac{1}{\tau_{max}}.$$	1M
9.	 Fig 3: Adaptive Modulation & Coding Block Diagram Techniques for tuning the Adaptive Modulation & Coding Controller: 1. PER and Received SINR 2. Automatic Repeat Request (ARQ) 3. Power Control 4. Adaptive Modulation in OFDMA	1M
10.	 Fig 4: An OFDM Communication System vector notation. The Key steps in OFDM Communication System are: - A wideband signal of bandwidth B is divided into L narrowband signals - subcarriers are created digitally using IFFT operation - cyclic prefix of length v is added after the IFFT operation - At the receiver the cyclic prefix is discarded, and the L received symbols are demodulated using an FFT operation - each subcarrier is then equalized via FEQ by simply dividing by the complex channel gain H[i] for that subcarrier	1M
	Doppler power spectrum gives the statistical power distribution of the channel versus frequency for a signal transmitted at just one exact frequency. $$f_D = \frac{\nu f_c}{c},$$	

	where, f_D is called the maximum Doppler or Doppler spread v is the maximum speed between the transmitter and the receiver c is the speed of light The channel coherence time gives the period of time over which the channel is significantly correlated. Mathematically, $|t_1 - t_2| \leq T_c \Rightarrow \mathbf{h}(t_1) \approx \mathbf{h}(t_2)$ $|t_1 - t_2| > t_c \Rightarrow \mathbf{h}(t_1)$ and $\mathbf{h}(t_2)$ are uncorrelated The coherence time and Doppler spread are also inversely related. $T_c \approx \frac{1}{f_D}.$	1M

Course In charge

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DEPARTMENT OF
ELECTRONICS & COMMUNICATION ENGINEERING

ASSIGNMENT QUESTIONS

Academic Year	2020-21		
Batch	2017-2021		
Year/Semester/section	IV/VIII/ B		
Course Code-Title	17EC81-Wireless Cellular & LTE 4G Broadband		
Name of the Instructor	Pooja S	Dept	ECE

Assignment No: 2
Date of Issue: 21/6/2021

Total marks:10
Date of Submission: 27/6/2021

Sl.No	Assignment Questions	K Level	CO	Marks
1.	**Explain** Spatial Diversity of multiple antenna techniques	K2 [Understanding]	2	1
2.	Explain Timing and frequency synchronization. What is PAR explain its effects on the LTE system	K2 [Understanding]	2	1
3.	**Identify** the LTE Radio Interface Protocols	K3 [Applying]	3	1
4.	**Explain** the hierarchical channel structure of LTE	K2 [Understanding]	3	1
5.	**Explain** briefly Layer mapping and Precoding in modulation mapping.	K2 [Understanding]	3	1
6.	**Identify** the transport channels in LTE	K3 [Applying]	3	1
7.	**Make use of** the structure of downlink resource grid and explain the types of resource allocation	K3 [Applying]	3	1
8.	**Identify** the seven different transmission modes, defined for data transmission on the PDSCH channel	K3 [Applying]	3	1
9.	With the help of a neat block diagram, **explain** the SC-FDMA base band signal generation	K2 [Understanding]	4	1
10.	**Explain** the random-access procedures in detail	K2 [Understanding]	4	1

Spooja
Course in-charge

ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

ASSIGNMENT - II 2020 – 21 EVEN SEMESTER

KSIT

SCHEME AND SOLUTION

Degree: B.E. **Semester: VIII**
Branch: ECE **Course Code:17EC81**
Course Title: Wireless Cellular & LTE 4G Broadband

<table>
<tr><th>Q No.</th><th>Points</th><th>Marks</th></tr>
<tr><td>1.</td><td>Spatial Diversity is exploited through two or more antennas, which are separated by enough distance so that fading is approximately decorrelated between them.
a) Array Gain
b) Diversity Gain
Types of spatial diversity: 1) Receive Diversity 2) Transmit Diversity</td><td>1M</td></tr>
<tr><td>2.</td><td>

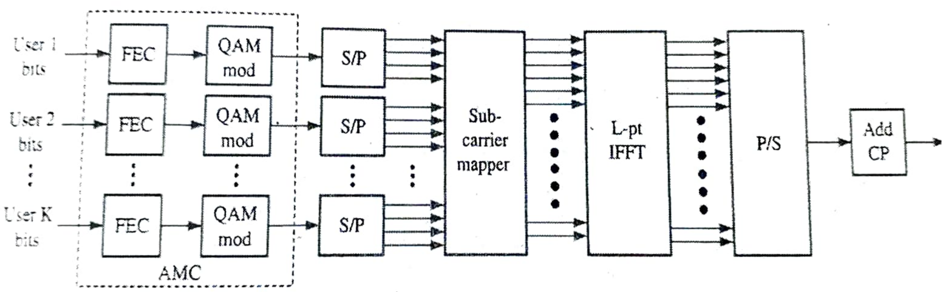


Figure 4.3 OFDMA downlink transmitter.

Explanation</td><td>1M</td></tr>
<tr><td>3.</td><td>Explanation of the following layers in LTE radio interface protocol:
1) Radio Resource Control (RRC)
2) Packet Data Convergence Protocol (PDCP)
3) Radio Link Control (RLC)
4) Medium Access Control (MAC)
5) Physical Layer (PHY)

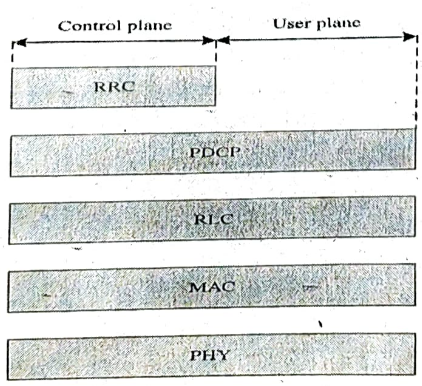


Figure 6.3 The LTE radio interface protocol stack.</td><td>3M</td></tr>
</table>

4. LTE adopts a hierarchical channel structure to provide efficient support to QoS There are three different channel types defined in LTE –

1) logical channels, 2) transport channels, and 3)physical channels,

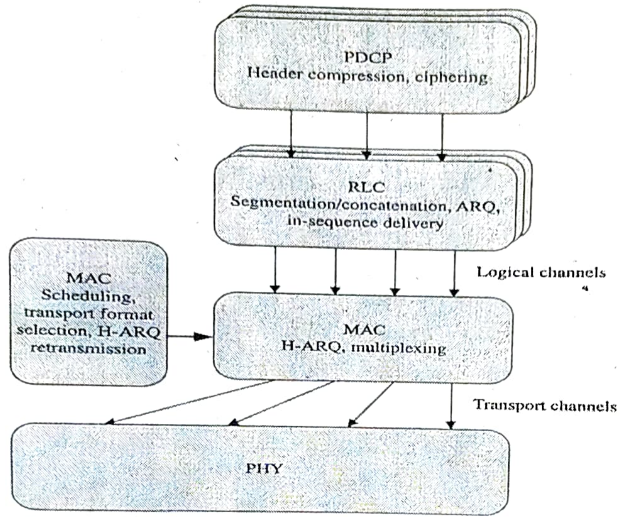


Figure 6.5 The radio interface protocol architecture and the SAPs between different layers. **1M**

5.

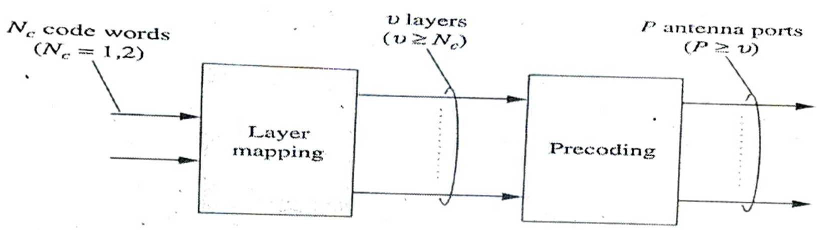


Figure 7.6 Layer mapping and precoding.

Explanation **1M**

6. The Transport Channels in LTE are classified as follows:

Downlink Transport Channels: -

- i) Downlink Shared Channel (DL-SCH)
- ii)Broadcast Channel (BCH)
- iii)Multicast Channel (MCH)
- iv)Paging Channel (PCH)

Uplink Transport Channels: -

- i) Uplink Shared Channel (UL-SCH):
- ii) Random Access Channel (RACH):

7. **1M**

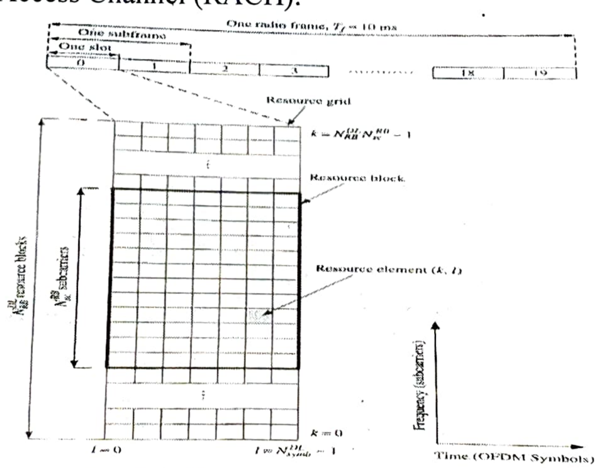


Figure 6.10 The structure of the downlink resource grid.

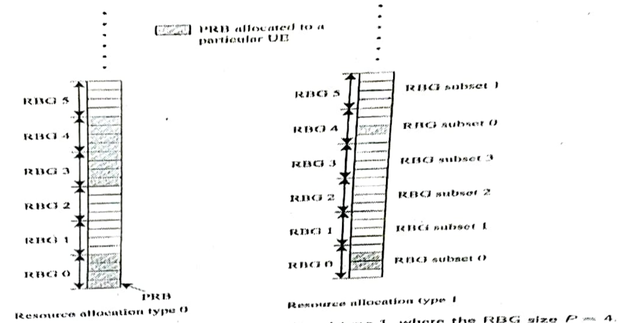


Figure 6.11 Examples of resource allocation type 0 and type 1, where the RBG size $P = 4$.

Explanation of Type 0 Resource Allocation, Type 1 Resource Allocation, Type 2 Resource Allocation — 1M

8. There are seven different transmission modes defined for data transmission modes defined for data transmission on the PDSCH channel:

i) Single antenna port (port 0)
ii) Transmit diversity
iii) Open-loop (OL) spatial multiplexing
iv) Closed-loop (CL) spatial multiplexing
v) Multiuser MIMO
vi) Closed-loop (CL) rank-1 precoding
vii) Single-antenna port (port 5) — 1M

9.

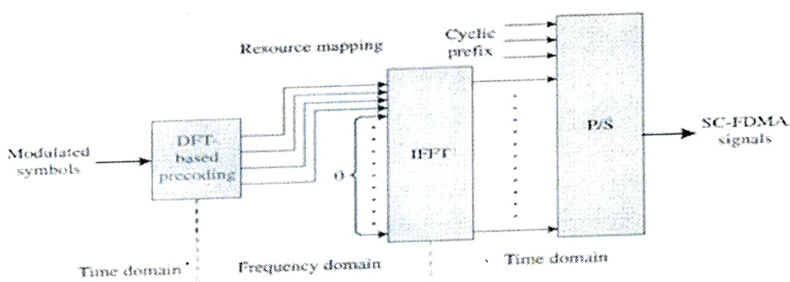


Figure: Generation of SC-FDMA baseband signals

Explanation — 1M

10. In LTE, there are two random access mechanisms:

1) Non-synchronized random access
2) Synchronized random access

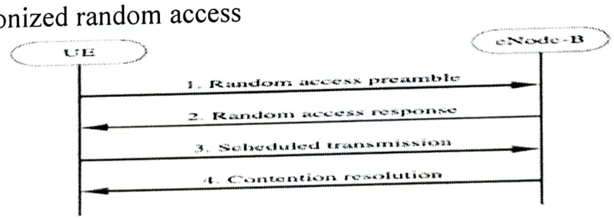


Figure: The non-synchronized Random Access Procedure — 1M

Course in-charge

ECE-HOD

K.S.Institute of Technology, Bangalore

DEPARTMENT OF
ELECTRONICS & COMMUNICATION ENGINEERING

ASSIGNMENT QUESTIONS

Academic Year	2020-21
Batch	2017-2021
Year/Semester/section	IV/VIII/ A & B
Course Code-Title	17EC81-Wireless Cellular & LTE 4G Broadband
Name of the Instructor	Pooja S — Dept: ECE

Assignment No: 3 — Total marks:10
Date of Issue: 15/7/2021 — Date of Submission: 22/7/2020

Sl.No	Assignment Questions	K Level	CO	Marks
1.	**Discuss** the scheduling and resource allocation in LTE	K2 [Understanding]	4	1
2.	**Explain** the types of uplink reference signals	K2 [Understanding]	4	1
3.	**Identify** the uplink control information	K3 [Applying]	4	1
4.	**Determine** the function of H-ARQ feedback in Downlink and Uplink transmission	K3 [Applying]	4	1
5.	**Demonstrate** the main services and functions of PDCP sublayer for the user plane	K2 [Understanding]	5	1
6.	**Establish** mobility management over the S1 interface.	K3 [Applying]	5	1
7.	**Explain** RRC states and its functions	K2 [Understanding]	5	1
8.	**Explain** three basic approaches to mitigate ICI in downlink	K2 [Understanding]	5	1
9.	**Describe** the various phases of X2 mobility with a neat diagram	K3 [Applying]	5	1
10.	**Illustrate** the data transfer modes and the main services and functions of the RLC sublayer	K2 [Understanding]	5	1

Spooja
Course in-charge

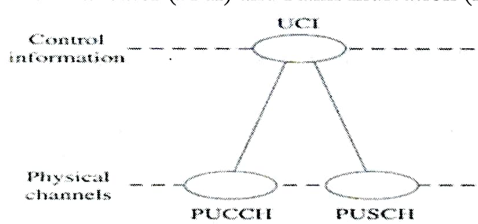
ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

ASSIGNMENT - III 2020 – 21 EVEN SEMESTER

SCHEME AND SOLUTION

Degree: B.E. **Semester: VIII**
Branch: ECE **Course Code:17EC81**
Course Title: Wireless Cellular & LTE 4G Broadband

<table>
<tr><th>Q No.</th><th>Points</th><th>Marks</th></tr>
<tr><td>1.</td><td>Explanation of the two categories of Scheduling algorithms for LTE
i) Channel-dependent Scheduling
ii) Channel-independent Scheduling
In a multicarrier system such as LTE, channel-dependent scheduling can be further divided into two categories:
i) Frequency diverse scheduling
ii) Frequency selective scheduling</td><td>1M</td></tr>
<tr><td>2.</td><td>Explanation for the two types of uplink reference signals
1) Demodulation reference signal and the 2) sounding reference signals</td><td>1M</td></tr>
<tr><td>3.</td><td>The Uplink Control Information (UCI) is to assist Physical Layer Procedures by providing the following types of Physical Layer Control Information
Downlink CQI,
H-ARQ acknowledgment
Scheduling Request (SR)
Precoding Matrix Indicator (PMI) and Rank Indication (RI)
Channel Mapping for Control Information in the Uplink</td><td>1M</td></tr>
<tr><td>4.</td><td>H-ARQ Feedback for Downlink (DL) Transmission
For H-ARQ transmissions in the downlink, UEs need to feedback the associated ACK/NAK information on the PUCCH or PUSCH
Two ACK/NAK feedback modes are supported by higher layer configuration:
i)ACK/NAK bundling using PUCCH format 1a or 1b: consists of one or two bits of information
ii) ACK/NAK multiplexing using PUCCH format 1b: consists of one to four bits of information
H-ARQ Indicator for Uplink (UL) Transmission
For the uplink H-ARQ process as spatial multiplexing is not supported, only a single-bit H-ARQ Indicator (HI) needs to be sent to each scheduled UE, which is carried on the PHICH physical channel</td><td>1M</td></tr>
</table>

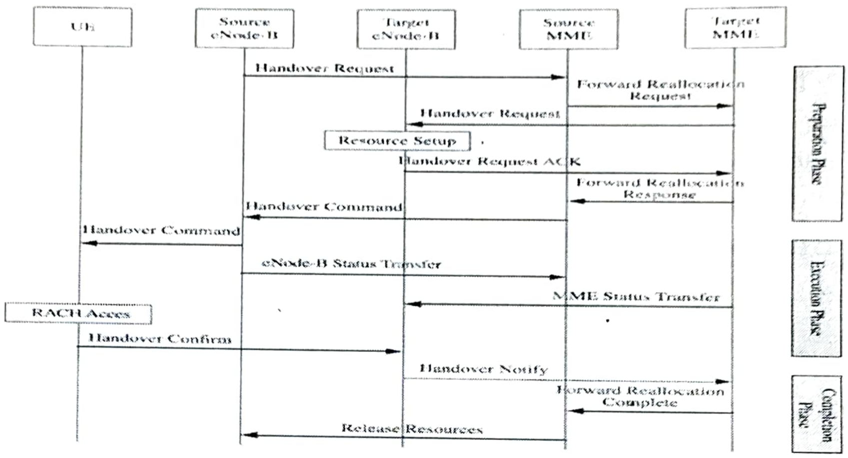
5. Packet Data Convergence Protocol (PDCP)

A PDCP entity is associated with the **control plane** or with the **user plane** depending on which radio bearer it is carrying data for.

User Plane Functions:

- Header Compression and decompression of IP data flows
- Ciphering and deciphering of user plane data.
- In-sequence delivery and reordering of upper layer PDUs at handover.
- Buffering and forwarding of upper layer Protocol Data Units (PDUs) **1M**
- Timer based discarding of Service Data Units (SDUs) in the uplink.

6. Explanation of the three phases of S1 mobility 1) Preparation Phase, 2) Completion phase, and 3) Execution Phase

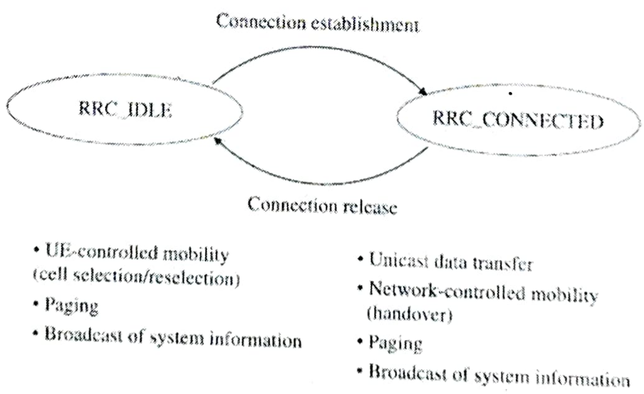


Mobility management over the S1 interface **1M**

7. LTE has 2 RRC states namely **RRC_IDLE** and **RRC_CONNECTED**.

The main functions of RRC protocol are

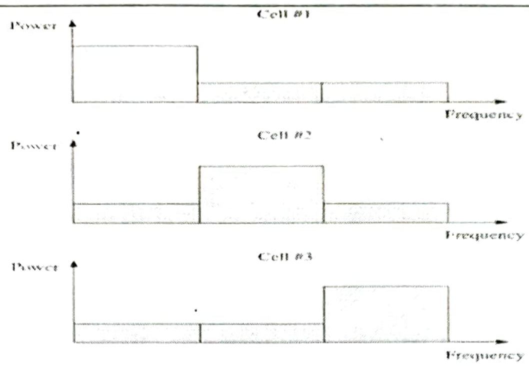
- Broadcast of system information
- RRC connection control
- Measurement configuration and reporting
- Other functions include transfer of dedicated NAS information and non-3GPP dedicated information



RRC states in LTE

8. Explanation of the three basic approaches to mitigate ICI in downlink are **1M**

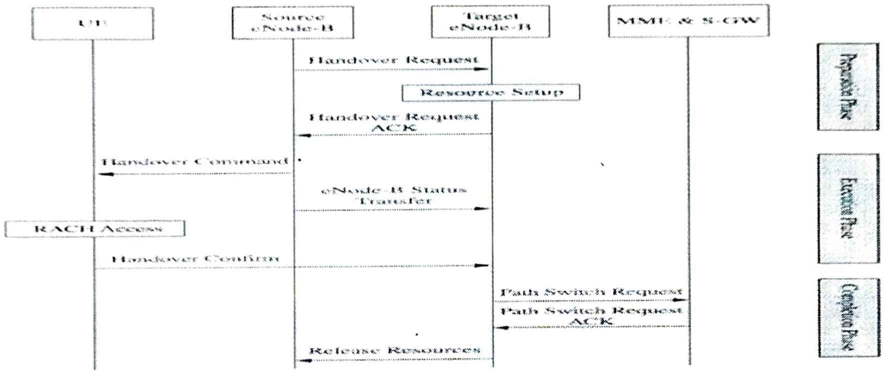
- ➢ ICI randomization
- ➢ ICI cancellation
- ➢ ICI coordination/avoidance



Possible downlink power levels of three neighboring cells. Edge users in each cell would be allocated to the higher power levels

1M

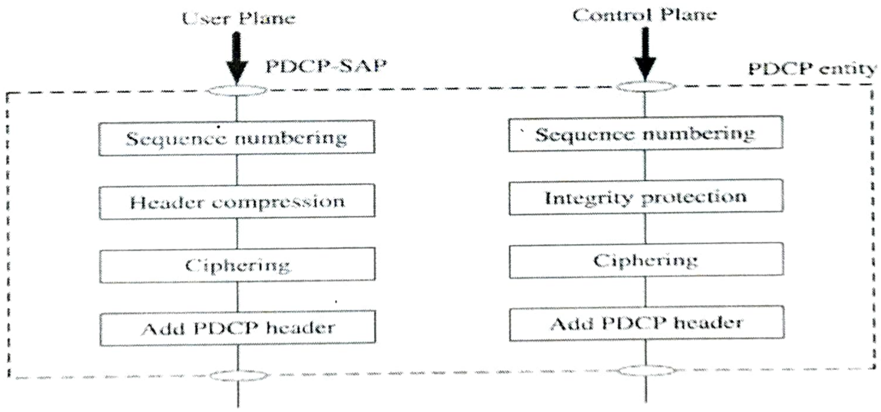
9. Explanation of the three phases of X2 mobility 1) Preparation Phase, 2) Completion phase, and 3) Execution Phase



Mobility management over the X2 interface

10. Explanation of the RLC entity operated in all of the **three Data Transfer Modes** 1) Transparent Mode (TM), 2) Unacknowledged Mode (UM) or 3) Acknowledged Mode (AM).

The main functions and services of the RLC sublayer



PDCP functions for the user plane and the control plane

Course In charge

HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

I SESSIONAL TEST QUESTION PAPER 2020 – 21 EVEN SEMESTER

Set A

USN

Degree	: B.E	Semester :	VIII
Branch	: Electronics & Communication Engg.	Course Code :	17EC81
Course Title	: Wireless Cellular & LTE 4G Broadband	Date :	24.05.2021
Duration	: 90 Minutes	Max Marks :	30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Identify** the key enabling technologies and features of LTE.	6	CO1	K3 [Applying]
(b)	**Establish** why the IP based network architecture is called flat and discuss its working in detail.	6	CO1	K3 [Applying]
(c)	**Identify** the different multi-antenna techniques used in LTE. Elaborate Fading in a Broadband Wireless Channel.	6	CO1	K3 [Applying]
	OR			
2(a)	**Identify** the advantages of OFDM in LTE.	6	CO1	K3 [Applying]
(b)	**Identify** the new nodes in the Evolved Packet Core network architecture and elaborate their working in it.	6	CO1	K3 [Applying]
(c)	**Identify** the mathematical equations representing Pathloss and Shadowing in an LTE system and elaborate its effect in the LTE system	6	CO1	K3 [Applying]
	PART-B			
3(a)	**Identify** the different techniques used for tuning Adaptive Modulation and Coding. **Distinguish** the effect of Delay Spread and Coherence Bandwidth in an LTE system with the necessary equations.	6	CO2	K3 [Applying]
(b)	Write the block diagram of an OFDMA downlink transmitter and **explain** its operation	6	CO2	K2 [Understanding]
	OR			
4(a)	**Identify** the different blocks in an OFDM Communication System and explain with the help of a neat block diagram. **Distinguish** the effect of Doppler Spread and Coherence Time in an LTE system with the necessary equations.	6	CO2	K3 [Applying]
(b)	Write the block diagram of an SC-FDMA uplink transmitter and **explain** its operation	6	CO2	K2 [Understanding]

Course in-charge **Module Coordinator** **ECE-HOD**

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

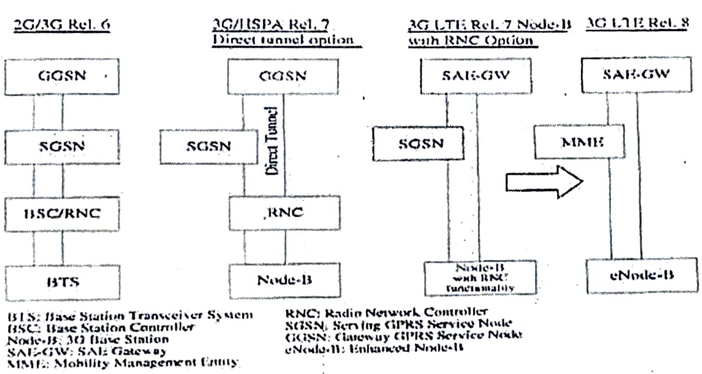
I SESSIONAL TEST 2020 – 21 EVEN SEMESTER

SET-A

SCHEME AND SOLUTION

Degree: B.E.
Branch: ECE
Course Title: Wireless Cellular & LTE 4G Broadband

Semester: VIII
Course Code: 17EC81

Q No.	Points	Marks
	PART-A	
1a.	To meet its service and performance requirements, LTE design incorporates several important enabling radio & core network technologies. They are: 1. Orthogonal Frequency Division Multiplexing (OFDM) 2. Single Carrier Frequency Domain Equalization (SC-FDE) and SC-FDMA 3. Channel Dependent Multi-user Resource Scheduling 4. Multi antenna Techniques 5. IP - Based Flat Network Architecture	6M
1b.	Flat here denotes reduced number of nodes. Explanation of the nodes along with their working  Fig1: IP-based Flat network architecture	1M 2M 3M
1c.	Multi-antenna Techniques:- – Transmit diversity – Beam forming – Spatial multiplexing – Multi-user MIMO Fading: fading is caused by the reception of multiple versions of the same signal. The multiple received versions are caused by reflections that are referred to as *multipath.*	3M 3M
2a.	The following advantages of OFDM led to its selection for LTE: – Elegant solution to multipath interference. – Reduced computational complexity. – Graceful degradation of performance under excess delay. – Exploitation of frequency diversity.	

- Enables efficient multi-access scheme.
- Robust against narrowband interference
- Suitable for coherent demodulation
- Facilitates use of MIMO.
- Efficient support of broadcast services.

6M

2b.

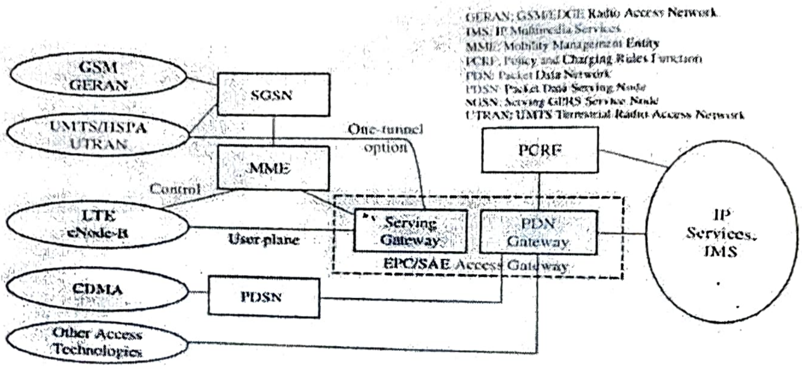


Fig 2: EPC Network Architecture

3M

Four new nodes of EPC

1. Serving Gateway (SGW)
2. Packet Data Network Gateway (PGW)
3. Mobility Management Entity (MME)
4. Policy & Charging Rules Function (PCRF)

Explanation of the nodes

2c.

3M

The *free space path loss formula* or Friis formula, is given more precisely as

$$P_r = P_t \frac{\lambda^2 G_t G_r}{(4\pi d)^2}$$

where P_r and P_t are the received & transmitted powers and λ is the wavelength.

As observed in Friis formula, $P_r \propto \lambda^2$, which means that $P_r \propto \frac{1}{f_c^2}$

With shadowing, the empirical path loss formula becomes

$$P_r = P_t P_0 \chi \left(\frac{d_0}{d}\right)^\alpha$$

where χ is a sample of the shadowing random process.

The shadowing value χ is typically modeled as a lognormal random variable, that is

$$\chi = 10^{x/10}, where x \sim N(0, \sigma_s^2)$$

where $N(0, \sigma_s^2)$ is a Gaussian (Normal) distribution with mean 0 and variance σ_s^2

6M

3a.

PART-B

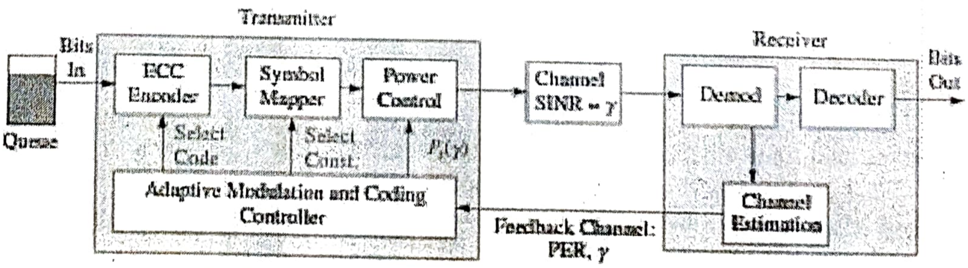


Fig 3: Adaptive Modulation & Coding Block Diagram

Techniques for tuning the Adaptive Modulation & Coding Controller:

1. PER and Received SINR
2. Automatic Repeat Request (ARQ)
3. Power Control
4. Adaptive Modulation in OFDMA

4M

Delay Spread: is the amount of time that elapses between the first arriving path and the last arriving path.

$$|f_1 - f_2| \le B_c \Rightarrow H(f_1) \approx H(f_2)$$
$$|f_1 - f_2| > B_c \Rightarrow H(f_1) \text{ and } H(f_2) \text{ are uncorrelated}$$

2M

$$B_c \approx \frac{1}{5\tau_{rms}} \approx \frac{1}{\tau_{max}}.$$

3b.

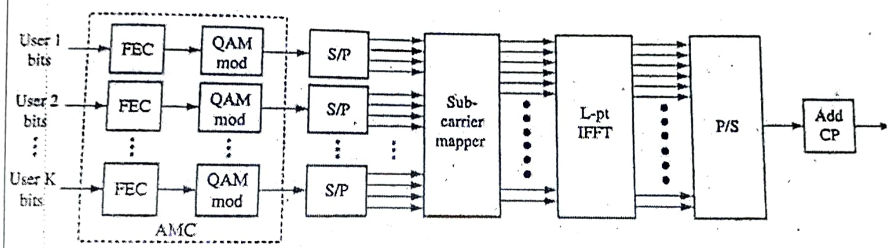


Fig : Block Diagram of an OFDMA Downlink Transmitter

- Forward Error Correction (FEC) is applied to the OFDM symbols of a particular user, they are then modulated using QAM by the adaptive modulation and coding block of the transmitter. 6M
- These OFDM symbols are allocated to various subcarriers
- Each subcarrier has only one user allocated to it

4a.

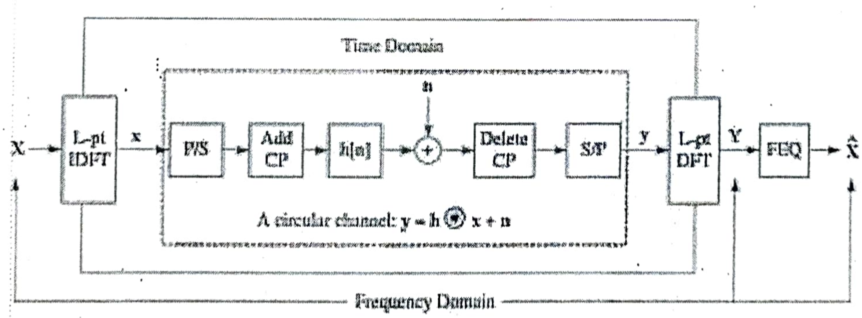


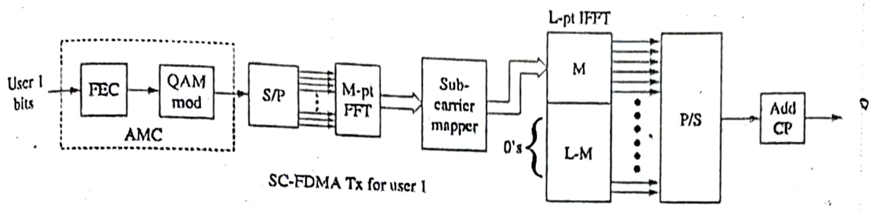
Fig : An OFDM Communication System vector notation.

The Key steps in OFDM Communication System are:

- A wideband signal of bandwidth B is divided into L narrowband signals 4M
- subcarriers are created digitally using IFFT operation
- cyclic prefix of length υ is added after the IFFT operation
- At the receiver the cyclic prefix is discarded, and the L received symbols are demodulated using an FFT operation 2M
- each subcarrier is then equalized via FEQ by simply dividing by the complex channel gain H[i] for that subcarrier

$$|t_1 - t_2| \le T_c \Rightarrow \mathbf{h}(t_1) \approx \mathbf{h}(t_2)$$

- $|t_1 - t_2| > t_c \Rightarrow \mathbf{h}(t_1) \text{ and } \mathbf{h}(t_2) \text{ are uncorrelated}$

	The coherence time and Doppler spread are also inversely related, $$T_c \approx \frac{1}{f_D}.$$  Fig : Block Diagram of an SCFDMA Uplink Transmitter • SC-FDMA is employed in uplink LTE • The goal of SC-FDMA is to take the low peak-to-average ratio (PAR) properties of SC-FDE and achieve them in an OFDMA type system	

Course in-charge　　　　Module Coordinator　　　　ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

I SESSIONAL TEST QUESTION PAPER 2020 – 21 EVEN SEMESTER

Set B

USN | | | | | | | | | | |

Degree	: B.E	Semester :	VIII
Branch	: Electronics & Communication Engg.	Course Code :	17EC81
Course Title	: Wireless Cellular & LTE 4G Broadband	Date :	24.05.2021
Duration	: 90 Minutes	Max Marks :	30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Identify** the advantages of OFDM in LTE.	6	CO1	K3 [Applying]
(b)	**Identify** the new nodes in the Evolved Packet Core network architecture and elaborate their working in it.	6	CO1	K3 [Applying]
(c)	**Identify** the mathematical equations representing Pathloss and Shadowing in an LTE system and elaborate its effect in the LTE system.	6	CO1	K3 [Applying]
	OR			
2(a)	**Identify** the key enabling technologies and features of LTE.	6	CO1	K3 [Applying]
(b)	**Establish** why the IP based network architecture is called flat and discuss its working in detail.	6	CO1	K3 [Applying]
(c)	**Identify** the different multi-antenna techniques used in LTE. Elaborate Fading in a Broadband Wireless Channel.	6	CO1	K3 [Applying]
	PART-B			
3(a)	**Identify** the different blocks in an OFDM Communication System and explain with the help of a neat block diagram. **Distinguish** the effect of Doppler Spread and Coherence Time in an LTE system with the necessary equations.	6	CO2	K3 [applying]
(b)	Write the block diagram of an SC-FDMA uplink transmitter and **explain** its operation	6	CO2	K2 [Understanding]
	OR			
4(a)	**Identify** the different techniques used for tuning Adaptive Modulation and Coding. **Distinguish** the effect of Delay Spread and Coherence Bandwidth in an LTE system with the necessary equations.	6	CO2	K3 [applying]
(b)	Write the block diagram of an OFDMA downlink transmitter and **explain** its operation	6	CO2	K2 [Understanding]

Course in charge　　　　Module Coordinator　　　　HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

I SESSIONAL TEST 2020 – 21 EVEN SEMESTER

SET-B

SCHEME AND SOLUTION

Degree: B.E.
Branch: ECE
Course Title: Wireless Cellular & LTE 4G Broadband

Semester: VIII
Course Code: 17EC81

Q No.	Points	Marks

PART-A

1a. The following advantages of OFDM led to its selection for LTE:

- Elegant solution to multipath interference.
- Reduced computational complexity.
- Graceful degradation of performance under excess delay.
- Exploitation of frequency diversity.
- Enables efficient multi-access scheme.
- Robust against narrowband interference.
- Suitable for coherent demodulation
- Facilitates use of MIMO.
- Efficient support of broadcast services.

6M

1b.

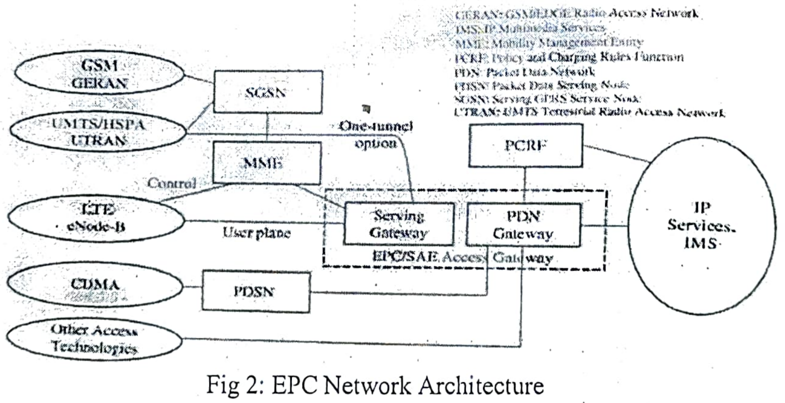


Fig 2: EPC Network Architecture

3M

Four new nodes of EPC

1. Serving Gateway (SGW)
2. Packet Data Network Gateway (PGW)
3. Mobility Management Entity (MME)
4. Policy & Charging Rules Function (PCRF)

Explanation of the nodes

3M

1c. The *free space path loss formula* or Friis formula, is given more precisely as

$$P_r = P_t \frac{\lambda^2 G_t G_r}{(4\pi d)^2}$$

where P_r and P_t are the received & transmitted powers and λ is the wavelength.

As observed in Friis formula, $P_r \propto \lambda^2$, which means that $P_r \propto \frac{1}{f_c^2}$

With shadowing, the empirical path loss formula becomes

$$P_r = P_t P_0 \chi \left(\frac{d_0}{d}\right)^{\alpha}$$

where χ is a sample of the shadowing random process.

The shadowing value χ is typically modeled as a lognormal random variable, that is

$$\chi = 10^{x/10}, where x \sim N(0, \sigma_s^2)$$

where $N(0, \sigma_s^2)$ is a Gaussian (Normal) distribution with mean 0 and variance σ_s^2 — 6M

2a.

To meet its service and performance requirements, LTE design incorporates several important enabling radio & core network technologies. They are:

1. Orthogonal Frequency Division Multiplexing (OFDM)
2. Single Carrier Frequency Domain Equalization (SC-FDE) and SC-FDMA
3. Channel Dependent Multi-user Resource Scheduling
4. Multi antenna Techniques
5. IP - Based Flat Network Architecture

6M

2b. Flat here denotes reduced number of nodes. — 1M

Explanation of the nodes along with their working — 2M

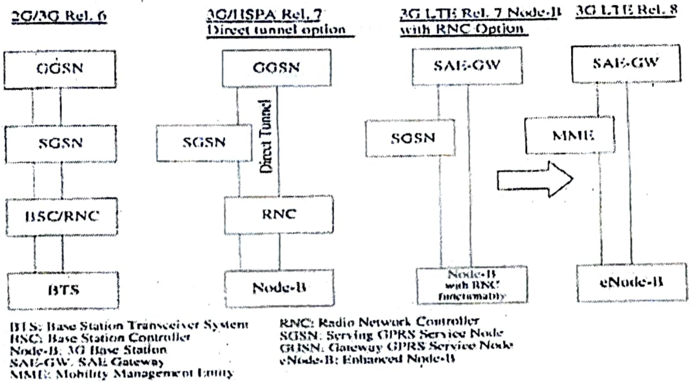


Fig1: IP-based Flat network architecture

3M

2c.

Multi-antenna Techniques:-

- Transmit diversity
- Beam forming
- Spatial multiplexing
- Multi-user MIMO

3M

Fading: fading is caused by the reception of multiple versions of the same signal. The multiple received versions are caused by reflections that are referred to as *multipath*. — 3M

PART-B

3a.

The Key steps in OFDM Communication System are:

- A wideband signal of bandwidth B is divided into L narrowband signals
- subcarriers are created digitally using IFFT operation
- cyclic prefix of length υ is added after the IFFT operation
- At the receiver the cyclic prefix is discarded, and the L received symbols are demodulated using an FFT operation
- each subcarrier is then equalized via FEQ by simply dividing by the complex channel gain H[i] for that subcarrier

3M

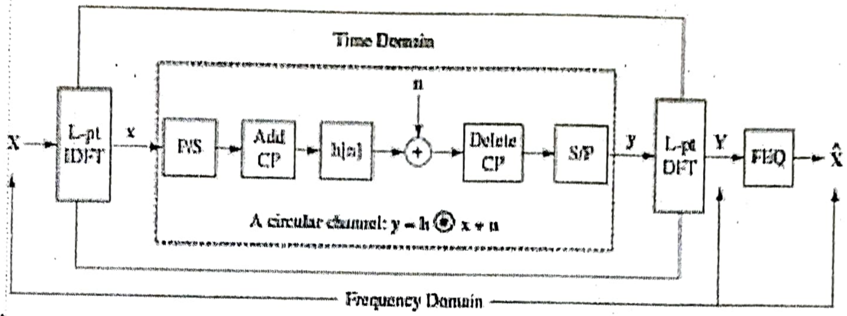


Fig 4: An OFDM Communication System vector notation.

The Key steps in OFDM Communication System are:
- A wideband signal of bandwidth B is divided into L narrowband signals
- subcarriers are created digitally using IFFT operation
- cyclic prefix of length υ is added after the IFFT operation
- At the receiver the cyclic prefix is discarded, and the L received symbols are demodulated using an FFT operation
- each subcarrier is then equalized via FEQ by simply dividing by the complex channel gain H[i] for that subcarrier 4M

$|t_1 - t_2| \le T_c \Rightarrow h(t_1) \approx h(t_2)$

- $|t_1 - t_2| > t_c \Rightarrow h(t_1)$ and $h(t_2)$ are uncorrelated

The coherence time and Doppler spread are also inversely related, 2M

$$T_c \approx \frac{1}{f_D}.$$

3b.

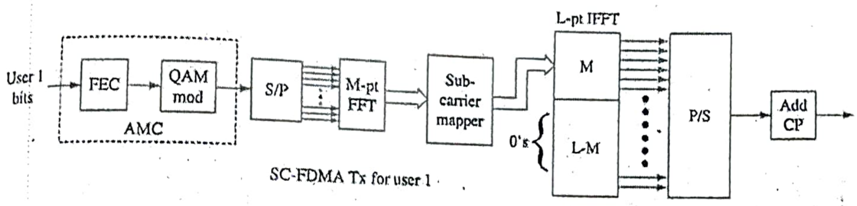


Fig : Block Diagram of an SCFDMA Uplink Transmitter

- SC-FDMA is employed in uplink LTE 6M
- The goal of SC-FDMA is to take the low peak-to-average ratio (PAR) properties of SC-FDE and achieve them in an OFDMA type system

4a.

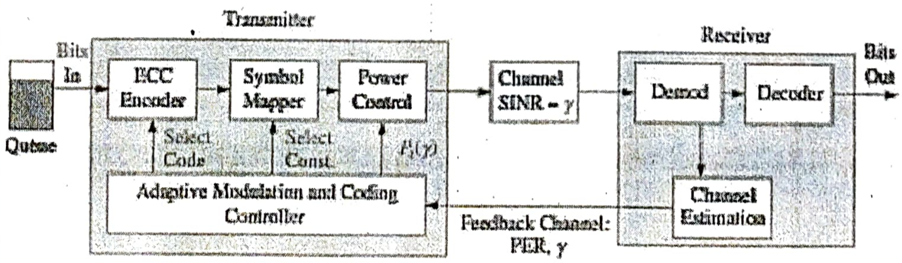


Fig : Adaptive Modulation & Coding Block Diagram

Techniques for tuning the Adaptive Modulation & Coding Controller: 4M

1. PER and Received SINR
2. Automatic Repeat Request (ARQ)
3. Power Control
4. Adaptive Modulation in OFDMA

Delay Spread: is the amount of time that elapses between the first arriving path and the last arriving path.

$$|f_1 - f_2| \le B_c \Rightarrow H(f_1) \approx H(f_2)$$
$$|f_1 - f_2| > B_c \Rightarrow H(f_1) \text{ and } H(f_2) \text{ are uncorrelated}$$
$$B_c \approx \frac{1}{5\tau_{rms}} \approx \frac{1}{\tau_{max}}.$$

2M

4b.

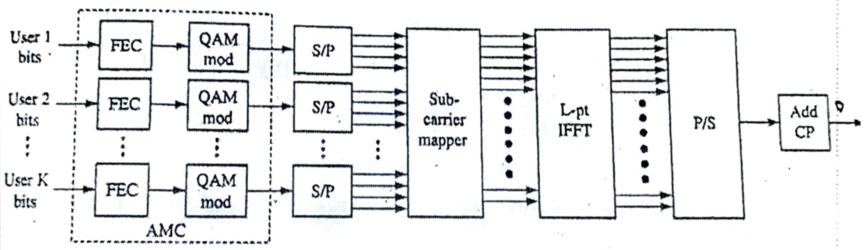


Fig : An OFDM Communication System vector notation. 3M

- Forward Error Correction (FEC) is applied to the OFDM symbols of a particular user, they are then modulated using QAM by the adaptive modulation and coding block of the transmitter.
- These OFDM symbols are allocated to various subcarriers
- Each subcarrier has only one user allocated to it

3M

Course in-charge   Module Coordinator   ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

II SESSIONAL TEST QUESTION PAPER 2019 – 20 EVEN SEMESTER

SET – A

USN										

Degree	: B.E	Semester :	VIII A & B
Branch	: Electronics and Communication Engg	Course Code :	17EC81
Course Title	: Wireless Cellular & LTE 4G Broadband	Date :	28/06/21
Duration	: 90 Minutes	Max Marks :	30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Identify** the LTE Radio Interface Protocols	6	CO3	K3 [applying]
(b)	**Explain** the hierarchical channel structure of LTE	6	CO3	K2 [understanding]
(C)	**Make use of** the structure of downlink resource grid and explain the types of resource allocation	6	CO3	K3 [applying]
	OR			
2(a)	**Identify** the transport channels in LTE	6	CO3	K3 [applying]
(b)	**Explain** briefly Layer mapping and Precoding in modulation mapping.	6	CO3	K2 [understanding]
(C)	**Identify** the seven different transmission modes, defined for data transmission on the PDSCH channel	6	CO3	K3 [applying]
	PART-B			
(a)	**Explain** Spatial Diversity of multiple antenna techniques	6	CO2	K2 [understanding]
(b)	With the help of a neat block diagram, **explain** the SC-FDMA base band signal generation	6	CO4	K2 [understanding]
	OR			
4(a)	Write the block diagram of an OFDMA downlink transmitter and **explain** its operation	6	CO2	K2 [understanding]
(b)	**Explain** the random-access procedures in detail	6	CO4	K2 [understanding]

Course in charge

Module Coordinator

HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

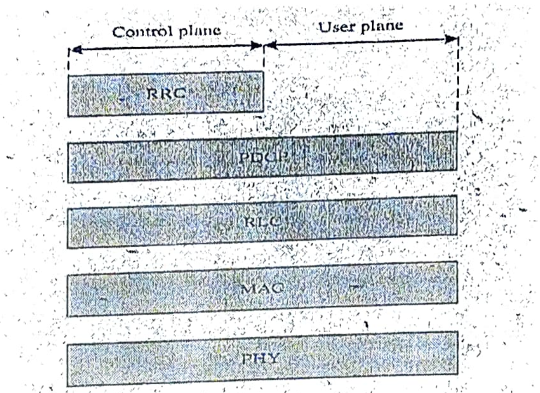
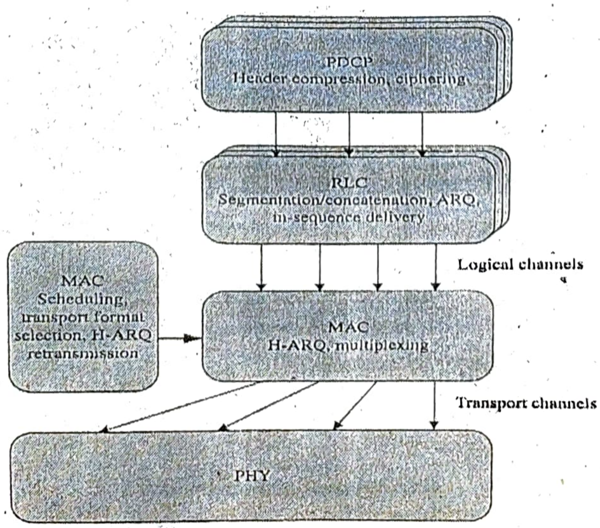
II SESSIONAL TEST 2020 – 21 EVEN SEMESTER

SET-A

SCHEME AND SOLUTION

Degree: B.E.
Branch: ECE
Course Title: Wireless Cellular & LTE 4G Broadband

Semester: VIII
Course Code:17EC81

Q No.	Points	Marks
	PART-A	
1a.	Explanation of the following layers in LTE radio interface protocol: 1) Radio Resource Control (RRC) 2) Packet Data Convergence Protocol (PDCP) 3) Radio Link Control (RLC) 4) Medium Access Control (MAC) 5) Physical Layer (PHY)	3M
	 Figure 6.3 The LTE radio interface protocol stack.	3M
1b.	-LTE adopts a hierarchical channel structure to provide efficient support to QoS There are three different channel types defined in LTE – 1) logical channels, 2) transport channels, and 3)physical channels,	3M
	 Figure 6.5 The radio interface protocol architecture and the SAPs between different layers.	3M

1c.

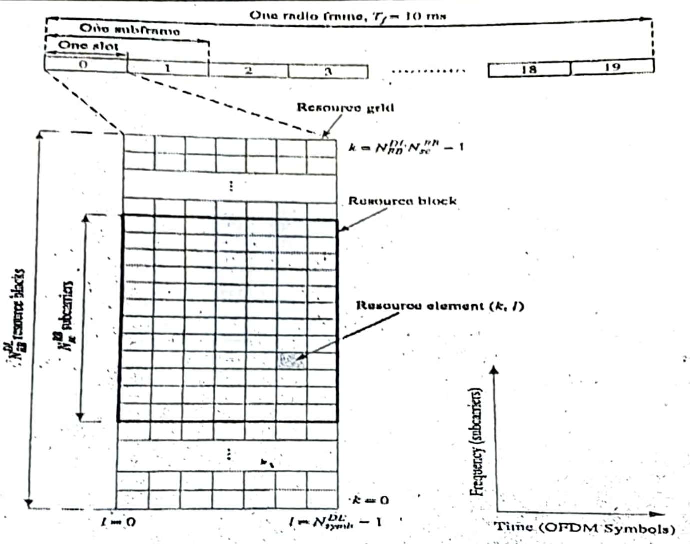


Figure 6.10 The structure of the downlink resource grid. — 2M

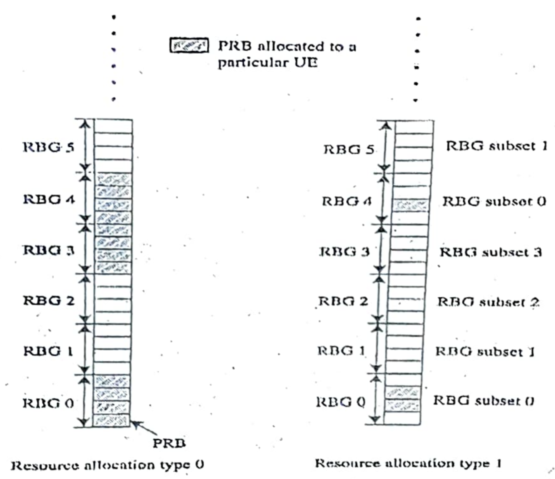


Figure 6.11 Examples of resource allocation type 0 and type 1, where the RBG size $P = 4$. — 2M

Explanation of Type 0 Resource Allocation, Type 1 Resource Allocation, Type 2 Resource Allocation — 2M

2a. Downlink Transport Channels: -

i) Downlink Shared Channel (DL-SCH)
ii)Broadcast Channel (BCH)
iii)Multicast Channel (MCH)
iv)Paging Channel (PCH)

Uplink Transport Channels: -

i) Uplink Shared Channel (UL-SCH):
ii) Random Access Channel (RACH): — 6M

2b.

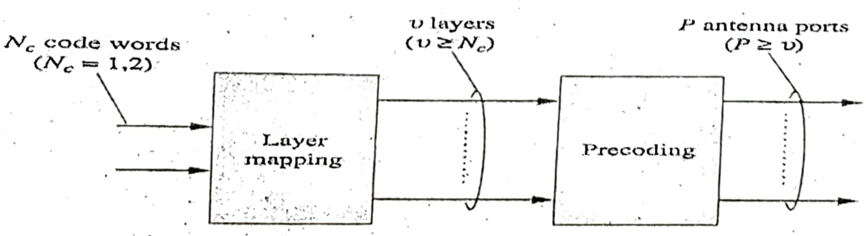


Figure 7.6 Layer mapping and precoding. — 3M

Explanation — 3M

2c. There are seven different transmission modes defined for data transmission modes defined for data transmission on the PDSCH channel:

i) Single antenna port (port 0)
ii) Transmit diversity
iii) Open-loop (OL) spatial multiplexing
iv) Closed-loop (CL) spatial multiplexing
v) Multiuser MIMO
vi) Closed-loop (CL) rank-1 precoding
vii) Single-antenna port (port 5) — 6M

PART-B

3a. Spatial Diversity is exploited through two or more antennas, which are separated by enough distance so that fading is approximately decorrelated between them.

a) Array Gain
b) Diversity Gain — 4M

Types of spatial diversity: 1) Receive Diversity 2) Transmit Diversity — 2M

3b.

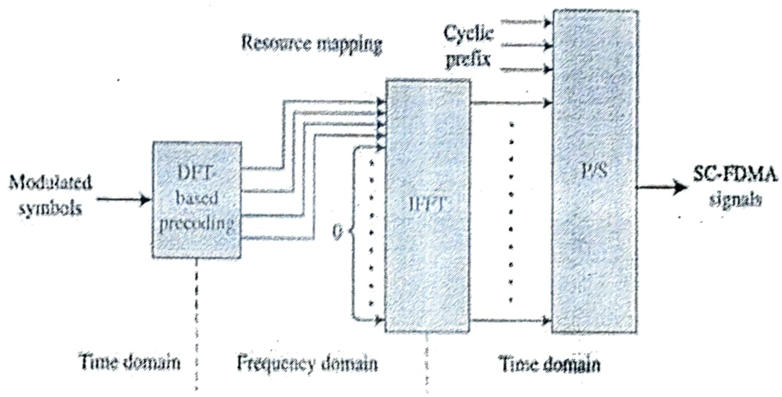


Figure: Generation of SC-FDMA baseband signals — 3M

Explanation — 3M

4a.

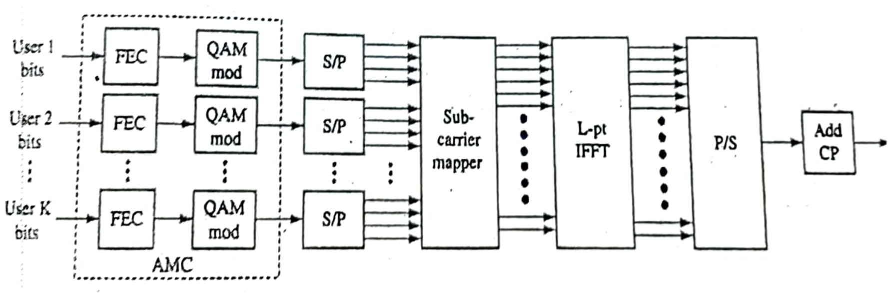


Figure 4.3 OFDMA downlink transmitter. — 3M

Explanation — 3M

4b. In LTE, there are two random access mechanisms:

1) Non-synchronized random access
2) Synchronized random access

2M

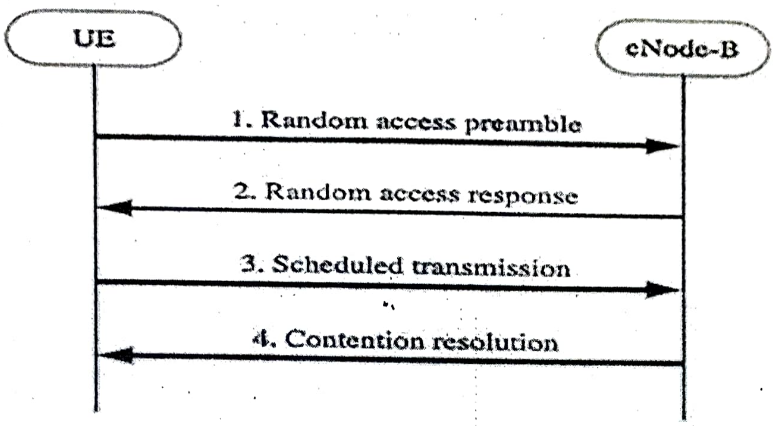


Figure: The non-synchronized Random Access Procedure

4M

Course in-charge

Module Coordinator

ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

II SESSIONAL TEST QUESTION PAPER 2019 – 20 EVEN SEMESTER

SET – B

USN

Degree	:	B.E	Semester	:	VIII A & B
Branch	:	Electronics and Communication Engg	Course Code	:	17EC81
Course Title	:	Wireless Cellular & LTE 4G Broadband	Date	:	28/06/21
Duration	:	90 Minutes	Max Marks	:	30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Identify** the transport channels in LTE	6	CO3	K3 [applying]
(b)	**Explain** briefly Layer mapping and Precoding in modulation mapping.	6	CO3	K2 [understanding]
(C)	**Identify** the seven different transmission modes, defined for data transmission on the PDSCH channel	6	CO3	K3 [applying]
	OR			
2(a)	**Identify** the LTE Radio Interface Protocols	6	CO3	K3 [applying]
(b)	**Explain** the hierarchical channel structure of LTE	6	CO3	K2 [understanding]
(C)	**Explain** briefly Layer mapping and Precoding in modulation mapping.	6	CO3	K3 [applying]
	PART-B			
3(a)	Write the block diagram of an OFDMA downlink transmitter and **explain** its operation	6	CO2	K2 [understanding]
(b)	**Explain** the random-access procedures in detail	6	CO4	K2 [understanding]
	OR			
4(a)	**Explain** Spatial Diversity of multiple antenna techniques	6	CO2	K2 [understanding]
(b)	With the help of a neat block diagram, **explain** the SC-FDMA base band signal generation	6	CO4	K2 [understanding]

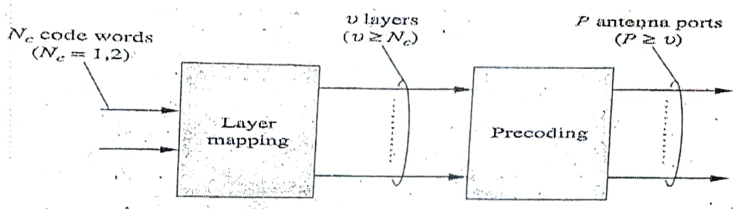
Course in charge   Module Coordinator   HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

II SESSIONAL TEST 2020 – 21 EVEN SEMESTER

SET-B SCHEME AND SOLUTION

Degree: B.E. Semester: VIII
Branch: ECE Course Code:17EC81
Course Title: Wireless Cellular & LTE 4G Broadband

Q No.	Points	Marks
	PART-A	
1a.	Downlink Transport Channels: - i) Downlink Shared Channel (DL-SCH) ii)Broadcast Channel (BCH) iii)Multicast Channel (MCH) iv)Paging Channel (PCH) Uplink Transport Channels: - i) Uplink Shared Channel (UL-SCH): ii) Random Access Channel (RACH):	6M
1b.	 **Figure 7.6** Layer mapping and precoding.	3M
	Explanation	3M
1c.	There are seven different transmission modes defined for data transmission modes defined for data transmission on the PDSCH channel: i) Single antenna port (port 0) ii) Transmit diversity iii) Open-loop (OL) spatial multiplexing iv) Closed-loop (CL) spatial multiplexing v) Multiuser MIMO vi) Closed-loop (CL) rank-1 precoding vii) Single-antenna port (port 5)	6M
2a.	Explanation of the following layers in LTE radio interface protocol: 1) Radio Resource Control (RRC) 2) Packet Data Convergence Protocol (PDCP) 3) Radio Link Control (RLC) 4) Medium Access Control (MAC) 5) Physical Layer (PHY)	3M

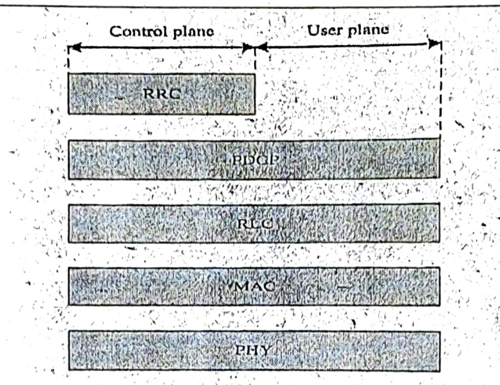


Figure 6.3 The LTE radio interface protocol stack.

3M

2b.

-LTE adopts a hierarchical channel structure to provide efficient support to QoS There are three different channel types defined in LTE –
1) logical channels, 2) transport channels, and 3)physical channels,

3M

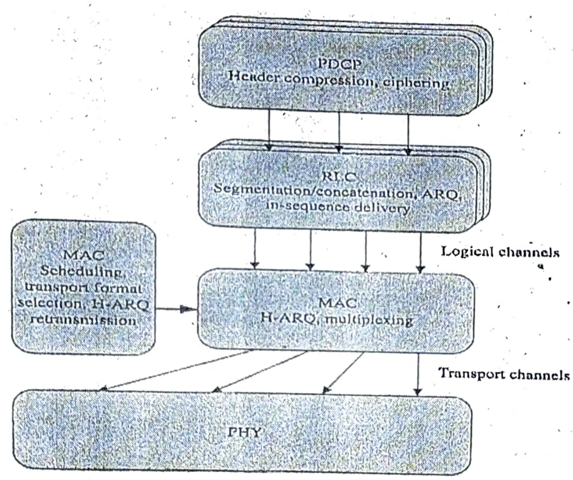


Figure 6.5 The radio interface protocol architecture and the SAPs between different layers.

3M

2c.

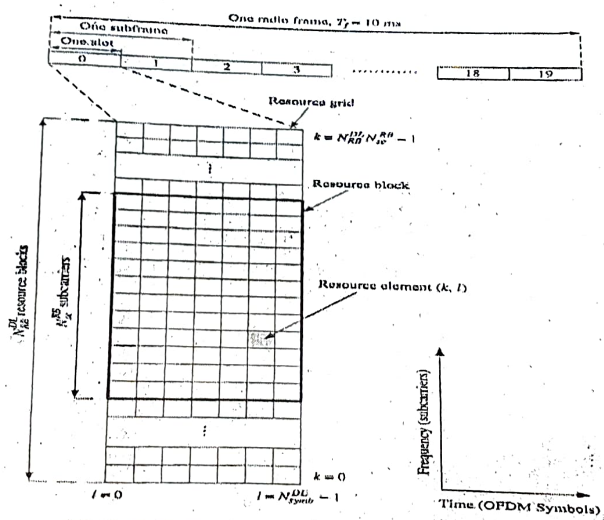


Figure 6.10 The structure of the downlink resource grid.

3M

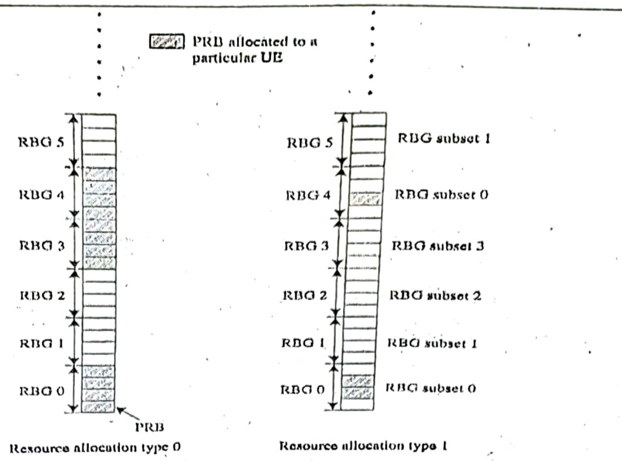
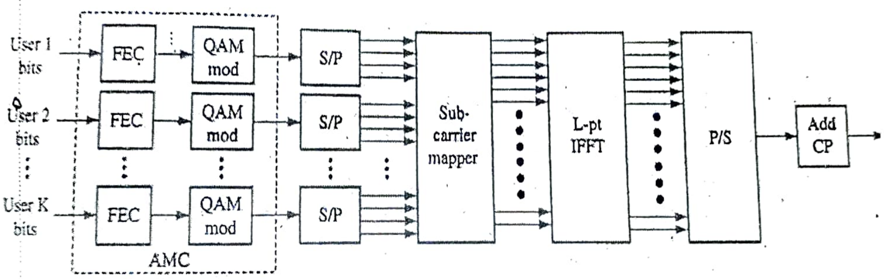


Figure 6.11 Examples of resource allocation type 0 and type 1, where the RBG size $P = 4$.

Explanation of Type 0 Resource Allocation, Type 1 Resource Allocation, Type 2 Resource Allocation — 3M

PART-B

3a.



3M

Figure 4.3 OFDMA downlink transmitter. — 3M

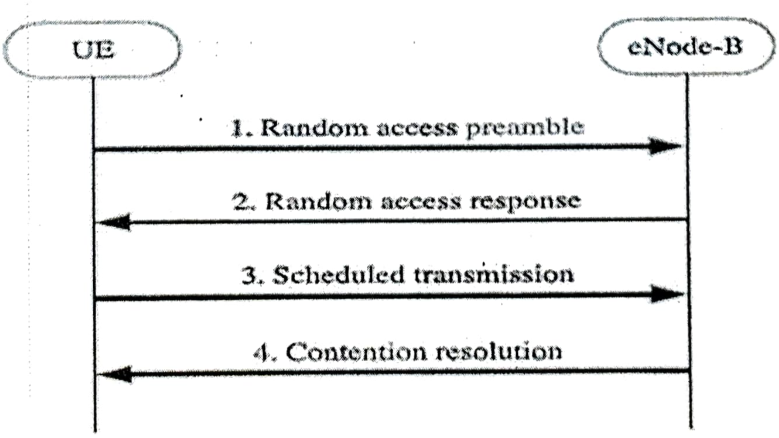
Explanation

3b.

In LTE, there are two random access mechanisms:

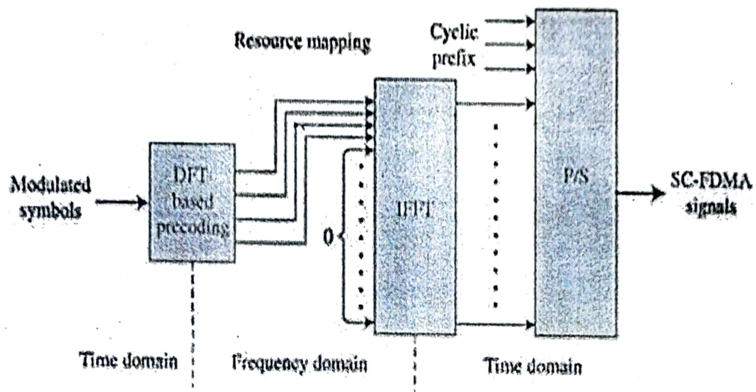
1) Non-synchronized random access
2) Synchronized random access

3M



3M

Figure: The non-synchronized Random Access Procedure

4a.	Spatial Diversity is exploited through two or more antennas, which are separated by enough distance so that fading is approximately decorrelated between them. a) Array Gain b) Diversity Gain Types of spatial diversity: 1) Receive Diversity 2) Transmit Diversity	3+3 M
4b.	 Figure: Generation of SC-FDMA baseband signals Explanation	3+3 M

Course in-charge

Module Coordinator

ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109
III SESSIONAL TEST QUESTION PAPER 2020 – 21 EVEN SEMESTER

Set A

USN										

Degree	:	B.E	Semester	:	VIII A & B
Branch	:	Electronics and Communication Engg	Course Code	:	17EC81
Course Title	:	Wireless Cellular & LTE 4G Broadband	Date	:	19/7/2021
Duration	:	90 Minutes	Max Marks	:	30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Demonstrate** the main services and functions of PDCP sublayer for the user plane	6	CO5	K2 [understanding]
(b)	**Establish** mobility management over the S1 interface.	6	CO5	K3 [applying]
(C)	**Explain** three basic approaches to mitigate ICI in downlink	6	CO5	K2 [understanding]
	OR			
2(a)	**Explain** RRC states and its functions	6	CO5	K2 [understanding]
(b)	**Illustrate** the data transfer modes and the main services and functions of the RLC sublayer	6	CO5	K3 [applying]
(C)	**Describe** the various phases of X2 mobility with a neat diagram	6	CO5	K2 [understanding]
	PART-B			
3(a)	**Discuss** the scheduling and resource allocation in LTE	6	CO4	K2 [understanding]
(b)	**Identify** the uplink control information	6	CO4	K3 [applying]
	OR			
4(a)	**Explain** the types of uplink reference signals	6	CO4	K2 [understanding]
(b)	**Determine** the function of H-ARQ feedback in Downlink and Uplink transmission	6	CO4	K3 [applying]

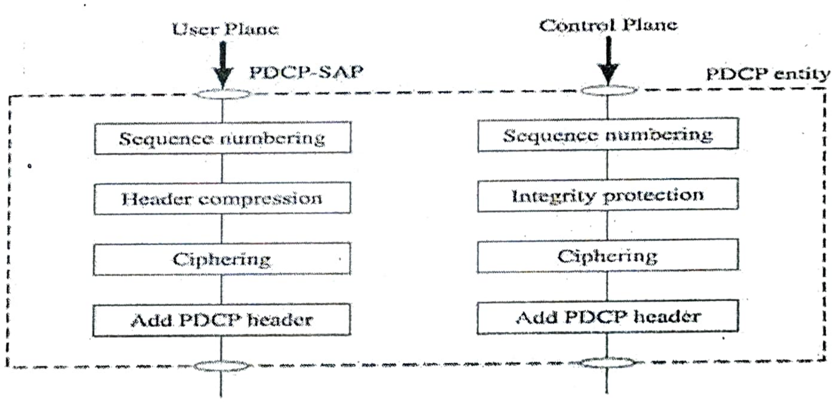
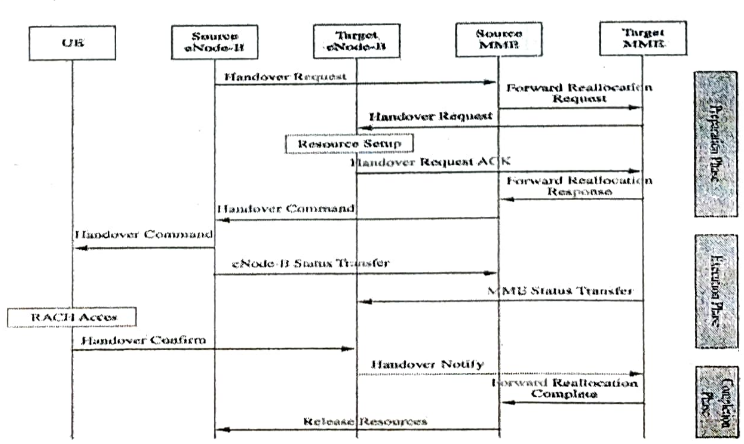
Course in-charge　　　　Module Coordinator　　　　ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

III SESSIONAL TEST 2020 – 21 EVEN SEMESTER

SET-A **SCHEME AND SOLUTION**

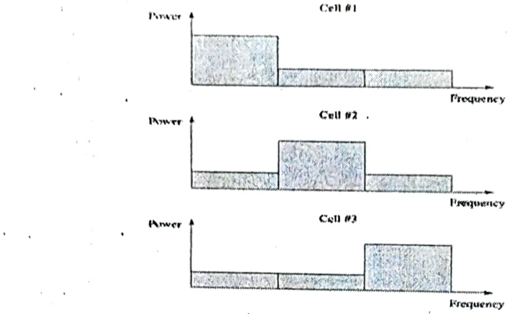
Degree: B.E. **Semester: VIII**
Branch: ECE **Course Code:17EC81**
Course Title: Wireless Cellular & LTE 4G Broadband

Q No.	Points	Marks
	<u>PART-A</u>	
1a.	Packet Data Convergence Protocol (PDCP) A PDCP entity is associated with the **control plane** or with the **user plane** depending on which radio bearer it is carrying data for. User Plane Functions: • Header Compression and decompression of IP data flows • Ciphering and deciphering of user plane data. • In-sequence delivery and reordering of upper layer PDUs at handover. • Buffering and forwarding of upper layer Protocol Data Units (PDUs) • Timer based discarding of Service Data Units (SDUs) in the uplink.	3M
	 **PDCP functions for the user plane and the control plane**	3M
1b.	Explanation of the three phases of S1 mobility 1) Preparation Phase, 2) Completion phase, and 3) Execution Phase	3M
	 **Mobility management over the S1 interface**	3M

1c. Explanation of the three basic approaches to mitigate ICI in downlink are

- ICI randomization
- ICI cancellation
- ICI coordination/avoidance

3M



Possible downlink power levels of three neighboring cells. Edge users in each cell would be allocated to the higher power levels

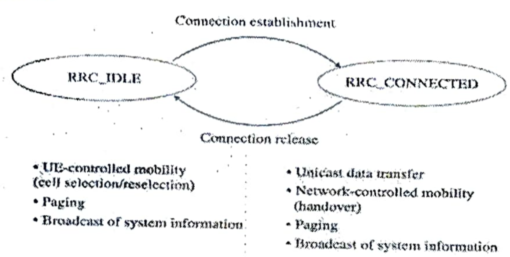
3M

2a.

LTE has 2 RRC states namely **RRC_IDLE** and **RRC_CONNECTED**.
The main functions of RRC protocol are

- Broadcast of system information
- RRC connection control
- Measurement configuration and reporting
- Other functions include transfer of dedicated NAS information and non-3GPP dedicated information

4M

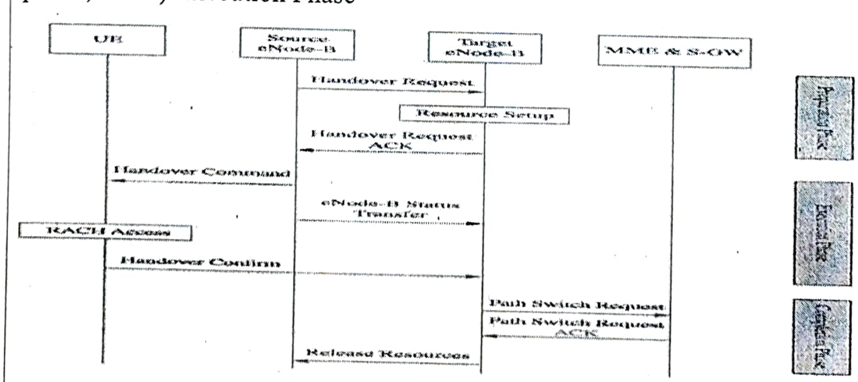


RRC states in LTE

2M

2b. Explanation of the three phases of X2 mobility 1) Preparation Phase, 2) Completion phase, and 3) Execution Phase

3M



Mobility management over the X2 interface

3M

2c.

Explanation of the RLC entity operated in all of the **three Data Transfer Modes** 1) Transparent Mode (TM), 2) Unacknowledged Mode (UM) or 3) Acknowledged Mode (AM).

3M

The main functions and services of the RLC sublayer

3M

PART-B

3a. Explanation of the two categories of Scheduling algorithms for LTE

i) Channel-dependent Scheduling

ii) Channel-independent Scheduling

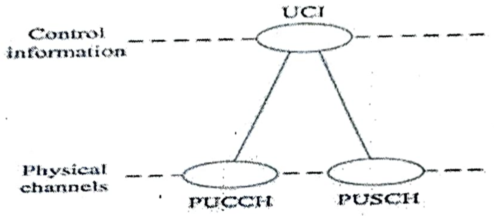
In a multicarrier system such as LTE, channel-dependent scheduling can be further divided into two categories:

i) Frequency diverse scheduling

ii) Frequency selective scheduling — 6M

3b. The Uplink Control Information (UCI) is to assist Physical Layer Procedures by providing the following types of Physical Layer Control Information

- Downlink CQI,
- H-ARQ acknowledgment
- Scheduling Request (SR)
- Precoding Matrix Indicator (PMI) and Rank Indication (RI) — 4M



Channel Mapping for Control Information in the Uplink — 2M

4a. Explanation for the two types of uplink reference signals

1) Demodulation reference signal and the 2) sounding reference signals — 3+3M

4b. **H-ARQ Feedback for Downlink (DL) Transmission**

For H-ARQ transmissions in the downlink, UEs need to feedback the associated ACK/NAK information on the PUCCH or PUSCH

Two ACK/NAK feedback modes are supported by higher layer configuration:

i)ACK/NAK bundling using PUCCH format 1a or 1b: consists of one or two bits of information

ii) ACK/NAK multiplexing using PUCCH format 1b: consists of one to four bits of information — 3M

H-ARQ Indicator for Uplink (UL) Transmission

For the uplink H-ARQ process as spatial multiplexing is not supported, only a single-bit H-ARQ Indicator (HI) needs to be sent to each scheduled UE, which is carried on the PHICH physical channel — 3M

Course in-charge | Module Coordinator | ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

III SESSIONAL TEST QUESTION PAPER 2020 – 21 EVEN SEMESTER

Set B

USN | | | | | | | | | |

Degree	:	B.E	Semester	:	VIII A & B
Branch	:	Electronics and Communication Engg	Course Code	:	17EC81
Course Title	:	Wireless Cellular & LTE 4G Broadband	Date	:	19/7/2021
Duration	:	90 Minutes	Max Marks	:	30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Explain** RRC states and its functions	6	CO5	K2 [understanding]
(b)	**Establish** mobility management over the S1 interface.	6	CO5	K3 [applying]
(C)	**Describe** the various phases of X2 mobility with a neat diagram	6	CO5	K2 [understanding]
	OR			
2(a)	**Demonstrate** the main services and functions of PDCP sublayer for the user plane	6	CO5	K2 [understanding]
(b)	**Illustrate** the data transfer modes and the main services and functions of the RLC sublayer	6	CO5	K3 [applying]
(C)	**Explain** three basic approaches to mitigate ICI in downlink	6	CO5	K2 [understanding]
	PART-B			
3(a)	**Discuss** the scheduling and resource allocation in LTE	6	CO4	K2 [understanding]
(b)	**Determine** the function of H-ARQ feedback in Downlink and Uplink transmission	6	CO4	K3 [applying]
	OR			
4(a)	**Explain** the types of uplink reference signals	6	CO4	K2 [understanding]
(b)	**Identify** the uplink control information	6	CO4	K3 [applying]

Course in charge — Module Coordinator — HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

III SESSIONAL TEST 2020 – 21 EVEN SEMESTER

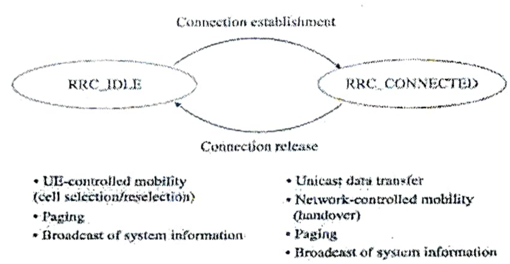
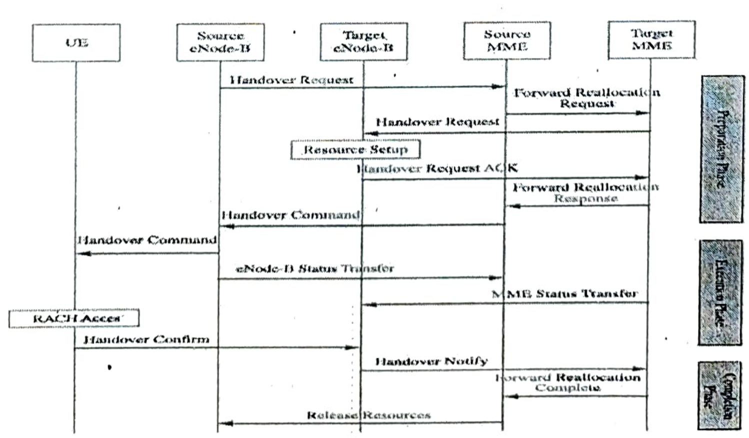
SET-B

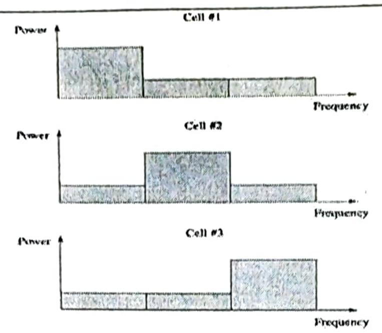
SCHEME AND SOLUTION

Degree: B.E. Semester: VIII

Branch: ECE Course Code:17EC81

Course Title: Wireless Cellular & LTE 4G Broadband

Q No.	Points	Marks
	PART-A	
1a.	LTE has 2 RRC states namely **RRC_IDLE** and **RRC_CONNECTED**. The main functions of RRC protocol are • Broadcast of system information • RRC connection control • Measurement configuration and reporting • Other functions include transfer of dedicated NAS information and non-3GPP dedicated information	3M
	 RRC states in LTE	3M
1b.	Explanation of the three phases of S1 mobility 1) Preparation Phase, 2) Completion phase, and 3) Execution Phase	3M
	 Mobility management over the S1 interface	3M
1c.	Explanation of the three basic approaches to mitigate ICI in downlink are ➢ ICI randomization ➢ ICI cancellation ➢ ICI coordination/avoidance	3M



Possible downlink power levels of three neighboring cells. Edge users in each cell would be allocated to the higher power levels

3M

2a. Packet Data Convergence Protocol (PDCP)

A PDCP entity is associated with the **control plane** or with the **user plane** depending on which radio bearer it is carrying data for.

User Plane Functions:

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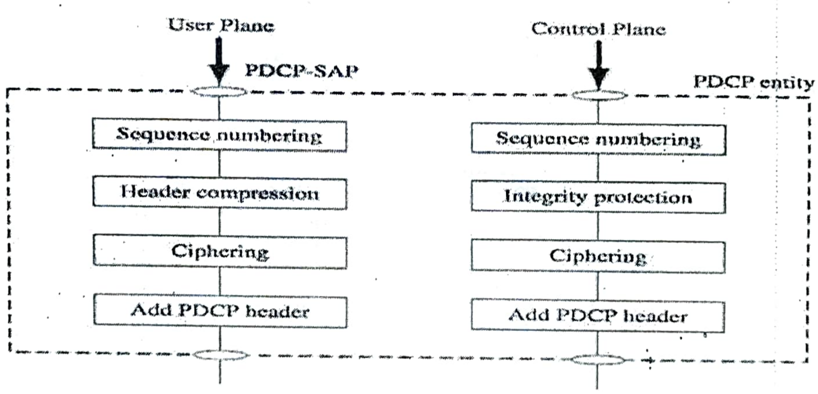
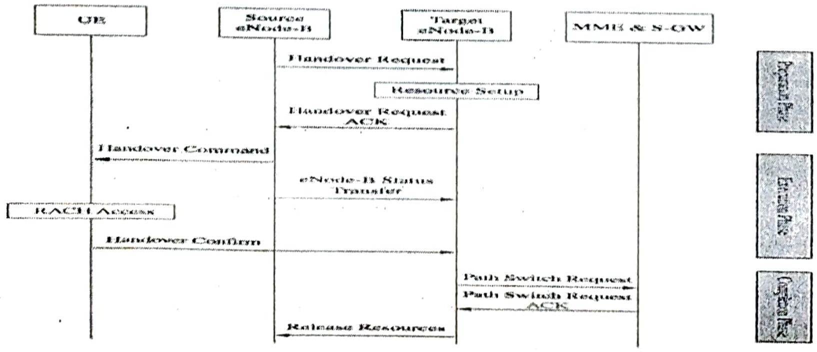
4M



2M

PDCP functions for the user plane and the control plane

2b. Explanation of the three phases of X2 mobility 1) Preparation Phase, 2) Completion phase, and 3) Execution Phase 3M



3M

Mobility management over the X2 interface

2c. Explanation of the RLC entity operated in all of the **three Data Transfer Modes** 1) Transparent Mode (TM), 2) Unacknowledged Mode (UM) or 3) Acknowledged 3M

Mode (AM). 3M

The main functions and services of the RLC sublayer

PART-B

3a. Explanation of the two categories of Scheduling algorithms for LTE

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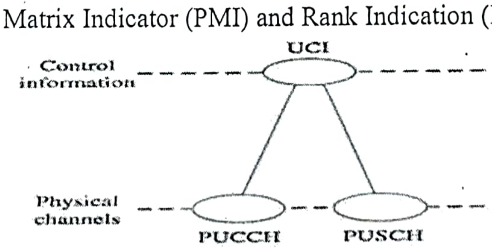

3M

Channel Mapping for Control Information in the Uplink

Course In-charge

Module Coordinator

ECE-HOD

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGG

Course:WC&LTE 4G Broadband **sem:VIII B**

Sl No.	USN No.	Name	IA1	IA2	IA3	Average Assignment	Average of three IA's	Final IA(Assignment+IA)
1	1KS16EC001	A. Yeshwanth	23	24	25	10	24	34
2	1KS17EC054	Manoj E	25	25	26	10	25	35
3	1KS17EC055	MANOJ KUMAR.R	25	26	27	10	26	36
4	1KS17EC056	MOHAMMAD FAIZAL	26	26	27	10	26	36
5	1KS17EC057	MOHAMMED SADATH	26	27	27	10	27	37
6	1KS17EC058	MONISHA.A	25	28	27	10	27	37
7	1KS17EC059	NAGANETRA.M	25	26	27	10	26	36
8	1KS17EC060	NAGELI JAYASAI	22	24	26	10	24	34
9	1KS17EC061	NAVEEN KUMAR BURUGUPALLY	AB	27	27	10	18	28
10	1KS17EC062	NAVIN KUMAR.H.G	26	27	27	10	27	37
11	1KS17EC063	NAVYA.S	27	27	27	10	27	37
12	1KS17EC064	NIKHIL.V	27	27	27	10	27	37
13	1KS17EC065	NIKHIL.V	25	26	27	10	26	36
14	1KS17EC066	PALLAVI.S	26	27	27	10	27	37
15	1KS17EC067	PAVAN PRASAD.R	27	27	27	10	27	37
16	1KS17EC068	PENUJURI NAGA SAI SNEHITHA	28	28	27	10	28	38
17	1KS17EC069	PRAJWAL.C	24	27	27	10	26	36
18	1KS17EC070	PRAJWAL SIMHA.S	26	26	27	10	26	36
19	1KS17EC071	PRATIMA.P.AGNIHOTRI	28	28	27	10	28	38
20	1KS17EC072	PRATIMA V KASHYAP	28	27	27	10	27	37
21	1KS17EC073	PRUTHVIRAJ.N	27	27	27	10	27	37
22	1KS17EC074	R. YASHAS	25	26	25	10	26	36
23	1KS17EC075	RACHANA.S	28	28	27	10	28	38
24	1KS17EC076	RAHUL.R.NADIG	AB	27	27	10	27	37
25	1KS17EC077	RAJESH C.S.	20	AB	27	10	16	26
26	1KS17EC078	RAMYA.R	27	28	27	10	27	37
27	1KS17EC079	RITU PATIL	27	27	27	10	27	37
28	1KS17EC080	ROHINI.D	27	28	27	10	27	37
29	1KS17EC082	RUTHVIK RAVISH	27	25	27	10	27	37
30	1KS17EC084	SAHANA.M.K	27	27	27	10	27	37
31	1KS17EC085	SAHANA.V	28	28	27	10	28	38
32	1KS17EC086	SANDEEP KUMAR.M	25	25	27	10	26	36
33	1KS17EC087	SHAMANTH RAJ.D.N	22	26	27	10	25	35
34	1KS17EC088	SHIVANI.K	27	27	27	10	27	37
35	1KS17EC089	SHRAVYA.S.ACHARYA	25	27	27	10	26	36
36	1KS17EC090	SHREYAS.H.R	25	26	27	10	26	36
37	1KS17EC092	SRIVIDYA.V.R	27	28	27	10	28	38

38	1KS17EC093	SUPRIYA.V	28	27	27	10	28	38
39	1KS17EC094	SURYA.N	26	28	27	10	27	37
40	1KS17EC095	SUSHMITHA.B.L	26	25	27	10	26	36
41	1KS17EC096	SUSHMITHA.K.N	26	26	27	10	27	37
42	1KS17EC097	SYED WAQAR KASHIF	27	28	27	10	27	37
43	1KS17EC098	TEJAS.K	24	26	27	10	26	36
44	1KS17EC099	VAIBHAVI SREENIVASA	27	26	27	10	27	37
45	1KS17EC100	VAISHNAVI.K.KATTI	26	27	27	10	27	37
46	1KS17EC101	VAISHNAVI.S	27	28	27	10	28	38
47	1KS17EC102	VAISHNAVI SRIHARSHA	28	28	27	10	28	38
48	1KS17EC103	VIDYA.V	26	27	27	10	27	37
49	1KS17EC104	VISHAL GOUTHAM.N	27	27	27	10	27	37
50	1KS17EC105	YASHASWINI.R	27	27	27	10	27	37
51	1KS18EC403	HARSHITHA B	26	26	27	10	26	36
52	1KS18EC406	MAHADEVA G R	26	26	27	10	26	36
53	1KS18EC408	VANITHA C	26	26	27	10	26	36
54	1KS14EC101	SOWJANYA K N	26	25	AB	10	26	18
55	1KS16EC075	RENUKAPRASAD M R	26	26	25	10	26	18
56	1KS16EC030	NIKHIL JAMADAGNI H M	AB	22	27	10	25	18

Advanced Learners- Challenging Questions

Q1: What Is E-utran?
Answer:
The E-UTRAN (Evolved UTRAN) consists of eNBs, providing the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME and to the Serving Gateway (S-GW) by means of the S1-U.

Q2. What Is Bsr?
Answer:
The Buffer Status reporting procedure is used to provide the serving eNB with information about the amount of data available for transmission in the UL buffers of the UE.

Q3. How Does Network Sharing Works In Lte?
Answer:
3GPP network sharing architecture allows different core network operators to connect to a shared radio access network. The operators do not only share the radio network elements, but may also share the radio resources themselves.

Q4: How Does Policy Control And Charging Works In Lte?
Answer:
An important component in LTE network is the policy and charging control (PCC) function that brings together and enhances capabilities from earlier 3GPP releases to deliver dynamic control of policy and charging on a per subscriber and per IP flow basis.

LTE Evolved Packet Core (EPC) EPC includes a PCC architecture that provides support for fine-grained QoS and enables application servers to dynamically control the QoS and charging requirements of the services they deliver. It also provides improved support for roaming. Dynamic control over QoS and charging will help operators monetize their LTE investment by providing customers with a variety of QoS and charging options when choosing a service.

The LTE PCC functions include:

- PCRF (policy and charging rules function) provides policy control and flow based charging control decisions.
- PCEF (policy and charging enforcement function) implemented in the serving gateway, this enforces gating and QoS for individual IP flows on the behalf of
- the PCRF. It also provides usage measurement to support charging
- OCS (online charging system) provides credit management and grants credit to the PCEF based on time, traffic volume or chargeable events.
- OFCS (off-line charging system) receives events from the PCEF and generates charging data records (CDRs) for the billing system.

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

TEACHING AND LEARNING

PEDAGOGY REPORT

Academic Year	2020-21 (Even Sem)
Name of the Faculty	Pooja S.
Course Name /Code	Wireless Cellular & LTE 4G Broadband/17EC81
Semester/Section	VIII/B
Activity Name	Unit Test
Topic Covered	Module 3 & 4
Date	23/05/2021
No. of Participants	46
Objectives/Goals	• To identify the key enablers of LTE and their advantages • To differentiate the different modeling techniques for a Broadband Wireless Channel • To differentiate the different types of multiple access techniques used in LTE
ICT Used	Projector
Appropriate Method/Instructional materials/Exam Questions • Questions are given considering Previous year VTU Question Paper Questions	
Relevant PO's	PO 1, 2
Significance of Results/Outcomes	• Students participated in a unit test covering the syllabus of Broadband Wireless Channel and OFDM transceiver basics. This has helped the students to understand the concepts in wireless cellular & LTE 4G communication better. • Improved knowledge of working of wireless LTE techniques and also learnt about time management in answering.
Reflective Critique	The subject comprises of new concepts which the students are not familiar with, hence more effort is required from them to remember the new concepts and their terminologies

Proofs (Photographs/Videos/Reports/Charts/Models)

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

2020 – 21 EVEN SEMESTER

UNIT TEST-02

Degree : B.E
Branch : Electronics & Communication Engg.
Course Title : Wireless Cellular & LTE 4G Broadband
Duration : 50 Minutes

Semester : VIII
Course Code : 17EC81
Date : 23.05.2021
Max Marks : 30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1.	**Identify** the LTE Radio Interface Protocols	10	CO3	K3 [applying]
2.	**Make use of** the structure of downlink resource grid and explain the types of resource allocation	10	CO3	K3 [applying]
	PART-B			
3.	With the help of a neat block diagram, **explain** the SC-FDMA base band signal generation	10	CO4	K2 [Understanding]

Signature of Course In charge

Signature of HOD ECE

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

DEARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

TEACHING AND LEARNING

PEDAGOGY REPORT

Academic Year	**2020-21 (Even Sem)**
Name of the Faculty	**Pooja S.**
Course Name /Code	**Wireless Cellular & LTE 4G Broadband/17EC81**
Semester/Section	**VIII/B**
Activity Name	**Unit Test**
Topic Covered	**Module 1 & 2**
Date	**17/05/2021**
No. of Participants	**45**
Objectives/Goals	• **To identify the key enablers of LTE and their advantages** • **To differentiate the different modeling techniques for a Broadband Wireless Channel** • **To differentiate the different types of multiple access techniques used in LTE**
ICT Used	**Projector**
Appropriate Method/Instructional materials/Exam Questions • **Questions are given considering Previous year VTU Question Paper Questions**	
Relevant PO's	**PO 1, 2**
Significance of Results/Outcomes	• **Students participated in a unit test covering the syllabus of Broadband Wireless Channel and OFDM transceiver basics. This has helped the students to understand the concepts in wireless cellular & LTE 4G communication better.** • **Improved knowledge of working of wireless LTE techniques and also learnt about time management in answering.**
Reflective Critique	**The subject comprises of new concepts which the students are not familiar with, hence more effort is required from them to remember the new concepts and their terminologies**

Proofs (Photographs/Videos/Reports/Charts/Models)

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

2020 – 21 EVEN SEMESTER

UNIT TEST-1

Degree : B.E
Branch : Electronics & Communication Engg.
Course Title : Wireless Cellular & LTE 4G Broadband
Duration : 50 Minutes

Semester : VIII
Course Code : 17EC81
Date : 17.05.2021
Max Marks : 30

Note: Answer ONE full question from each part.

Q No.	Question	Marks	CO mapping	K-Level
	PART-A			
1(a)	**Identify** the key enabling technologies and features of LTE.	10	CO1	K3 [applying]
(b)	**Explain** the EPC network architecture	10	CO1	K2 [Understanding]
	OR			
2(a)	Establish why the IP based network architecture is called flat and **identify** its working in detail.	10	CO1	K3 [applying]
(b)	**Elaborate** the effects of Pathloss and Shadowing in an LTE system	10	CO1	K2 [Understanding]
	PART-B			
3.	**Distinguish** the effect of Delay Spread and Coherence Bandwidth in an LTE system with the necessary equations.	10	CO2	K3 [applying]
	OR			
4.	**Distinguish** the effect of Doppler Spread and Coherence Time in an LTE system with the necessary equations.	10	CO2	K3 [applying]

Signature of Course In charge

Signature of HOD ECE

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Wireless Cellular & LTE 4G Broadband/17EC81
Question Bank

Module 1

1. Discuss the key enabling technologies of LTE
2. Explain the advantages of OFDM that has led to its selection for LTE.
3. Explain the IP-based flat network architecture.
4. With a neat block diagram, explain LTE network architecture and describe briefly the new elements in it.
5. Explain the cellular concept, Frequency Reuse and sectoring.
6. Explain the path loss and shadowing effects in Broadband Wireless Channel (BWC)
7. Explain fading in BWC
8. Mention the broadband fading parameters
9. Define delay spread and coherence bandwidth and express the relation between them
10. Define Doppler spread and coherence time and express the relation between them
11. Define angular spread and coherence distance and express the relation between them.
12. Explain the statistical channel and empirical channel models.
13. Explain Adaptive modulation and coding with block diagram.
14. Explain the techniques used for the mitigation of narrowband and broadband fading

Module 2

1. Explain the concept of cyclic prefix in OFDM.
2. With a block diagram, explain OFDM.
3. Explain Timing and Frequency Synchronization in OFDM.
4. What is Peak to Average Ratio (PAR) in OFDM?
5. Compare OFDM transmitter and receiver with SC-FDE transmitter and receiver block diagram
6. Compare OFDM-FDMA with OFDM-TDMA and OFDM-CDMA.
7. Explain OFDMA downlink transmitter and receiver working with diagram.
8. Explain OFDMA Uplink transmitter and receiver working with diagram.
9. Explain SCFDMA uplink transmitter and receiver working with diagram.
10. Explain the concept of Array Gain and Diversity Gain
11. Explain Selection Combining and Maximal Ratio Combining
12. Compare open loop transmit diversity with closed loop transmit diversity.
13. Discuss 2 X 1 Alamouti code with relevant expressions.
14. Explain Linear Diversity Precoding.

15. Explain Linear Interference Suppression with a simple two user interface cancellation example
16. Explain the concept of spatial multiplexing
17. Explain Linear detectors or spatial multiplexing with linear receiver
18. Compare V-Blast and D-blast encoding Techniques
19. Explain SVD precoding and postcoding in closed loop MIMO

Module 3

1. Explain in detail the design principles of LTE
2. Explain the LTE end-to-end network architecture
3. Explain the LTE Radio Interface Protocols
4. Explain each layer in the hierarchical channel structure of LTE
5. Write the mapping between different channel types also mapping of control information to physical channels
6. Explain Frame Structure Type 1 and Type 2
7. Explain the Downlink Resource Grid and compare it with the uplink Resource Grid
8. Explain the Downlink Transport Channel Coding Processing
9. Explain the OFDMA signal generation
10. Explain the Downlink Control Information

Module 4

1. With a diagram, explain the Uplink Transport Channel Processing.
2. Expalin Modulation Processing or Generation of SC_FDMA baseband signals in uplink
3. Discuss the channel mapping for the uplink shared channel and the control information in the uplink
4. What is frequency hopping? Illustrate intra subframe and inter subframe frequency hopping in uplink transport channel
5. Explain the concept of Multi Antenna Transmission.
6. Write mapping to physical resource blocks for PUCCH.
7. Explain Uplink Reference Signals.
8. Compare H-ARQ process in Uplink for TDD mode and FDD mode.
9. Explain Cell Search process.
10. Explain Random Access procedures.

Module 5

1. With a diagram, explain PDCP functions for user plane and control plane.
2. Compare TM, UM and AM operations in RLC entities
3. Explain the format of Status PDU and MAC PDU

4. Write the MAC PDU format for random access response.
5. Explain RRC states and its functions in LTE
6. Explain the Mobility management over S1 interface.
7. Explain the Mobility management over X2 interface.
8. Explain RAN procedures for mobility.
9. Explain the approaches to mitigate ICI in Downlink.
10. Explain the approaches for Uplink ICI mitigation.

CBCS SCHEME

USN

17EC81

Eighth Semester B.E. Degree Examination, July/August 2021
Wireless Cellular and LTE 4G Broadband

Time: 3 hrs. Max. Marks: 100

Note: *Answer any FIVE full questions.*

1 a. Explain the advantages of OFDM leading to its selection for LTE. (08 Marks)
b. Explain adaptive modulating and coding with neat block diagram. (08 Marks)
c. Explain briefly path loss. (04 Marks)

2 a. Explain with neat block diagram flat LTE SAE architecture. (08 Marks)
b. Explain delay spread and coherence bandwidth. (08 Marks)
c. Mention advantages and disadvantages of cell sectoring in cellular wireless communications. (04 Marks)

3 a. Explain the basic multicarries transmitter and receiver with neat block diagram. (08 Marks)
b. Explain the principle of operation of OFDM downlink transmitter with neat sketch. (08 Marks)
c. Mention the differences between V-BLAST and D-BLAST encoding techniques. (04 Marks)

4 a. Explain peak to average power ratio (PAR). (08 Marks)
b. Explain SC-FDMA uplink transmitter and receiver with neat block diagram. (08 Marks)
c. Compare OFDM and SCFDE. (04 Marks)

5 a. Explain uplink and downlink transport channels. (08 Marks)
b. Explain frame structures used in LTE. (08 Marks)
c. Explain Broadcast channel used in LTE. (04 Marks)

6 a. Explain LTE end to end network architecture with neat block diagram. (08 Marks)
b. With neat block diagram explain radio interface protocols stack. (08 Marks)
c. Explain uplink transport channels. (04 Marks)

7 a. Explain the types of uplink reference signals. (08 Marks)
b. With neat block diagram, explain the uplink transport channel processing. (08 Marks)
c. Explain buffer status reporting in uplink. (04 Marks)

8 a. Explain with neat sketch cell search procedure used in LTE. (08 Marks)
b. Explain random access procedure used in LTE. (08 Marks)
c. What is meant by periodic and aperiodic reporting in CQI feedback? (04 Marks)

9 a. Explain RRC states and function with neat sketch. (08 Marks)
b. Explain mobility management over X2 mobility with neat sketch. (04 Marks)
c. Explain data transfer modes. (08 Marks)

10 a. Explain RAN procedure for mobility. (08 Marks)
b. Explain the main services and function of RLC and MAC layers. (08 Marks)
c. Explain paging used in RRC protocol. (04 Marks)

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CBCS SCHEME

USN

15EC81

Eighth Semester B.E. Degree Examination, Dec.2019/Jan.2020
Wireless Cellular and LTE 4G Broadband

Time: 3 hrs. Max. Marks: 80

Note: *Answer FIVE full questions, choosing ONE full question from each module.*

Module-1

1 a. List the advantages of OFDM leading to its selection for LTE and explain. **(08 Marks)**
b. Discuss the delay spread and coherence bandwidth with relevant expressions. **(08 Marks)**

OR

2 a. Write the block diagram of end to end architecture of EPC supporting current and legacy Radio access networks and discuss the elements of EPC. **(08 Marks)**
b. Consider a user in downlink of a cellular system where the desired base station is at a distance 0.5 KM and the interfering base stations (i) B_1 and B_2 located at a distance of 1.0 KM, (ii) B3, B4 and B5 located at a distance of 2 KM (iii) B6 to B11 treated at a distance of 2.66 KM. Each of the stations transmitted power at the same level. Find the SIR when the path loss exponent $\alpha = 3$ and also when $\alpha = 5$. **(08 Marks)**

Module-2

3 a. With the help of neat diagrams explain how the timing and frequency synchronization is performed by the receiver to demodulate an OFDM signal. **(08 Marks)**
b. Write the block diagrams of receive diversity and explain the principle of operation. **(08 Marks)**

OR

4 a. Write the block diagram of OFDMA down link transmitter and explain the principle of operation. **(08 Marks)**
b. Explain the spatial multiplexing MIMD system and the key points of single user MIMD system model. **(08 Marks)**

Module-3

5 a. Discuss the radio interface protocol stock of LTE. **(08 Marks)**
b. Write the structure of downlink resource grid and explain the types of resource allocation. **(08 Marks)**

OR

6 a. Write the Frame structure Type 2 and explain the various fields applicable to TDD mode. **(08 Marks)**
b. Discuss the Broadcast channels and multicast channels. **(08 Marks)**

Module-4

7 a. With the help of a neat block diagram, explain the SC-FDMA base band signal generation. **(08 Marks)**
b. Discuss the random access procedures in detail. **(08 Marks)**

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

OR

8 a. Explain the seven different transmission modes, defined for data transmission on the PDSCH channel. **(07 Marks)**

b. Discuss the scheduling and resource allocation in LTE. **(09 Marks)**

Module-5

9 a. Explain the main services and functions of the PDCP. **(08 Marks)**

b. Describe the various phases of S1 mobility with a neat diagram. **(08 Marks)**

OR

10 a. Explain the data transfer modes and the main services and functions of the RLC sublayer. **(08 Marks)**

b. Discuss the intercell interference coordination in downlink and uplink. **(08 Marks)**

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CBCS SCHEME

USN

15EC81

Eighth Semester B.E. Degree Examination, June/July 2019
Wireless Cellular and LTE 4G Broadband

Time: 3 hrs. Max. Marks: 80

Note: ***Answer FIVE full questions, choosing ONE full question from each module.***

Module-1

1 a. Explain the advantages of OFDM for LTE. ([illegible] Marks)
b. Explain flat LTE SAE architecture. ([illegible] Marks)

OR

2 a. Explain the following in brief.
(i) Pathloss and Shadowing.
(ii) Angular Spread and coherence distance.
(iii) Doppler spread and coherence time. (09 Marks)
b. Explain with a neat diagram, adaptive modulation and coding. (07 Marks)

Module-2

3 a. With a neat block diagram, explain OFDM communication system. Also mention the need of timing and frequency synchronization. (09 Marks)
b. Explain SC-FDMA uplink transmitter with a neat figure. (07 Marks)

OR

4 a. Explain spatial diversity of multiple antenna techniques. (08 Marks)
b. Explain open-loop MIMO in spatial multiplexing. (08 Marks)

Module-3

5 a. Explain the LTE Radio Interference protocols. (08 Marks)
b. Explain the transport channels in LTE. (08 Marks)

OR

6 a. Explain the hierarchical channel structure of LTE. (08 Marks)
b. Explain briefly layer mapping and precoding in modulation mapping. (08 Marks)

Module-4

7 a. Explain uplink control information. (08 Marks)
b. Explain the types of uplink reference signals. (08 Marks)

OR

8 a. Briefly explain the function of H-ARQ feedback in Downlink and Uplink transmission. (08 Marks)
b. Explain in brief types of Random Access procedure in LTE. (08 Marks)

Module-5

9 a. Explain the main services and functions of PDCP sublayer for the user plane. (08 Marks)
b. Explain RRC states and its functions. (08 Marks)

OR

10 a. Explain mobility management over the S1 transfer. (08 Marks)
b. Explain three basic approaches to mitigate ICI in downlink. (08 Marks)

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K.S.INSTITUTE OF TECHNOLOGY

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGG.

Subject Code: 17EC81-Wireless Cellular and 4G LTE Broadband(2021)

Course End Survey

Name of the Student	USN	Faculty Name	1.Have you understand the overview of Key enabling Feature of LTE and Cellular concepts ?	2.What is your level of understanding on multi-carrier Modulation techniques in LTE?	3.Are you able to explain the functions of Downlink and Uplink channel procedures ?	4.To what extent you understood Physical layer procedures in LTE?	5.What is your level of understanding Radio Resource management ,Mobility management?
Sowjanya KN	1KS14EC101	Mrs. Pooja.S	2	3	2	3	3
AMAN KUMAR SI	1KS16EC007	Dr.Sangappa.S B	3	3	3	3	3
K UNNIMAYA	1KS16EC033	Dr.Sangappa.S B	3	3	3	3	3
Kshitiz Gurung	1KS16EC038	Dr.Sangappa.S B	3	2	3	2	3
Purushothama v	1KS16EC068	Dr.Sangappa.S B	3	3	3	3	3
R Sharath Kumar	1KS16EC069	Dr.Sangappa.S B	3	3	3	3	3
Renukaprasad M R	1KS16EC075	Mrs. Pooja.S	3	3	3	3	3
Shivdatt B	1KS16EC086	Dr.Sangappa.S B	3	3	3	3	3
Somashekar S	1KS16EC093	Dr.Sangappa.S B	3	3	3	3	3
Vinayak	1KS16EC113	Dr.Sangappa.S B	3	3	3	3	3
Rakesh. Md	1KS16EC431	Dr.Sangappa.S B	3	3	3	3	3
Rakesh MD	1KS16EC431	Dr.Sangappa.S B	3	3	3	3	3
Vaishnavi S	1KS17EC101	Mrs. Pooja.S	2	2	2	2	2
Abhishek K V	1KS17EC001	Dr.Sangappa.S B	3	3	3	3	3
Abijith Sudhir	1KS17EC002	Dr.Sangappa.S B	3	3	3	3	3
Abijith Sudhir	1KS17EC002	Dr.Sangappa.S B	3	3	3	3	3
Akkshay U.L	1KS17EC003	Dr.Sangappa.S B	3	3	3	3	3
Shreenidhi BD	1KS17EC003	Dr.Sangappa.S B	3	3	3	3	3
Akshitha V Rames	1KS17EC004	Dr.Sangappa.S B	3	3	3	3	3
Amoghavarsha	1KS17EC005	Dr.Sangappa.S B	3	3	3	3	3
Amulya S Iyengar	1KS17EC006	Dr.Sangappa.S B	3	2	2	2	3
Ana Epsiba F	1KS17EC007	Dr.Sangappa.S B	2	2	2	2	2
Anagha A Kashyap	1KS17EC008	Dr.Sangappa.S B	3	3	3	3	3
ANITHA R	1KS17EC009	Dr.Sangappa.S B	3	3	3	3	3
Anoop Deekshith R	1KS17EC010	Dr.Sangappa.S B	3	3	3	3	3
ANUPAM M L	1KS17EC011	Dr.Sangappa.S B	3	3	3	3	3
ANUSHA.L	1KS17EC012	Dr.Sangappa.S B	3	3	3	3	3
Anushree M	1KS17EC013	Dr.Sangappa.S B	3	3	3	3	3
Anushri VK	1KS17EC014	Dr.Sangappa.S B	3	3	3	3	3
Anushri VK	1KS17EC014	Dr.Sangappa.S B	3	3	3	3	3
Apeksha Ravi Kum	1KS17EC015	Dr.Sangappa.S B	3	3	3	3	3
Arpitha	1KS17EC016	Dr.Sangappa.S B	2	2	2	2	2
Asiya Fathima N	1KS17EC017	Dr.Sangappa.S B	1	1	1	1	1
Ayesha Rosheen	1KS17EC018	Dr.Sangappa.S B	3	3	3	3	3
BHAVANA B S	1KS17EC020	Dr.Sangappa.S B	2	2	2	2	2
Bhavana. J	1KS17EC021	Dr.Sangappa.S B	3	3	3	3	3
Bhoomika PK	1KS17EC022	Dr.Sangappa.S B	3	3	3	3	2
Bindu J	1KS17EC023	Dr.Sangappa.S B	3	3	3	3	3
Chaithra VM	1KS17EC024	Dr.Sangappa.S B	3	3	3	3	3
Charan Sai Y	1KS17EC025	Dr.Sangappa.S B	3	3	3	3	3
CHETHAN DR	1KS17EC026	Dr.Sangappa.S B	3	3	3	3	3
CHETHAN G	1KS17EC027	Dr.Sangappa.S B	3	3	3	3	3
Chethana K S	1KS17EC028	Dr.Sangappa.S B	3	2	2	2	2
Chethana Prasad K	1KS17EC029	Dr.Sangappa.S B	3	3	3	3	3
Darshan T G	1KS17EC030	Dr.Sangappa.S B	2	2	2	2	2
Devale Sudarshan	1KS17EC031	Dr.Sangappa.S B	2	3	3	3	2
Disha S	1KS17EC035	Dr.Sangappa.S B	2	2	2	2	2

Name of the Student	USN	Faculty Name	1.Have you understand the overview of Key enabling Feature of LTE and Cellular concepts ?	2.What is your level of understanding on multi-carrier Modulation techniques in LTE?	3.Are you able to explain the functions of Downlink and Uplink channel procedures ?	4.To what extent you understood Physical layer procedures in LTE?	5.What is your level of understanding Radio Resource management ,Mobility management?
Divya TM	1KS17EC036	Dr.Sangappa.S B	3	3	3	3	3
GOPINATH H C	1KS17EC038	Dr.Sangappa.S B	2	2	2	2	2
Gowtham B	1KS17EC039	Dr.Sangappa.S B	2	3	2	1	2
Surabhi	1KS17EC040	Dr.Sangappa.S B	3	3	3	3	3
H G SRINIDHI	1KS17EC041	Dr.Sangappa.S B	2	2	2	2	2
JEEVAN R S	1KS17EC042	Dr.Sangappa.S B	3	3	3	3	3
Jeevan r s	1KS17EC042	Dr.Sangappa.S B	3	3	3	3	3
Kamnoor Sushma	1KS17EC044	Dr.Sangappa.S B	3	3	3	3	3
Krithika P	1KS17EC045	Dr.Sangappa.S B	3	3	3	3	3
Lakshan	1KS17EC046	Dr.Sangappa.S B	3	3	3	3	3
Lekha Yadav B	1KS17EC047	Dr.Sangappa.S B	3	3	3	3	3
M.R.Srinivas	1KS17EC048	Dr.Sangappa.S B	2	2	2	2	2
M RANJITH	1KS17EC049	Dr.Sangappa.S B	2	2	2	2	2
M Sirisha	1KS17EC050	Dr.Sangappa.S B	3	3	3	3	3
Madhu S	1KS17EC051	Dr.Sangappa.S B	3	3	3	3	3
Mahadeva G	1KS17EC052	Dr.Sangappa.S B	2	2	2	2	2
Mamathaks	1KS17EC053	Dr.Sangappa.S B	3	3	3	3	3
Manoj E	1KS17EC054	Mrs. Pooja.S	2	2	2	2	2
Manoj Kumar r	1KS17EC055	Mrs. Pooja.S	3	3	3	3	3
Mohammad faizal	1KS17EC056	Mrs. Pooja.S	2	2	2	2	2
Mohammed Sadat	1KS17EC057	Mrs. Pooja.S	3	3	3	3	3
Mohammed Sadat	1KS17EC057	Mrs. Pooja.S	3	3	3	3	3
MONISHA A	1KS17EC058	Mrs. Pooja.S	3	3	3	3	3
Naganetra. M	1KS17EC059	Mrs. Pooja.S	2	2	2	2	2
Nageli jayasai Nai	1KS17EC060	Mrs. Pooja.S	3	3	3	3	3
Naveen Kumar Bu	1KS17EC061	Mrs. Pooja.S	3	3	3	3	3
Navin Kumar HG	1KS17EC062	Mrs. Pooja.S	3	3	3	3	3
Navya S	1KS17EC063	Mrs. Pooja.S	3	3	3	3	3
Nikhil	1KS17EC064	Mrs. Pooja.S	3	3	3	3	3
Nikhil	1KS17EC065	Mrs. Pooja.S	3	3	2	3	3
Pallavi S	1KS17EC066	Mrs. Pooja.S	3	3	3	3	3
Pavanprasad.R	1KS17EC067	Mrs. Pooja.S	3	3	3	3	3
Penujuri Naga Sai	1KS17EC068	Mrs. Pooja.S	3	3	3	3	3
Prajwal C	1KS17EC069	Mrs. Pooja.S	3	3	3	3	3
Pratima P Agnihot	1KS17EC071	Mrs. Pooja.S	2	3	2	3	3
Pratima V Kashyap	1KS17EC072	Mrs. Pooja.S	2	2	2	2	2
Pruthviraj	1KS17EC073	Mrs. Pooja.S	3	3	3	3	3
RACHANA S	1KS17EC075	Mrs. Pooja.S	3	2	2	2	2
Rahul R Nadig	1KS17EC076	Mrs. Pooja.S	3	3	3	3	3
Ramya R	1KS17EC078	Mrs. Pooja.S	3	2	3	2	3
Ritu Patil	1KS17EC079	Mrs. Pooja.S	3	2	2	2	2
ROHINI D	1KS17EC080	Mrs. Pooja.S	3	2	3	2	2
Ruthvik Ravish	1KS17EC082	Mrs. Pooja.S	3	3	3	3	3
Sahana.M.k	1KS17EC084	Mrs. Pooja.S	2	2	2	2	2
Sahana V	1KS17EC085	Mrs. Pooja.S	3	3	3	3	3
Sandeep Kumar M	1KS17EC086	Mrs. Pooja.S	2	2	2	2	2
Shivani K	1KS17EC088	Mrs. Pooja.S	2	2	2	2	2
Shravya	1KS17EC089	Mrs. Pooja.S	2	2	2	2	2
Shreyas	1KS17EC090	Mrs. Pooja.S	2	2	2	2	2
Srividya VR	1KS17EC092	Mrs. Pooja.S	2	3	2	3	2
Supriya V	1KS17EC093	Mrs. Pooja.S	2	2	2	2	2
Sushmita BL	1KS17EC095	Mrs. Pooja.S	3	3	3	3	3

Name of the Student	USN	Faculty Name	1.Have you understand the overview of Key enabling Feature of LTE and Cellular concepts ?	2.What is your level of understanding on multi-carrier Modulation techniques in LTE?	3.Are you able to explain the functions of Downlink and Uplink channel procedures ?	4.To what extent you understood Physical layer procedures in LTE?	5.What is your level of understanding Radio Resource management ,Mobility management?
Sushmitha KN	1KS17EC096	Mrs. Pooja.S	3	3	2	3	3
Syed Waqar Kash	1KS17EC097	Mrs. Pooja.S	3	3	3	3	3
Tejas K	1KS17EC098	Mrs. Pooja.S	2	2	2	2	2
Vaibhavi Sreeniva	1KS17EC099	Mrs. Pooja.S	3	3	3	3	3
Vaishnavi K Katti	1KS17EC100	Mrs. Pooja.S	3	3	3	3	3
Vaishnavi S	1KS17EC101	Mrs. Pooja.S	2	2	2	2	2
Vaishnavi Sriharsh	1KS17EC102	Mrs. Pooja.S	3	3	3	3	3
Vidya V	1KS17EC103	Mrs. Pooja.S	3	3	3	3	3
Vishal Goutham N	1KS17EC104	Mrs. Pooja.S	2	2	2	2	2
Yashashwini R	1KS17EC105	Mrs. Pooja.S	3	3	3	3	3
Bhavana G	1KS17EC403	Dr.Sangappa.S B	2	2	3	3	3
Yathish S Dhanan	1KS17EC414	Dr.Sangappa.S B	3	3	3	3	3
Harshitha B	1KS18EC403	Mrs. Pooja.S	3	3	3	3	3
Mahadeva gr	1KS18EC406	Mrs. Pooja.S	3	3	3	3	3
Vanitha c	1KS18EC408	Mrs. Pooja.S	3	3	3	3	3
Dhakshith nk	1KS17EC033	Dr.Sangappa.S B	3	3	3	3	3
A Yeswanth	1KS16EC001	Mrs. Pooja.S	3	3	3	3	3
Rajesh C S	1KS17EC077	Mrs. Pooja.S	3	3	3	2	3
Nikhil	1KS16EC030	Mrs. Pooja.S	3	3	3	3	3
Tejas K	1KS17EC098	Mrs. Pooja.S	3	3	3	3	3
		No.of 1s	1	1	1	2	1
		Total	119	119	119	119	119
		percentage	99.1596639	99.159664	99.159664	98.31932773	99.15966387
		Average	98.9915966				

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGG

YEAR / SEMESTER	**4/8SEM**
COURSE TITLE	**WC&LTE 4G Broadband**
COURSE CODE	**17EC81**
ACADEMIC YEAR	**2020-2021**
BATCH	**2017-2021**

CO Attainment Level	Significance
Level 3	60% and above students should have scored >= 60% of Total marks
Level 2	55% to 59% of students should have scored >= 60% of Total marks
Level 1	50% to 54% of students should have scored >= 60% of Total marks

For Direct attainment , 50% of CIE and 50% of SEE marks are considered.
For indirect attainment, Course end survey is considered.
CO attainment is 90%of direct attainment + 10% of Indirect atttainment.
PO attainment = CO-PO mapping strength/3 * CO attainment .

Sl. NO.	USN	NAME	IA1							Assignment 1							IA2										Assignment 2										IA3							Assignment 3							EXTERNAL MARKS		
			IA1	CO 1	Scores	Target 60%	CO 2	Scores	Target 60%	A1	CO 1	Scores	Target 60%	CO 2	Scores	Target 60%	IA2	CO 2	Scores	Target 60%	CO 3	Scores	Target 60%	CO 4	Scores	Target 60%	A2	CO 2	Scores	Target 60%	CO 3	Scores	Target 60%	CO 4	Scores	Target 60%	IA3	CO 4	Scores	Target 60%	CO 5	Scores	Target 60%	A3	CO 4	Scores	Target 60%	CO 5	Scores	Target 60%	SEE	Scores	Target 60%
	Maximum Marks		**30**	**18**			**12**			**10**	**6**			**4**			**30**	**6**			**18**			**6**			**10**	**2**			**6**			**2**			**30**	**12**			**18**			**10**	**6**			**4**			**60**		
1	1KS17EC001	ABHISHEK.K.V	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	23	5	3	Y	13	3	Y	5	3	Y	6	2	3	Y	6	3	Y	2	3	Y	26	11	3	Y	15	3	Y	0	5.00	3	Y	4	3	Y	**38**	3	Y
2	1KS17EC002	ABIJITH SUDHIR	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	0	0.00	0	N	4	3	Y	**34**	2	N
3	1KS17EC003	AKKSHAY.U.L	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	0	6.00	3	Y	4	3	Y	**23**	0	N
4	1KS17EC004	ESH	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	0	0	0	N	0	0	N	10	4.00	3	Y	3	3	Y	**23**	0	N
5	1KS17EC005	N.D	27	17	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	9	3.00	1	N	3	3	Y	**33**	2	N
6	1KS17EC006	AR	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	8	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	10	5.00	3	Y	4	3	Y	**41**	3	Y
7	1KS17EC007	ANA EPSIBA.F	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	29	6	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	9	6.00	3	Y	4	3	Y	**35**	2	N
8	1KS17EC008	AP	28	16	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	28	12	3	Y	16	3	Y	10	6.00	3	Y	4	3	Y	**38**	3	Y
9	1KS17EC009	ANITHA.R	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	9	6.00	3	Y	4	3	Y	**38**	3	Y
10	1KS17EC010	DEEKSHITH.R	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	8	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	8	3.00	1	N	0	0	N	**49**	3	Y
11	1KS17EC011	ANUPAM.M.L	25	15	3	Y	10	3	Y	A	5	3	Y	0	0	N	28	5	3	Y	18	3	Y	5	3	Y	0	1	1	N	4	3	Y	0	0	N	28	10	3	Y	18	3	Y	0	4.00	3	Y	3	3	Y	**24**	0	N
12	1KS17EC012	ANUSHA.L	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	9	6.00	3	Y	4	3	Y	**30**	1	N
13	1KS17EC013	ANUSHREE.M	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	15	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	12	3	Y	16	3	Y	9	4.00	3	Y	3	3	Y	**31**	1	N
14	1KS17EC014	ANUSHRI.V.K	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	9	6.00	3	Y	4	3	Y	**26**	0	N
15	1KS17EC015	KUMAR	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	10	6.00	3	Y	4	3	Y	**32**	1	N
16	1KS17EC016	ARPITHA	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	0	1.00	0	N	3	3	Y	**30**	1	N
17	1KS17EC017	ASIYA FATHIMA.N	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	29	6	3	Y	18	3	Y	5	3	Y	8	2	3	Y	6	3	Y	2	3	Y	27	12	3	Y	15	3	Y	9	6.00	3	Y	4	3	Y	**26**	0	N
18	1KS17EC018	AYESHA ROSHEEN	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	27	12	3	Y	15	3	Y	0	3.00	1	N	3	3	Y	**35**	2	N
19	1KS17EC019	B.D.SHREENIDHI	30	18	3	Y	12	3	Y	A	4	3	Y	2	1	N	28	5	3	Y	18	3	Y	5	3	Y	8	2	3	Y	4	3	Y	0	0	N	30	12	3	Y	18	3	Y	0	3.00	1	N	3	3	Y	**24**	0	N
20	1KS17EC020	BHAVANA.B.S	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	26	11	3	Y	15	3	Y	10	4.00	3	Y	3	3	Y	**51**	3	Y
21	1KS17EC021	BHAVANA.J	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	9	4.00	3	Y	3	3	Y	**35**	2	N
22	1KS17EC022	BHOOMIKA.P.K	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	26	10	3	Y	16	3	Y	10	6.00	3	Y	4	3	Y	**36**	3	Y
23	1KS17EC023	BINDU.J	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	8	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	9	2.00	0	N	2	0	N	**36**	3	Y
24	1KS17EC024	CHAITHRA.V.M	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	9	4.00	3	Y	3	3	Y	**39**	3	Y
25	1KS17EC025	CHARAN SAI.Y	23	15	3	Y	8	3	Y	10	0	0	N	0	0	N	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	26	11	3	Y	15	3	Y	8	4.00	3	Y	4	3	Y	**44**	3	Y

26	1KS17EC026	CHETHAN.D.R	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	15	3	Y	6	3	Y	8	2	3	Y	0	0	N	0	0	N	27	12	3	Y	15	3	Y	0	0.00	0	N	3	3	Y	**25**	0	N
27	1KS17EC027	CHETHAN.G	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	0	4.00	3	Y	3	3	Y	**21**	0	N
28	1KS17EC028	CHETHANA.K.S	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	9	6.00	3	Y	4	3	Y	**42**	3	Y
29	1KS17EC029	PRASAD.K	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	9	6.00	3	Y	4	3	Y	**33**	2	N
30	1KS17EC030	DARSHAN.T.G	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	15	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	0	2.00	0	N	2	0	N	**42**	3	Y
31	1KS17EC031	SUDARSHAN	23	13	3	Y	10	3	Y	8	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	0	0	N	2	3	Y	28	10	3	Y	18	3	Y	9	3.00	1	N	3	3	Y	**30**	1	N
32	1KS17EC032	DEVIYANI.G	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	0	2.00	0	N	2	0	N	**26**	0	N
33	1KS17EC033	DHAKSHITH.N.K	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	0	0.00	0	N	3	3	Y	**48**	3	Y
34	1KS17EC035	DISHA.S	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	16	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	28	12	3	Y	16	3	Y	0	6.00	3	Y	4	3	Y	**51**	3	Y
35	1KS17EC036	DIVYA.T.M	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	0	6.00	3	Y	4	3	Y	**36**	3	Y
36	1KS17EC038	GOPINATH.H.C	23	15	3	Y	8	3	Y	10	0	0	N	3	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	8	0.00	0	N	2	0	N	**21**	0	N
37	1KS17EC039	GOWTHAM.B	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	6	3	Y	15	3	Y	5	3	Y	8	2	3	Y	1	0	N	2	3	Y	27	12	3	Y	15	3	Y	8	0.00	0	N	3	3	Y	**45**	3	Y
38	1KS17EC040	G.S.SURABHI	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	0	10	3	Y	16	3	Y	8	6.00	3	Y	4	3	Y	**29**	0	N
39	1KS17EC041	H.G.SRINIDHI	28	18	3	Y	10	3	Y	10	1	0	N	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	2	3	Y	1	0	N	2	3	Y	28	10	3	Y	18	3	Y	0	0.00	0	N	2	0	N	**29**	0	N
40	1KS17EC042	JEEVAN.R.S	26	15	3	Y	11	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	15	3	Y	6	3	Y	8	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	8	6.00	3	Y	4	3	Y	**39**	3	Y
41	1KS17EC043	K.SHREYA	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	12	3	Y	15	3	Y	10	2.00	0	N	2	0	N	**37**	3	Y
42	1KS17EC044	SUSHMA	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	10	1	1	N	0	0	N	2	3	Y	28	10	3	Y	18	3	Y	10	4.00	3	Y	4	3	Y	**30**	1	N
43	1KS17EC045	KRITHIKA.P	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	10	6.00	3	Y	4	3	Y	**45**	3	Y
44	1KS17EC046	LAKSHAN.N.S	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	9	0	0	N	0	0	N	0	0	N	25	10	3	Y	15	3	Y	9	4.00	3	Y	4	3	Y	**24**	0	N
45	1KS17EC047	LEKHA YADAV.B	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	9	2	3	Y	6	3	Y	2	3	Y	26	10	3	Y	16	3	Y	10	6.00	3	Y	4	3	Y	**41**	3	Y
46	1KS17EC048	M.R.SRINIVAS	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	15	3	Y	6	3	Y	0	2	3	Y	4	3	Y	2	3	Y	25	10	3	Y	15	3	Y	0	0.00	0	N	3	3	Y	**15**	0	N
47	1KS17EC049	RANJITH.M	23	14	3	Y	9	3	Y	10	6	3	Y	4	3	Y	25	5	3	Y	15	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	26	10	3	Y	16	3	Y	9	6.00	3	Y	4	3	Y	**12**	0	N
48	1KS17EC050	M.SIRISHA	30	18	3	Y	12	3	Y	10	6	3	Y	4	3	Y	30	6	3	Y	18	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	30	12	3	Y	18	3	Y	10	6.00	3	Y	4	3	Y	**43**	3	Y
49	1KS17EC051	MADHU.S	28	18	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	18	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	28	10	3	Y	18	3	Y	10	6.00	3	Y	4	3	Y	**48**	3	Y
50	1KS17EC052	MAHADEVA.G	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	25	5	3	Y	15	3	Y	5	3	Y	6	2	3	Y	6	3	Y	2	3	Y	29	11	3	Y	18	3	Y	0	2.00	0	N	2	0	N	**43**	3	Y
51	1KS17EC053	MAMATHA.K.S	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	25	5	3	Y	15	3	Y	5	3	Y	9	2	3	Y	6	3	Y	2	3	Y	25	10	3	Y	15	3	Y	8	4.00	3	Y	3	3	Y	**35**	2	N
52	1KS17EC054	manoj E	25	16	3	Y	9	3	Y	10	6	3	Y	4	3	Y	25	4	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	26	10	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**21**	0	N
53	1KS17EC055	MANOJ KUMAR.R	25	16	3	Y	9	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**56**	3	Y
54	1KS17EC056	FAIZAL	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**22**	0	N
55	1KS17EC057	SADATH	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**35**	2	N
56	1KS17EC058	MONISHA.A	25	16	3	Y	9	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**24**	0	N
57	1KS17EC059	NAGANETRA.M	25	16	3	Y	9	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	17	3	Y	4	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**33**	2	N
58	1KS17EC060	NAIDU	22	13	3	Y	9	3	Y	10	6	3	Y	4	3	Y	24	5	3	Y	15	3	Y	4	3	Y	10	2	3	Y	6	3	Y	2	3	Y	26	11	3	Y	15	3	Y	10	6	3	Y	4	3	Y	**32**	1	N
59	1KS17EC061	BURUGUPALLY	AB	0	3	Y	0	0	N	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**34**	2	N
60	1KS17EC062	KUMAR.H.G	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**41**	3	Y
61	1KS17EC063	NAVYA.S	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**24**	0	N
62	1KS17EC064	NIKHIL.V	27	17	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**32**	1	N
63	1KS17EC065	NIKHIL.V	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	4	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**42**	3	Y
64	1KS17EC066	PALLAVI.S	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**42**	3	Y
65	1KS17EC067	PAVAN PRASAD.R	27	17	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	15	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**35**	2	N
66	1KS17EC068	SAI SNEHITHA	28	16	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	12	3	Y	15	3	Y	10	6	3	Y	4	3	Y	**46**	3	Y
67	1KS17EC069	PRAJWAL.C	24	14	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	16	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**32**	1	N
68	1KS17EC070	SIMHA.S	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**36**	3	Y
69	1KS17EC071	HOTRI	28	16	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**45**	3	Y
70	1KS17EC072	KASHYAP	28	16	3	Y	12	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**43**	3	Y
71	1KS17EC073	PRUTHVIRAJ.N	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**23**	0	N
72	1KS17EC074	R Yashas	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**29**	0	N

73	1KS17EC075	RACHANA.S	28	16	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	17	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**43**	3	Y
74	1KS17EC076	RAHUL.R.NADIG	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**29**	0	N
75	1KS17EC077	Rajesh	20	15	3	Y	5	0	N	10	6	3	Y	4	3	Y	AB	0	0	N	0	0	N	0	0	N	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**35**	2	N
76	1KS17EC078	RAMYA.R	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**29**	0	N
77	1KS17EC079	RITU PATIL	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**31**	1	N
78	1KS17EC080	ROHINI.D	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**31**	1	N
79	1KS17EC082	RUTHVIK RAVISH	27	15	3	Y	12	3	Y	10	6	3	Y	4	3	Y	25	5	3	Y	15	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**32**	1	N
80	1KS17EC084	SAHANA.M.K	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**38**	3	Y
81	1KS17EC085	SAHANA.V	28	17	3	Y	11	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**39**	3	Y
82	1KS17EC086	KUMAR.M	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	25	5	3	Y	15	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**31**	1	N
83	1KS17EC087	RAJ.D.N	22	12	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	6	3	Y	15	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	9	3	Y	18	3	Y	10	6	3	Y	4	3	Y	**35**	2	N
84	1KS17EC088	SHIVANI.K	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**25**	0	N
85	1KS17EC089	RYA	25	16	3	Y	9	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**30**	1	N
86	1KS17EC090	SHREYAS.H.R	25	14	3	Y	11	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**30**	1	N
87	1KS17EC092	SRIVIDYA.V.R	27	17	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	5	3	Y	17	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	28	11	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**39**	3	Y
88	1KS17EC093	SUPRIYA.V	28	17	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	28	11	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**43**	3	Y
89	1KS17EC094	SURYA.N	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**23**	0	N
90	1KS17EC095	SUSHMITHA.B.L	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	25	5	3	Y	15	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**42**	3	Y
91	1KS17EC096	SUSHMITHA.K.N	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**27**	0	N
92	1KS17EC097	KASHIF	27	17	3	Y	10	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**33**	2	N
93	1KS17EC098	TEJAS.K	24	14	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**27**	0	N
94	1KS17EC099	SREENIVASA	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	26	6	3	Y	15	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**40**	3	Y
95	1KS17EC100	TI	26	16	3	Y	10	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	15	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**36**	3	Y
96	1KS17EC101	VAISHNAVI.S	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	28	11	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**32**	1	N
97	1KS17EC102	SRIHARSHAN	28	16	3	Y	12	3	Y	10	6	3	Y	4	3	Y	28	6	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**45**	3	Y
98	1KS17EC103	VIDYA.V	26	17	3	Y	9	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	17	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**29**	0	N
99	1KS17EC104	GOUTHAM.N	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	5	3	Y	16	3	Y	6	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**38**	3	Y
100	1KS17EC105	YASHASWINI.R	27	16	3	Y	11	3	Y	10	6	3	Y	4	3	Y	27	6	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**29**	0	N
101	1KS18EC403	HARSHITHA B	25	15	3	Y	10	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**30**	1	N
102	1KS18EC406	MAHADEVA G R	26	15	3	Y	11	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	11	3	Y	16	3	Y	10	6	3	Y	4	3	Y	**27**	0	N
103	1KS18EC408	VANITHA C	26	15	3	Y	11	3	Y	10	6	3	Y	4	3	Y	26	5	3	Y	16	3	Y	5	3	Y	10	2	3	Y	6	3	Y	2	3	Y	27	10	3	Y	17	3	Y	10	6	3	Y	4	3	Y	**28**	0	N
	CO				**CO1**			**CO2**				**CO1**			**CO2**				**CO2**			**CO3**			**CO4**				**CO2**			**CO3**			**CO4**				**CO4**			**CO5**				**CO4**			**CO5**			**SEE**	
	Number of Not Attempted(NA)					**0**			**0**				**0**			**0**				**0**			**0**			**0**				**0**			**0**			**0**				**0**			**0**				**0**			**0**			**0**
	Score index & No of Y's				**3.00**	**103**		**2.94**	**101**			**2.91**	**100**		**2.92**	**100**			**2.97**	**69**		**2.97**	**102**			**102**			**2.93**	**100**		**2.83**	**97**		**2.9**	**99**			**2.97**	**102**		**2.97**	**102**			**2.52**	**85**		**2.77**	**95**		**1.63**	**41**
	No. of N's					**0**			**2**				**3**			**3**				**0**			**1**			**1**				**3**			**6**			**4**				**1**			**1**				**18**			**8**			**62**
	CO Attainment					**100**			**98**				**97**			**97**				**100**			**99**			**99**				**97**			**94**			**96**				**99**			**99**				**83**			**92**			**40**
	Level					**3**			**3**				**3**			**3**				**3**			**3**							**3**			**3**							**3**			**3**				**3**			**3**			**0**

CO	CIE	SEE	DIRECT ATTAINMENT	Level	T ATT	inal Att
CO1	98.54	39.8	69.17	3.00	3.00	3.00
CO2	98.06	39.8	68.93	3.00	3.00	3.00
CO3	96.60	39.8	68.20	3.00	3.00	3.00
CO4	94.17	39.8	66.99	3.00	3.00	3.00
CO5	95.63	39.8	67.72	3.00	3.00	3
AVERAGE						3.00

CO	Score index out of 3
CO1	2.32
CO2	2.51
CO3	2.30
CO4	2.30
CO5	2.30

					Co-Po Mapping Table									
CO'S	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	3	2	_	_	_	_	_	_	_	_	_	_	3	2
CO2	3	2	_	_	_	_	_	_	_	_	_	_	3	2
CO3	3	2	_	_	_	_	_	_	_	_	_	_	3	2
CO4	3	2	_	_	_	_	_	_	_	_	_	_	3	2
CO5	3	2	_	_	_	_	_	_	_	_	_	_	3	2
AVG	3.0	2.0	_	_	_	_	_	_	_	_	_	_	3.0	2.0

PO Attainment

CO'S	CO Attainment	CO RESULT	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	3.00	Y	3.0	2.0	_	_	_	_	_	_	_	_	_	_	3.0	2.0
CO2	3.00	Y	3.0	2.0	_	_	_	_	_	_	_	_	_	_	3.0	2.0
CO3	3.00	Y	3.0	2.0	_	_	_	_	_	_	_	_	_	_	3.0	2.0
CO4	3.00	Y	3.0	2.0	_	_	_	_	_	_	_	_	_	_	3.0	2.0
CO5	3.00	Y	3.0	2.0	_	_	_	_	_	_	_	_	_	_	3.0	2.0
Average			**3.0**	**2.0**	_	_	_	_	_	_	_	_	_	_	**3.0**	**2.0**

Wireless Cellular and LTE 4G Broadband

Pooja S

Asst. Prof.
Dept. of ECE
KSIT

April 20, 2021

Overview

Text Books

Text Book:Fundamentals of LTE

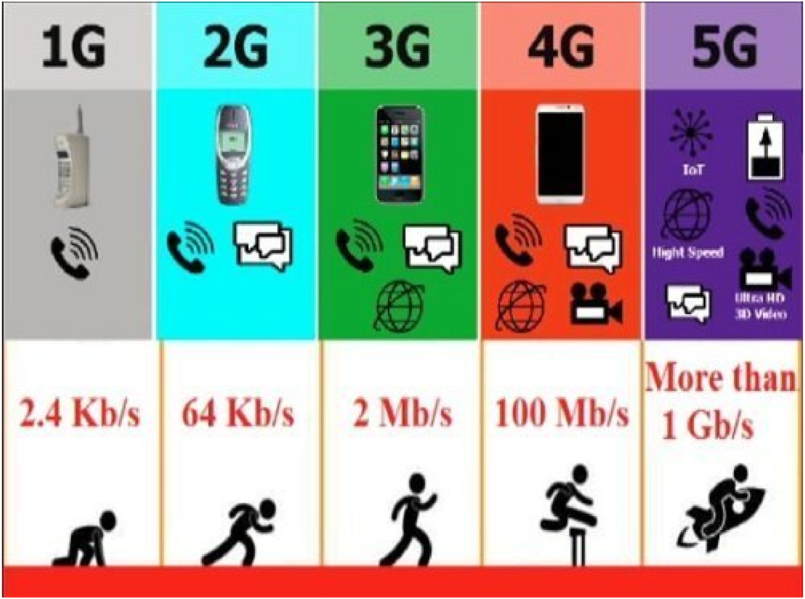
Arunabha Ghosh, Jan Zhang, Jefferey Andrews, Riaz Mohammed, Prentice Hall, Communications Engg and Emerging Technologies.

Reference Books:

1. **LTE for UMTS Evolution to LTE-Advanced** Harri Holma and Antti Toskala, Second Edition - 2011, John Wiley & Sons,
2. **EVOLVED PACKET SYSTEM (EPS) ; THE LTE AND SAE EVOLUTION OF 3G UMTS** by Pierre Lescuyer and Thierry Lucidarme, 2008, John Wiley & Sons,
3. **LTE The UMTS Long Term Evolution ; From Theory to Practice** by Stefania Sesia, Issam Toufik, and Matthew Baker, 2009 John Wiley & Sons

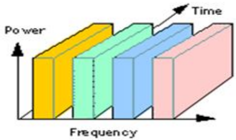
Evolution of Wireless Communication

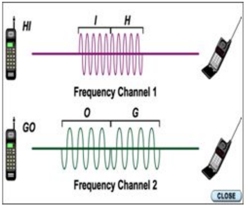
Evolution of Wireless Communication



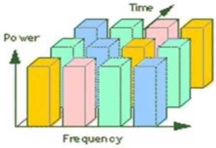
Comparison of FDMA, TDMA, and CDMA

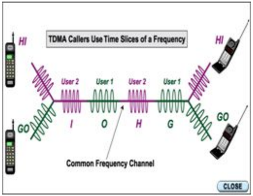
FDMA



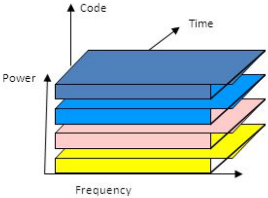


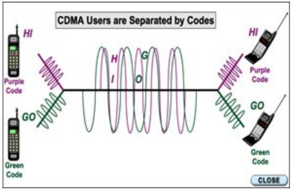
TDMA



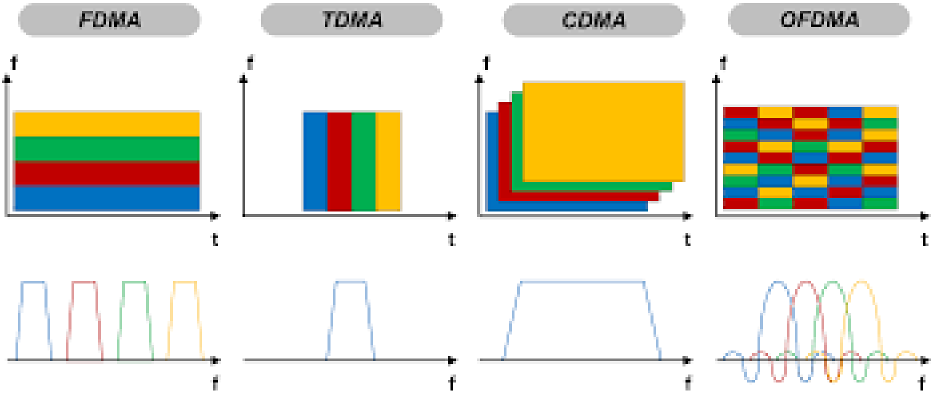


CDMA





Multiple Access Methods



Key Enabling Technologies & Features of LTE

Orthogonal Frequency Division Multiplexing

OFDM has merged asbgt the technology of choice for achieving high data rates due to the following advantages

1. Elegant solution to multipath interference

- When time delay b/w signal paths is very less compared to the TXed signal's symbol period, a TXed symbol may arrive during the next symbol causing ISI(Inter Symbol Interference)
- In OFDM, subcarriers are selected such that they are all orthogonal to one another (non-overlapping)
- ISI can be completely eliminated by using guard intervals b/w OFDM symblos, that are larger than expected multipath delay

Key Enabling Technologies & Features of LTE

2. Reduced Computational Complexity

- OFDM can be easily implemented using FFT/IFFT
- The computational complexity of OFDM $= O(BlogBT_m)$ where B is bandwidth T_m is the delay spread
- The computational complexity of TDM $= O(B^2 T_m)$
- It simplifies receiver processing and thus reduces mobile device cost and power consumption

3. Graceful degradation of performance under excess delay

- When delay spread exceeds the value designed for, then greater coding & low constellation sizes can be used for graceful degradation
- OFDM is well suited for *adaptive modulation and coding*
- This contrasts the abrupt degradation in single carrier systems

Key Enabling Technologies & Features of LTE

4. Exploitation of frequency diversity
- OFDM facilitates coding and interleaving across sub carriers in the frequency domain, providing robustness against burst errors
- OFDM allows channel bandwidth to be scalabe(increased) without impacting the hardware design of the base station and the mobile station
- Hence LTE can be deployed in various spectrums and different channel bandwidths

5. Enables efficient multi-access scheme
- OFDM can be used as a multiple access scheme by partioning different subcarriers among multiple users (OFDMA)
- OFDMA offers significant capacity improvements, particularly in slow time-varying channels

Key Enabling Technologies & Features of LTE

6. Robust against narrowband interference
- Such interferenc affects only a fraction of the subcarriers

7. Suitable for coherent demodulation
- Relatively easy to do pilot-based channel estimation in OFDM Systems
- Hence they are suitable for coherrent demodulation schemes which are more power efficient

Key Enabling Technologies & Features of LTE

8. Facilitates use of MIMO

- (Multiple Input Multiple Output): signal processing techniques which use multiple antennas at the Tx and the Rx
- For MIMO the channel has to be a Flat fading channel uniform fading across all frequency components of the signal) and not a frequency selective one
- OFDM Converts a frequency selective broadband channel into multiple narrowband flat fading channels
- MIMO & OFDM are already combined effectively in Wi-Fi and WiMAX systems

9. Efficient support of broadcast services

- By synchronising Base Stations to timing errors in the OFDM guard interval, the OFDM n/w can fuction as a single frequency network(SFN)
- Therby enabling higher data rate broadcast transmissions

Disadvantages of OFDM

High peak-to-average ratio (PAR)
- which causes non-linearities & clipping distortion when passed through an RF amplifier
- solving this problem requires the use of expensive and inefficient power amplifiers, which increases the cost of the transmitter & is wasteful of power

Increased Amplifier costs & power inefficiency in OFDM
- is tolerated in downlink as part of the design
- For uplink LTE selects a variation of OFDM that has lower peak-to-average ratio
- This modulation of uplink is called **Single Carrier Frequency Division Multiple Access(SC-FDMA)**

SC-FDE & SC-FDMA

Single Carrier Frequency Domain

-To keep the cost down & the battery life up, LTE incorporated a power efficient transmission scheme for the **uplink**

SC-FDE

- Conceptually similar to OFDM
- but instead of transmitting IFFT of actual data symbols, the data symbols are sent as a sequence of QAM symbols with a cyclic prefix
- The IFFT is added at the end of the receiver

SC-FDE Properties

SC-FDE retains all advantages of OFDM with low peak-to -average ratio of 4-5 dB

-The uplink LTE implements multi-user version of SC-FDE, called as SC-FDMA, which allows multiple users to use parts of thefrequency spectrum

SC-FDMA Properties

- closely resembles OFDMA
- Tcan be thought of as "DFT precoded OFDMA"
- SC-FDMA also preserves the PAR properties of SC-FDE
- But increases the complexity of the Transmitter and the Receiver

Channel Dependent Multi-user Resource Scheduling

OFDMA used in LTE provides enormous flexibility for Channel Resource Allocation

-OFDMA allows for allocation in **both time & frequency**

- it is possible to design algorithms to allocate resources in a **flexible & dynamic** manner
- inorder to meet the required **throughput, delay and other requirements**

- It supports dynamic channel-dependent scheduling **to enhance overall system capacity**

Channel Dependent Multi-user Resource Scheduling

Flat Fading or Non selective Fading
- is that type of fading in which all frequency components of the received signal fluctuate in the same proportions simultaneously

Frequency Selective Fading
- affects unequally the different spectral components of a radio signal

Frequency Selective Multi-user Scheduling
- Focussing Transmission power in each user's best channel portion, thereby increasing the overall capacity

Channel Dependent Multi-user Resource Scheduling

Frequency Selective Scheduling
- requires good channel tracking and is generally only viable in slow varying channels
- for fast varying channel the ovehead involved negates the capacity gains

In OFDMA frequency selective scheduling can be combined with **multi-user time domain scheduling**

Capacity Gain
- by adapting modulation and coding to SNR of each user subcarrier

For High Mobility Users - OFDMA can be used to achieve frequency diversity

-By coding and interleaving across subcarriers in the frequency domain using a **uniform random distribution of subcarriers over the whole spectrum**

Hence the signal can be made more robust against frequency selective fading or burst errors

Frequency diverse scheduling is best suited for **control signaling** and **delay sensitive services**

Multiantenna Techniques

Multiantenna techniques supported in LTE include

1.Transmit Diversity

- The idea here is to send copies of the same signal, coded differently, over multiple transmit antennas
- LTE Transmit diversity is based on space-frequency block coding(SFBC)
- Used in commomn downlink channels
- Transmit diversity increases system capacity and cell range

2.Beamforming

- Multiple antennas in LTE may also be used to transmit the same signal, with appropriate weights for each antenna such that the effect is to focus the transmitted beam in the direction of the Rx and away from the interference

Multiantenna Techniques

2.Beamforming contd..

- it improves the received signal to interference ratio
- improves coverage range, capacity, relaibility & battery life
- useful in providing angular information for user tracking
- LTE supports beamforming in the down link

3.Spatial Multilexing

- The idea behind it:- multiple independent streams can be transmitted in parallel through multiple antennas
- These can be seperated at the receiver using multiple receive chains through appropriate signal processing
- possible as long as multipath channels from different antennas are sufficiently decorrelated

-Theoretically spatial Multiplexing provides data rate & capacity gains proportional to the no. of antennas used.

Multiantenna Techniques

3.Spatial Multilexing contd..

- LTE standard supports spatial multiplexing with up to four Tx antennas & four Rx antennas

4.Multi User MIMO

- Spatial multiplexing is not supported in the uplink due to complexity and cost considerations of multiple transmit chains
- But multi-user MIMO(MU-MIMO) allows multiple users in the uplink
-each user transmits using the same frequency and time resource
-signals from different users are seperated at the base station using accurate channel state information of each user obtained through uplink reference signals that are orthogonal to each other

IP-Based Flat Network Architecture

Air-interface

Flat radio & core network architecture

-flat implies fewer nodes & a less hierarchial structure for the network
- lower cost & lower latency requirements drove the design towards a flat architecture
- as fewer nodes mean lower infrastructure cost
- fewer nodes allow better optimization of radio interface, merging of some control plane protocols & short session start-up time

IP-Based Flat Network Architecture

LTE was developed by the 3GPP standards body

Hence we will focus here only on the 3GPP standards evolution

3GPP Release 6 Architecture[2G/3G] (4 network elements)

-the base station or node B
- Radio Network Controller(RNC)
- serving GPRS serving Node (SGSN)
- gateway GPRS serving node(GGSN)

3GPP Release 7 Architecture [3G] (3 network elements)

-introduced a direct tunnel option from the RNC to GGSN, hence eliminated SGSN from thed data path

IP-Based Flat Network Architecture

3GPP Release 7 LTEArchitecture (2 network elements)

-the enhanced Node-B or eNodeB
- System Architecture Evolution-Gateway (SAE-GW)
- LTE merges BS & RNC functionality into a single unit

3GPP Release 8 LTE Architecture (2 network elements)

-the control path includes a functional entity called the Mobility Management Entity (MME)

LTE

-key aspect of LTE is, all services including voice are supported on the IP packet network using IP protocols

LTE Network Architecture

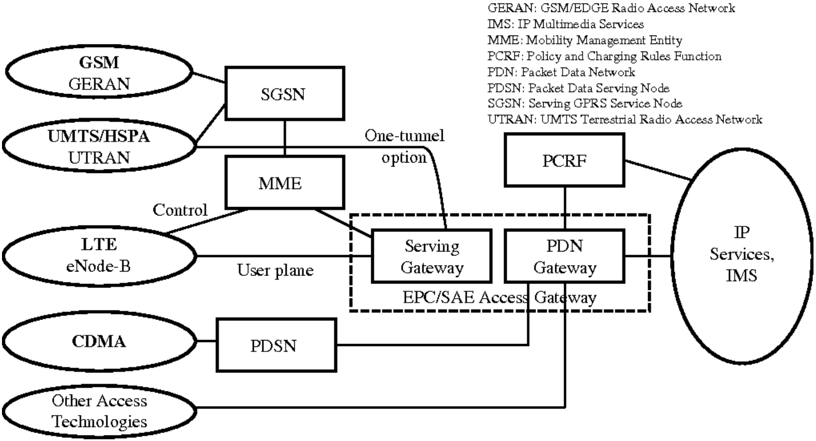


Figure: Evolved Packet Core Architecture

LTE Network Architecture

Evolved Packet Core (EPC)

-high capacity

- all IP

- reduced latency

-flat architecture that dramatically reduces cost

- supports advanced real-time & media rich services with enhanced quality of experience

supports new LTE

interworking with:

-legacy 2G GERAN & 3G UTRAN networks connected via SGSN

LTE Network Architecture

four new elements

1) Serving Gateway (SGW)

-interface b/w core network & 3GPP radio access networks (RAN)
- serves as mobility anchor when terminals move across areas served by different elements such as GERAN and UTRAN
-performs lawful interception, packet routing and forwarding
-transport level packet marking in uplink and down link
-inter-operator charging

LTE Network Architecture

2) Packet Data Network Gateway (PGW)

-interface b/w EPC and other Packet Data Networks (PDN)
-controls IP data services, does routing, allocates IP addresses
-enforces policy: operator defined rules for resource allocation to control data rate, QoS & usage
-provides access for non-3GPP access networks

3) Mobility Management Entity (MME)

-supports user equipment context and identity
-performs signaling and control functions to manage user terminal access to n/w connections & resources
-**mobility management functions:** idle mode location tracking, paging, roaming, & handovers
-**security functions:** providing temporary identities, interacting with Home Subscriber Server (HSS) for authentication, negotiation of ciphering and integrity protection algorithms

LTE Network Architecture

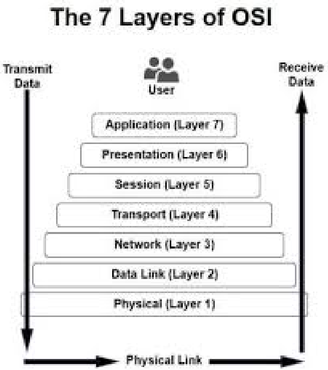
3) Mobility Management Entity (MME) contd..

-**responsible for selecting appropriate serving and PDN gateways:** MME manages thousands of eNode B elements

4) Policy and Charging Rules Function (PCRF)

-manages Quality of Service aspects
-authenticates & authorizes users
-concatenation of Policy Decision Function(PDF) & Charging Rules Function(CRF)
-although defined ahead of LTE, was not deployed in pre-LTE systems
-mandatory for LTE

Wireless Fundamentals



Communication System Building Blocks

- An LTE system can be conceptually broken down into a collection of links, with each link consisting of a **transmitter, channel, & receiver**

Wireless Fundamentals

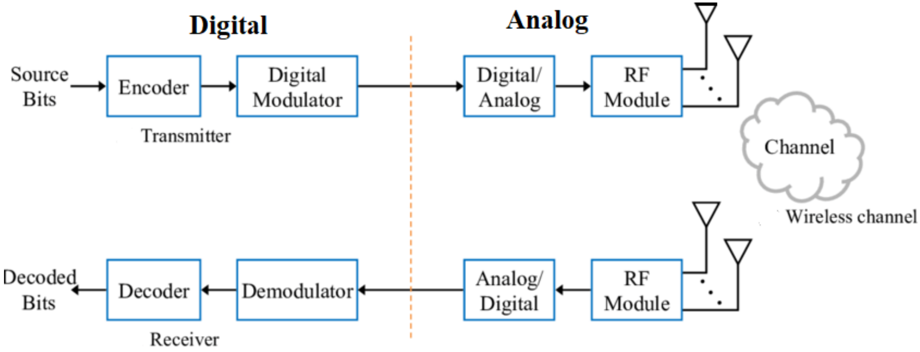


Figure: Wireless Digital Communication System

Communication System Building Blocks

Transmitter

- Receives packets of bits from a higher protocol layer & its duty is to send those bits as electromagnetic waves toward the reciever
- The key steps are encoding & modulation
- The modulated digital signal is converted into a representative analog waveform by a digital-to-analog converter
- This is upconverted to one of the desired LTE radio frequency (RF) bands
- This RF signal is then radiated as electromagnetic waves by a suitable antenna

Communication System Building Blocks

Receiver

- The receiver performs essentially the reverse of these operations
- After downconverting the received RF signal & filtering out signals at other frequencies, the resulting baseband signal is converted to a digital signal by an analog-to-digital (A/D) convertor
- This digital signal is demodulated & decoded to reproduce the original bit stream

LTE Standard

- Since there are endless choices, the LTE standard is primarily relevant to the digital aspects, in particular at the transmitter side
-as the receiver must understand what the transmitter did in order to make sense of the received signal.

Path Loss & Shadowing

Path Loss

- Path Loss models attempt to account for distance dependent relationship between transmitted and received power

Other Factors

- Many factors other than distance can have a large effect on the total received power.

-For eg: obstacles such as trees & buildings, temporary line-of-sight transmission path would result in abnormally high received power

Shadowing

- The standard method of accounting for these variations in signal strength is to introduce a random effect called **Shadowing**

The Cellular Concept

Cells

In cellular systems, the service area is subdivided into smaller geographic areas called **cells** that are served by their own base stations
To minimize interference b/w cells, the transmit power level of each base station is regulated to be just enough to provide the required signal strength at the cell boundaries

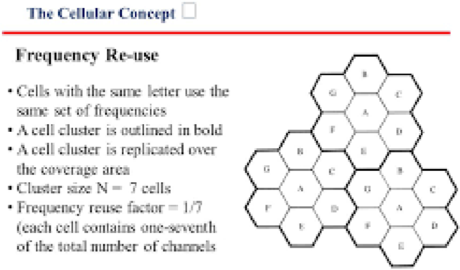
Frequency Planning

-Although perfect spatial isolation cannot be achieved
-frequency planning is required to determine a proper frequency reuse factor

Frequency Reuse Factor

-The **Frequency Reuse Factor** is defined as $f \leq 1$, where $f = 1$ means all cells reuse all frequencies
-Similarly $f = 1/3$ means a given frequency band is used by only 1 out of every 3 cells

Frequency Reuse Factor



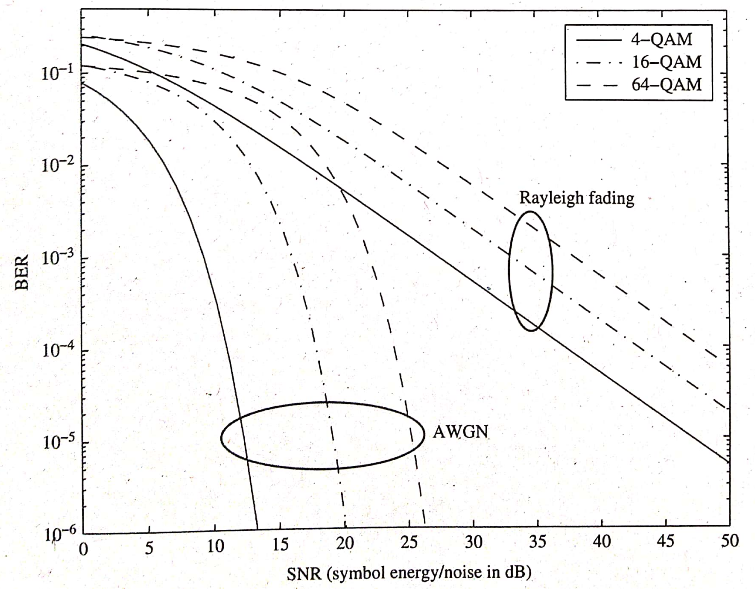
Broadband Fading Parameters

Quantity	If "Large"?	If "Small"?	LTE Design Impact
Delay Spread, τ	If $\tau \gg T$, then frequency selective	If $\tau \ll T$, then frequency flat	The larger the delay spread relative to the symbol time, the more severe the ISI.
Coherence Bandwidth, B_c	If $\frac{1}{B_c} \ll T$, then frequency flat	If $\frac{1}{B_c} \gg T$, then frequency selective	Provides a guideline to subcarrier width $B_{sc} \approx B_c/10$, and hence number of subcarriers needed in OFDM: $L \geq 10B/B_c$.
Doppler Spread, $f_D = \frac{f_c \nu}{c}$	If $f_c \nu \gg c$, then fast fading	If $f_c \nu \leq c$, then slow fading	As f_D/B_{sc} becomes non-negligible, subcarrier orthogonality is compromised.
Coherence Time, T_c	If $T_c \gg T$, then slow fading	If $T_c \leq T$, then fast fading	T_c small necessitates frequent channel estimation and limits the OFDM symbol duration, but provides greater time diversity.
Angular Spread, θ_{rms}	Non-LOS channel, lots of diversity	Effectively LOS channel, not much diversity	Multiantenna array design, beamforming vs. diversity.
Coherence Distance, D_c	Effectively LOS channel, not much diversity	Non-LOS channel, lots of diversity	Determines antenna spacing.

Doppler spreads & approximate Coherence Time

f_c	Speed (km/hr)	Speed (mph)	Max. Doppler, f_D (Hz)	Coherence Time, $T_c \approx \frac{1}{f_D}$ (msec)
700MHz	2	1.2	1.3	775
700MHz	45	27	29.1	34
700MHz	350	210	226.5	4.4
2.5GHz	2	1.2	4.6	200
2.5GHz	45	27	104.2	10
2.5GHz	350	210	810	1.2

Effects of Unmitigated Fading



Mitigation of Narrowband Fading

Diversity

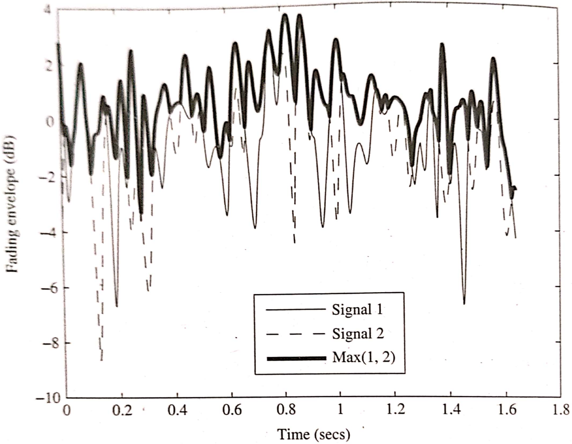
many different techniques used to overcome Narrowband Fading are collectively referred to as **Diversity**

The most important types of diversity used in LTE systems

Spatial Diversity

Coding & Interleaving

Spatial Diversity



Simplest form of space diversity:

- Two receive antennas, where the stronger of the two signals is selected **selection diversty**, most of the deep fades can be avoided

Coding & Interleaving

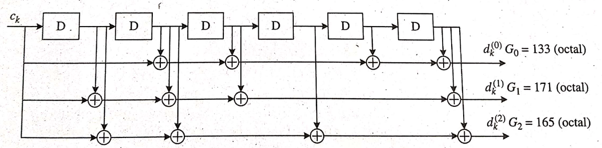


Figure 2.22 The rate $\frac{1}{3}$ convolutional encoder defined by LTE for use in the Broadcast Channel (BCH).

A type of time diversity which can capture frequency diversity also

- categorised by their coding rate r $\leq 1/3$

Coding & Interleaving

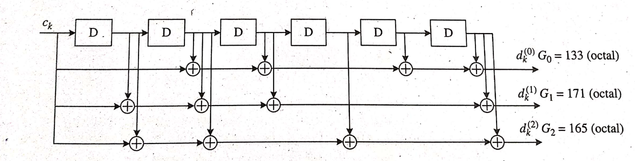


Figure 2.22 The rate $\frac{1}{3}$ convolutional encoder defined by LTE for use in the Broadcast Channel (BCH).

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K.S. INSTITUTE OF TECHNOLOGY

Department of Electronics & Communication Engineering

Wireless Cellular and LTE 4G Broadband (17EC81)

Course Syllabus

Module – 1

Key Enablers for LTE features: OFDM, Single carrier FDMA, Single carrier FDE, Channel Dependent Multiuser Resource Scheduling, Multiantenna Techniques, IP based Flat network Architecture, LTE Network Architecture.

Wireless Fundamentals: Cellular concept, Broadband wireless channel (BWC), Fading in BWC, Modeling BWC – Empirical and Statistical models, Mitigation of Narrow band and Broadband Fading.

Module – 2

Multicarrier Modulation: OFDM basics, OFDM in LTE, Timing and Frequency Synchronization, PAR, SC-FDE

OFDMA and SC-FDMA:OFDM with FDMA,TDMA,CDMA, OFDMA, SC-FDMA, OFDMA and SC-FDMA in LTE.

Multiple Antenna Transmission and Reception: Spatial Diversity overview, Receive Diversity, Transmit Diversity, Interference cancellation and signal enhancement, Spatial Multiplexing, Choice between Diversity, Interference suppression and Spatial Multiplexing.

Module – 3

Overview and Channel Structure of LTE: Introduction to LTE, Channel Structure of LTE, Downlink OFDMA Radio Resource, Uplink SC-FDMA Radio Resource.

Downlink Transport Channel Processing: Overview, Downlink shared channels, Downlink Control Channels, Broadcast channels, Multicast channels, Downlink physical channels, H-ARQ on Downlink.

Module – 4

Uplink Channel Transport Processing: Overview, Uplink shared channels, Uplink Control Information, Uplink Reference signals, Random Access Channels, H-ARQ on uplink.

Physical Layer Procedures: Hybrid – ARQ procedures, Channel Quality Indicator CQI feedback, Precoder for closed loop MIMO Operations, Uplink channel sounding, Buffer status Reporting in uplink, Scheduling and Resource Allocation, Cell Search, Random Access Procedures, Power Control in uplink.

Module – 5

Radio Resource Management and Mobility Management:

PDCP overview, MAC/RLC overview, RRC overview, Mobility Management, Inter-cell Interference Coordination

Introduction to Wireless Communication

Evolution of Wireless Communication

- Before 1892 – Theoretical basis for radio communication – Nikola Tesla, Jagadish Bose & Alexander Popov
- 1897 - Marconi demonstrated radio communication & awarded patent for it.
- 1934 - AM Radio Systems used in US.
- 1935 - Edwin Armstrong demonstrated FM.
- 1948 - Claude Shannon published theory on Channel Capacity: $C = Blog_2(1 + SNR)$
- 1960 to 70 - Bell labs developed Cellular concept.
- 1983 - AMPS (Advanced Mobile Phone Service) launched in Chicago.
- 1991 - First Commercial GSM in Europe.
- 1995 - First Commercial launch of CDMA (IS - 95).
- 2001 - NTT DoCoMo launched first commercial 3G service.
- 2005 - IEEE 802.16e standard, the air - interface for mobile WiMAX, completed & approved.
- 2007 - First Apple iPhone launched.
- 2009 - 3GPP Release 8 LTE/SAE specifications completed.

First Generation (1G) Cellular Systems

- The United States, Japan and parts of Europe led the development of cellular wireless systems.
- These systems were characterized by analog modulation schemes & were designed primarily for delivering voice services.
- Japan's Nippon Telephone & Telegraph Company (NTT) implemented the world's first commercial cellular system in 1979.
- Europe's Nordic Mobile Telephone (NMT - 400) system implemented automatic handover & international roaming.

- The more successful first-generation systems were AMPS in the United States.
- Major First-Generation Cellular Systems are
  - **AMPS** (Advanced Mobile Phone Service)
  - **ETACS** (Extended Total Access Communication Systems) in Europe
  - **NTACS** (Nippon Total Access Communication Systems) in Japan
  - **NMT - 450 / NMT - 900**

2G Digital Cellular Systems

- Improvements in processing abilities of hardware platforms enabled the development of 2G wireless systems.
- 2G systems were also focused on voice transmission, but used digital modulation techniques.
- Shifting from Analog to Digital enabled several improvements in system performance.
  1. System capacity was improved through the use of spectrally efficient digital speech codecs.
  2. Multiplexing techniques were used to accommodate several users on the same frequency channel.
  3. Frequency re-use enabled by better error performance of digital modulation.
- Major 2G Cellular Systems are
  1. GSM : Introduced in 1990
  2. blackIS - 54 / IS - 136: Introduced in 1991
  3. IS - 95: Introduced in 1993
- Besides providing improved voice quality, capacity & security, 2G systems also enabled new application.

  That is **Short Message Service (SMS)**
- In addition to SMS, 2G systems also supported low data rate wireless data applications.
- These systems supported circuit switched data services.

3G Broadband Wireless Systems

- The circuit - switched paradigm based on which 2G systems were built, made these systems very inefficient for data, hence only low - data rates were supported.

- 3G systems employed packet data services. Hence provided much higher data rates.
- Voice quality significantly increased.
- 3G systems also supported **multimedia, Web browsing, e - mail & interactive games.** Major 3G Standards are
  - IMT - 2000
  - Wideband CDMA (W - CDMA)
  - CDMA 2000 (3G evolution of IS-95)
  - EV - DO (Evolution Data Only)
  - HSPA (High Speed Packet Access)

Beyond 3G

- From 2009, mobile operators around the world started planning their next step in the evolution of their networks.
- Major technologies are
  - **HSPA+**
  - **WiMAX**
  - **LTE**

MODULE 1

Key Requirements of LTE Design

LTE was designed with the following objectives in mind to effectively meet the growing demand.

1. Performance on par with Wired Broadband.
   - High throughput and Low latency
   - Data rate targets: 100 Mbps for Downlink & 50 Mbps for Uplink
2. Flexible Spectrum Usage.
   - Operators can deploy LTE in 700 MHz, 900 MHz, 1800 MHz & 2.6 GHz Bands.
   - LTE supports a variety of channel bandwidths: 1.4, 3, 5, 10, 15 & 20 MHz
3. Co-existence and Interworking with 3G Systems as well as Non-3GPP Systems.
4. Reducing Cost per Megabyte.

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Key Enabling Technologies & Features of LTE

To meet its service and performance requirements, LTE design incorporates several important enabling radio & core network technologies, they are:

1. Orthogonal Frequency Division Multiplexing (OFDM)
2. Single Carrier Frequency Domain Equalization (SC-FDE) and SC-FDMA
3. Channel Dependent Multi-user Resource Scheduling
4. Multi antenna Techniques
5. IP - Based Flat Network Architecture

Orthogonal Frequency Division Multiplexing (OFDM)

- OFDM has emerged as a technology of choice for achieving high data rates.
- It is the core technology used by a variety of systems including **Wi-Fi & WiMAX.**
- The following *advantages of OFDM led to its selection for LTE*:

  1 Elegant solution to multipath interference
  - When time delay b/w signal paths are very less compared to the transmitted signal's symbol period, a transmitted symbol may arrive during the next symbol causing ISI(Inter Symbol

Interference).
- In OFDM, subcarriers are selected such that they are all orthogonal to one another (non-overlapping)
- ISI can be completely eliminated by using guard intervals b/w OFDM symbols, that are larger than expected multipath delay

2 Reduced computational complexity
- OFDM can be easily implemented using FFT/IFFT
- The computational complexity of OFDM is O(B log BT_m), where B is bandwidth $T_m$is the delay spread
- The computational complexity of TDM is O(B^2T_m)
- It simplifies receiver processing and thus reduces mobile device cost and power consumption

3 Graceful degradation of performance under excess delay
- When delay spread exceeds the value designed for, then greater coding & low constellation sizes can be used for graceful degradation
- OFDM is well suited for adaptive modulation and coding
- This contrasts the abrupt degradation in single carrier systems

4 Exploitation of frequency diversity
- OFDM facilitates coding and interleaving across sub carriers in the frequency domain, providing robustness against burst errors
- OFDM allows channel bandwidth to be scalable(increased) without impacting the hardware design of the base station and the mobile station
- Hence LTE can be deployed in various spectrums and different channel bandwidths

5 Enables efficient multi-access scheme
- OFDM can be used as a multiple access scheme by partioning different subcarriers among multiple users (OFDMA)
- OFDMA offers significant capacity improvements, particularly in slow time-varying channels

6 Robust against narrowband interference
- Such interference affects only a fraction of the subcarriers

7 Suitable for coherent demodulation
- Relatively easy to do pilot-based channel estimation in OFDM Systems
- Hence, they are suitable for coherent demodulation schemes which are more power efficient

8 Facilitates use of MIMO
-For MIMO the channel has to be a Flat fading channel (uniform fading across all frequency components of the signal) and not a frequency selective one
- OFDM Converts a frequency selective broadband channel into multiple narrowband flat fading channels
- MIMO & OFDM are already combined effectively in Wi-Fi and WiMAX systems

9 Efficient support of broadcast services

- By synchronizing Base Stations to timing errors in the OFDM guard interval, the OFDM network can function as a single frequency network(SFN)
- Thereby enabling higher data rate broadcast transmissions for a given transmit power

Disadvantages of OFDM

The main disadvantage of OFDM is its High peak-to-average ratio (PAR)

- which causes non-linearities & clipping distortion when passed through an RF amplifier
- solving this problem requires the use of expensive and inefficient power amplifiers, which increases the cost of the transmitter & is wasteful of power
- Increased Amplifier costs & power inefficiency in OFDM is tolerated in downlink as part of the design
- For uplink LTE selects a variation of OFDM that has lower peak-to-average ratio called the Single Carrier Frequency Division Multiple Access(SC-FDMA)

SC-FDE and SC-FDMA & Channel Dependent Multi-user Resource Scheduling

- Single Carrier Frequency Domain Equalization (SC-FDE) is conceptually similar to OFDM but instead of using IFFT, it uses QAM symbols with cyclic prefix.
- The uplink of LTE implements a multi-user version of SC-FDE, called SC-FDMA, which allows multiple users to use parts of the frequency spectrum.
- SC-FDE retains all advantages of OFDM with low peak-to -average ratio of 4-5 dB. SC-FDMA also preserves the PAR properties of SC-FDE. But it increases the complexity of the Transmitter and the Receiver

Channel Dependent Multi-user Resource Scheduling

- OFDMA allows for allocation in both time & frequency
- it is possible to design algorithms to allocate resources in a flexible & dynamic manner in order to meet the required throughput, delay and other requirements
- It supports dynamic channel-dependent scheduling to enhance overall system capacity
- *Frequency Selective Multi-user Scheduling*: to focus transmission power in each user's best channel portion, thereby increasing the overall capacity
- *Capacity Gain:* by adapting modulation and coding to SNR of each user subcarrier

Multi-antenna Techniques

- The LTE standard provides extensive support for implementing advanced multi-antenna solutions to improve link robustness, system capacity and spectral efficiency.

- Multiantenna techniques supported in LTE include:

1 Transmit diversity

- The idea here is to send copies of the same signal, coded differently, over multiple transmit antennas

- LTE Transmit diversity is based on space-frequency block coding(SFBC) used in common downlink channels

- Transmit diversity increases system capacity and cell range

2 Beamforming

- Multiple antennas in LTE may also be used to transmit the same signal, with appropriate weights for each antenna such that the effect is to focus the transmitted beam in the direction of the Rx and away from the interference

- it improves the received signal to interference ratio, coverage range, capacity, reliability & battery life

- useful in providing angular information for user tracking

- LTE supports beamforming in the down link

3 Spatial multiplexing

- The idea behind it:- multiple independent streams can be transmitted in parallel through multiple antennas

- These can be separated at the receiver using multiple receive chains through appropriate signal processing

- possible as long as multipath channels from different antennas are sufficiently decorrelated

-Theoretically spatial Multiplexing provides data rate & capacity gains proportional to the no. of antennas used.

- LTE standard supports spatial multiplexing with up to four Tx antennas & four Rx antennas

4 Multi-user MIMO

- Spatial multiplexing is not supported in the uplink due to complexity and cost considerations of multiple transmit chains

- But multi-user MIMO(MU-MIMO) allows multiple users in the uplink, each user transmits using the same frequency and time resource

-signals from different users are separated at the base station using accurate channel state information of each user obtained through uplink reference signals that are orthogonal to each other

IP - Based Flat Network Architecture

- Flat here implies fewer nodes and a less heirarchial structure for the network.
- Lower cost and lower latency requirements have driven the design towards a flat architecture.
- Since fewer nodes implies a lower infrastructure cost, fewer interfaces and protocol related processing better optimization of radio interface & short session start-up time

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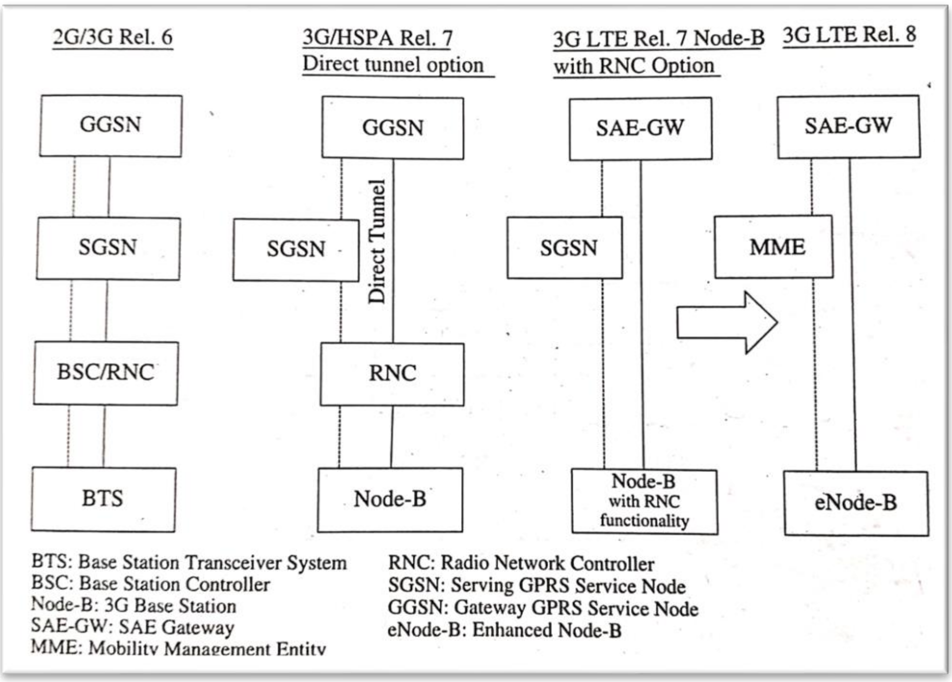

Figure 1: Demonstrates the 3GPP evolution toward a flat LTE SAE architecture.

- Figure 1 shows how the 3GPP network architecture has evolved over a few releases.
- LTE was developed by the 3GPP standards body:

- 3GPP Release 6 Architecture [2G/3G] consists of 4 network elements
  - the base station or Node-B
  - Radio Network Controller(RNC)
  - serving GPRS serving Node (SGSN)
  - gateway GPRS serving node(GGSN)

- Release 7 introduced a direct tunnel option from RNC to GGSN which eliminated the SGSN

- The LTE version of Release 7 has only 2 network elements
  -the enhanced Node-B or e Node B
  - System Architecture Evolution-Gateway (SAE-GW): LTE merges BS & RNC functionality into a single unit

- 3GPP Release 8 LTE Architecture (2 network elements)
  -the control path includes a functional entity called the Mobility Management Entity (MME)

- The key aspect of LTE is, all services including voice are supported on the IP packet network using IP protocols

- Unlike previous systems which had a separate circuit switched subnetwork for supporting voice , LTE envisions a single evolved packet-switched core, the EPC over which all services are supported

- Although LTE has been designed for IP services due to compatibility reasons certain non-IP aspects such as GPRS tunneling protocol and PDCP (packet data convergence protocol) still exists within the LTE architecture

LTE Network Architecture

- LTE includes the evolution of:
  - the radio access through the E-UTRAN (Evolved - Terrestrial Radio Access Network)
  - the non-radio aspects under the term **System Architecture Evolution (SAE)**
- Entire system composed of both LTE and SAE is called the **Evolved Packet System (EPS)**
- At a high-level, the network is comprised of:
  - Core Network (CN), called **Evolved Packet Core (EPC)** in SAE
  - access network (E-UTRAN)
- A *bearer* (a messenger) is an IP packet flow with a defined QoS between the gateway and the User

Terminal (UE).

- CN is responsible for overall control of UE and establishment of the bearers.

Evolved Packet Core Architecture

- Main logical nodes in EPC are:
  - Packet Data Network Gateway **(PGW)**
  - Serving Gateway **(SGW)**
  - Mobility Management Entity **(MME)**
- EPC also includes other nodes and functions, such as:
  - Home Subscriber Server **(HSS)**
  - Policy Control and Charging Rules Function **(PCRF)**
- EPS only provides a bearer path of a certain QoS, control of multimedia applications is provided by the IP Multimedia Subsystem **(IMS)**, which is considered outside of EPS.
- E-UTRAN solely contains the evolved base stations, called **eNodeB or eNB**

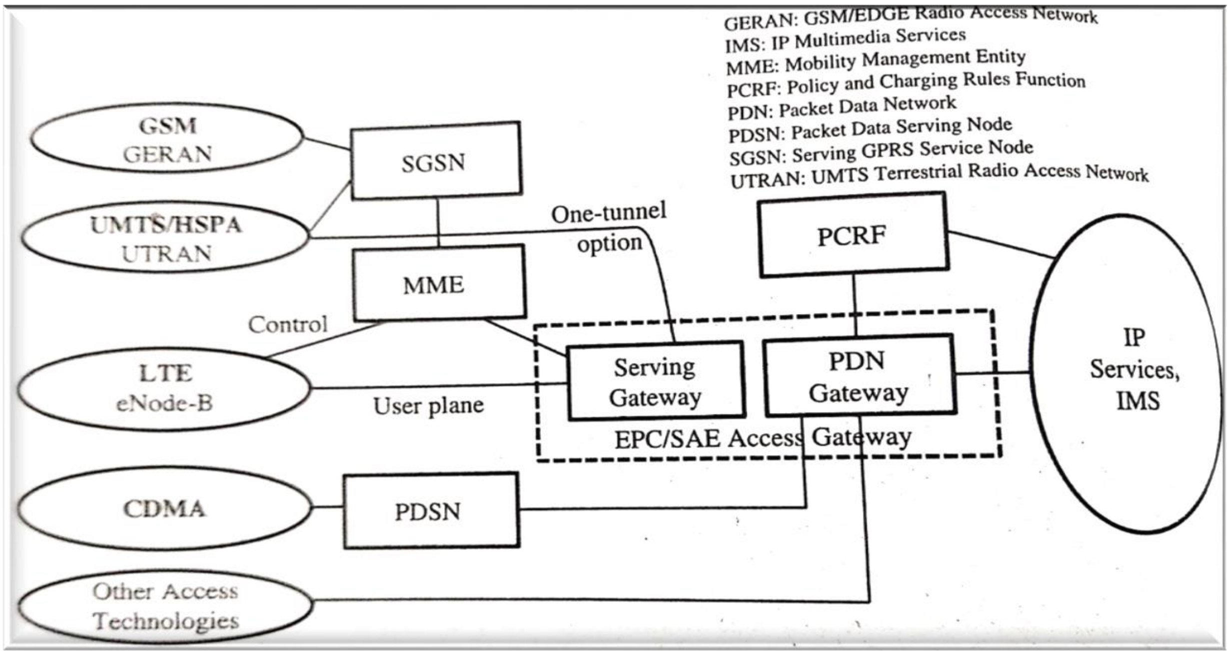

Figure 2: Evolved Packet Core Architecture

Four new elements of EPC

1. Serving Gateway (SGW)
    - It acts as a demarcation point between the RAN & core network.
    - It manages user plane mobility.
2. Packet Data Network Gateway (PGW)
    - It acts as the termination point of the EPC toward other networks such as Internet, private IP network or the multimedia service.
    - It provides functions such as user IP address allocation, policy enforcement, packet filtering & charging support.
3. Mobility Management Entity (MME)
    - It performs the signaling and control functions to manage the user terminal.
4. Policy & Charging Rules Function (PCRF)
    - It is a concatenation of Policy Decision Function (PDF) and Charging Rules Function (CRF).

The Broadband Wireless Channel

In this topic we discuss the fundamental factors affecting the received signal in a wireless system, And how they can be modeled using the different parameters.

- Here we introduce the overall channel model, and discuss the large - scale trends that affect this model.
- In discrete-time, the overall channel model is described using a simple **tap-delay line (TDL).**

$$h[k, t] = h_0\delta[k, t] + h_1\delta[k-1, t] + \cdots + h_v\delta[k-v, t]$$

- Here, the discrete-time channel is time - varying and has **non - negligible** values over a span of (v + 1) channel taps.
- Here its assumed that the channel is sampled at a frequency $f_s = \frac{1}{T}$ where T is the symbol period.
- Hence, the duration of the channel is **vT**.
- Assuming that the channel is static over a period of (v+1)T seconds, the output of the channel can be described as

$$y[k,t] = \sum_{j=-\infty}^{\infty} h[j,t]x[k-j] \triangleq h[k,t] * x[k],$$

  where x[k] is an input sequence of data symbols with rate 1/ T
  In a simple notation, the channel can be represented as a time-varying (v+1) x 1 column vector.

$$\mathbf{h}(t) = [h_0(t)\ h_1(t) \ldots h_v(t)]^T$$

- Although this tapped-delay line model is general and accurate, it is difficult to design a communication system for the channel without knowing some of the key attributes about h(t).

Path Loss

- The first obvious difference between wired and wireless channels is the amount of transmitted power that actually reaches the receiver.

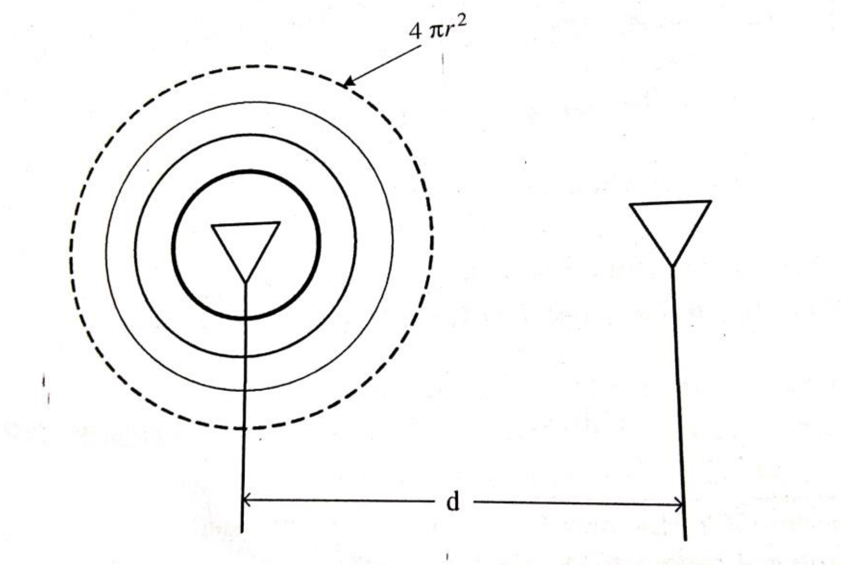

Figure 1: Free space propagation

- Assuming an isotropic antenna is used, as shown in figure above
- The propagated signal energy expands over a spherical wave front.
- Therefore, the energy received at an antenna a distance **d** away is inversely proportional to the sphere surface are, $4\pi d^2$
- The *free space path loss formula* or **Friis formula**, is given more precisely as

$$Pr = Pt\frac{\lambda^2 G_t G_r}{(4\pi d)^2}$$

where P_r and P_t are the received & transmitted powers and λ is the wavelength.

- As observed in Friis formula, $P_r \propto \lambda^2$, which means that $P_r \propto \frac{1}{f_c^2}$
- Clearly, higher frequencies suffer greater power loss than lower frequencies.
- As a result, lower carrier frequencies are generally more desirable, and hence very crowded.
- Therefore, bandwidth at higher carrier frequencies is more plentiful, more consistently available on a global basis, and almost always **less expensive.**
- Hence, a high-rate, low-cost system would generally prefer to operate at higher frequencies.
- But, the terrestrial propagation environment is not free space.
- The reflections from the Earth or other objects would actually increase the received power since more energy would reach the receiver.

- However, because a reflected wave often experiences a 180-degrees phase shift, at relatively large distances the reflection serves to create **destructive interference.**
- Therefore, the common 2 - ray approximation for path loss is:

$$P_r = P_t \frac{G_t G_r h_t^2 h_r^2}{d^4},$$

which is significantly different from free-space path loss in several aspects.

Empirical Path Loss Formula

- In order to more accurately describe different propagation environments, empirical models are often developed using experimental data.
- One of the simplest and most common is

$$P_r = P_t P_o \left(\frac{d_o}{d}\right)^{\alpha},$$

where α is the path loss exponent and the measured path loss P_0 at a reference distance of d_0

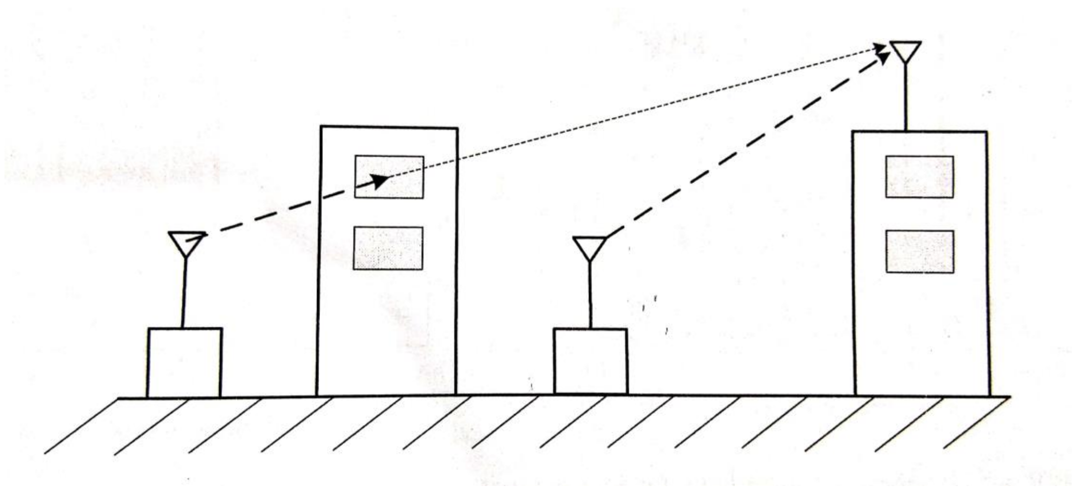

Figure 2: Shadowing can cause large deviations from path loss predictions.

Shadowing

- Obstacles located between Transmitter & Receiver cause temporary degradation in received signal strength.
- Modeling the locations of all objects in every possible communication environment is generally impossible.
- Therefore, a random effect, called as **shadowing**, is introduced to measure these variations.
- With shadowing, the empirical path loss formula becomes

$$P_r = P_t P_o \chi \left(\frac{d_o}{d}\right)^{\alpha},$$

where χ is a sample of the shadowing random process.

- Hence, the received power is also now modeled as a random process.
- The shadowing value χ is typically modeled as a lognormal random variable, that is

$$\chi = 10^{x/10}, \textit{ where } x \sim N(0, \sigma_s^2)$$

where $N(0,\sigma^2)$ is a Gaussian (Normal) distribution with mean 0 and variance σ^2

- Thus, shadowing is an important effect in wireless networks because it causes the received SINR to vary dramatically over long time scales.
- In some given cell, reliable high-rate communication may be nearly impossible.

Cellular Systems

- In cellular systems, the service area is subdivided into smaller geographic areas called **cells**.
- Each cell is served by its own base station (BS).
- In order to minimize interference between cells, the transmit power level of each BS is regulated to be just enough to provide the required signal strength at the cell boundaries.
- The same frequency channels can be reassigned to different cells, as long as those cells are spatially isolated.
- The reuse of the same frequency channels should be intelligently planned in order to maximize the geographic distance between the co-channel base stations.

Some advantages of Cellular systems are:

- Cellular systems allow the overall system capacity to increase by simply making the cells smaller & turning down the power.
- Cellular systems support user mobility, seamless call transfer from one cell to another is provided.
- The handoff process provides a means of the seamless transfer of a connection from one BS to another.
- Small cells give a large capacity & reduce power consumption.
- Primary drawbacks are, **system needs more Base Stations, and their associated hardware costs, and the need for frequent handoffs.**
- Although perfect spatial isolation cannot be achieved frequency planning is required to determine a proper frequency reuse factor
- The **Frequency Reuse Factor** is defined as $f \leq 1$, where f=1 means all cells reuse all frequencies
- Similarly f=1/3 means a given frequency band is used by only 1 out of every 3 cells

Cell Sectoring

- The performance of wireless cellular systems is significantly limited by co-channel interference (CCI).
- This comes from other users in the same cell or from other cells

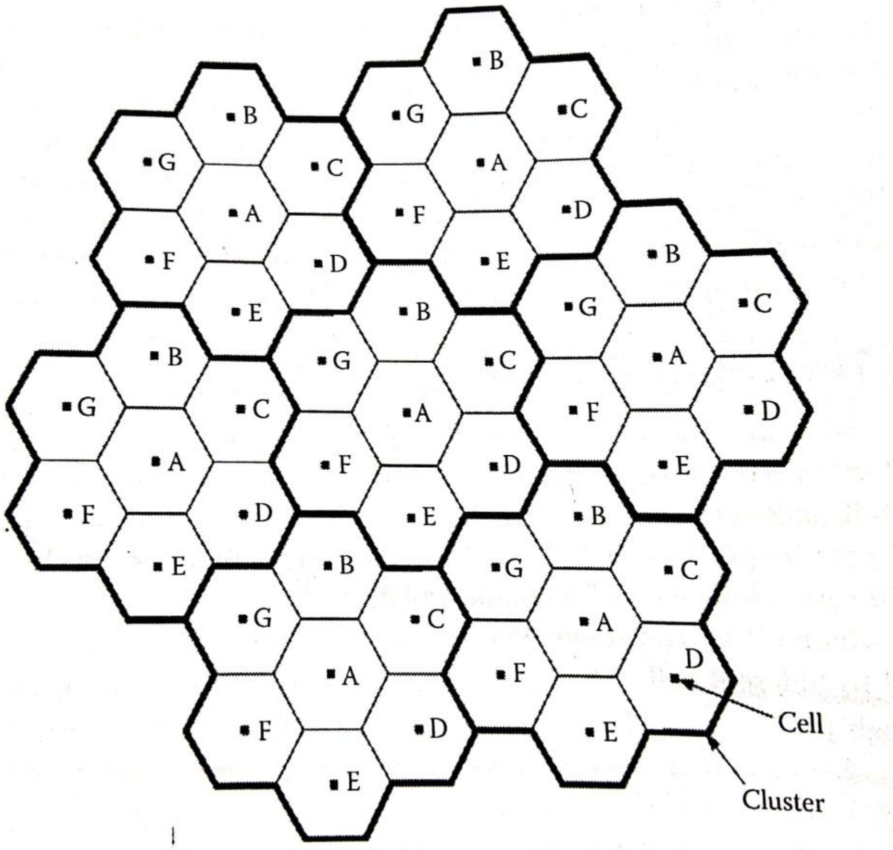

Figure 3: Standard figure of a hexagonal cellular system with frequency reuse factor f = 1/7

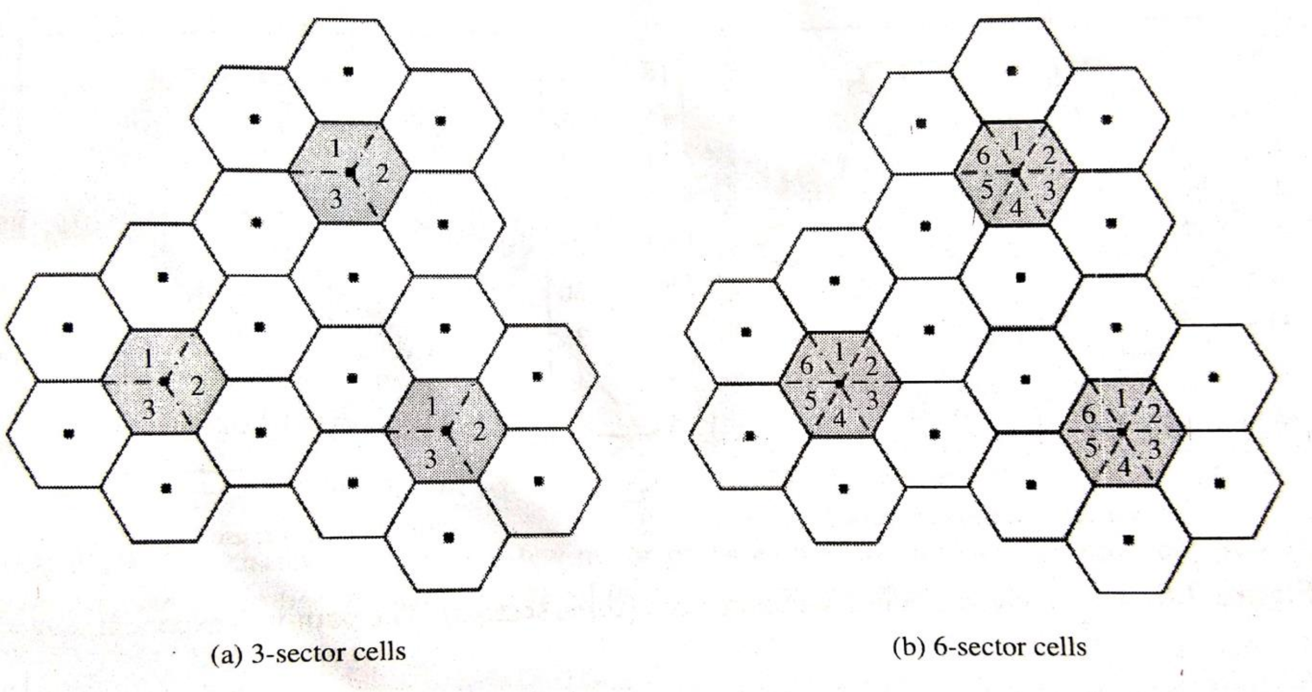

Figure 4: 3-Sector (120-degree) and 6-Sector (60-degree) cells.

- In Cellular Systems, Other Cell Interference (OCI) is a decreasing function of the radius of the cell (R) & the distance to the center of the neighbouring co-channel cell and an increasing function of transmit power.
- Since the SIR is so bad in most of the cell, it is desirable to find techniques to improve it without sacrificing so much bandwidth.
- A popular technique is to **sectorize** the cells, which is effective if frequencies are reused in each cell. Directional antennas are used instead of omni-directional antenna at the base station.

The Broadband Wireless Channel: Fading

- One of the most disturbing aspects of wireless channels is the fading phenomenon.
- Unlike path loss or shadowing, which are large-scale attenuation effects due to distance or obstacles, fading is caused by the reception of multiple versions of the same signal.
- The multiple received versions are caused by reflections that are referred to as *multipath.*

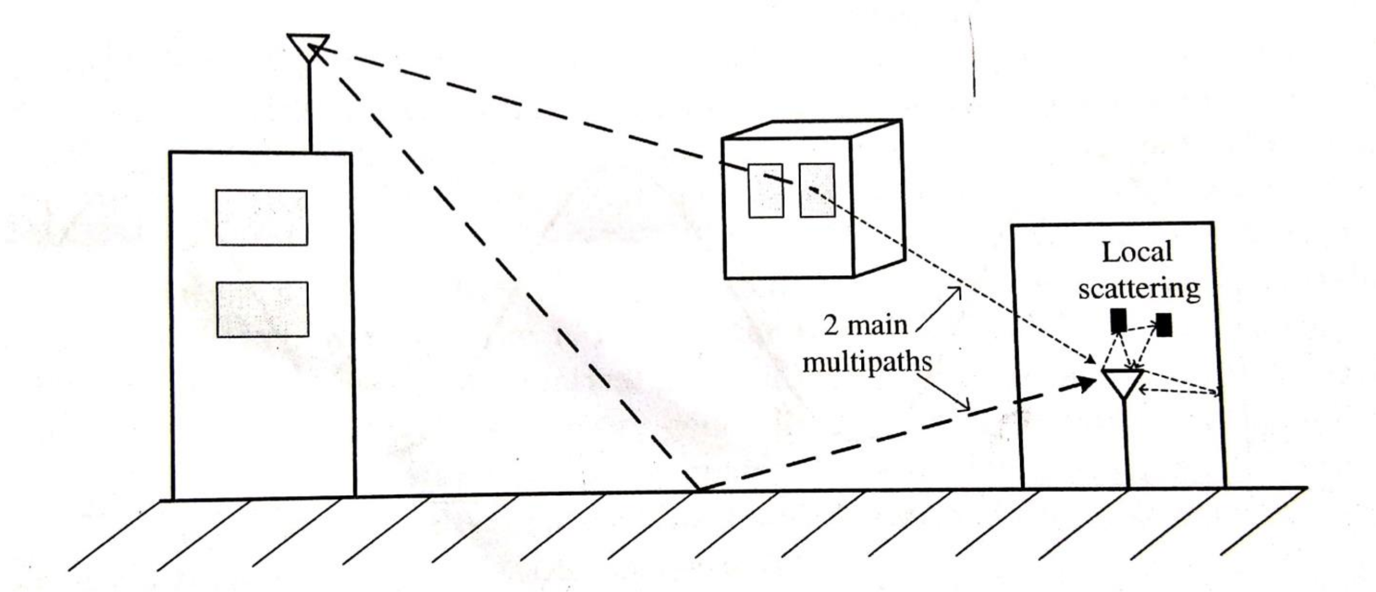

Figure 5: The channel may have a few major paths with quite different lengths, and then the receiver may see a number of locally scattered versions of those paths.

- Depending on the phase difference between the arriving signals, the interference can be either constructive or destructive.
- This causes a very large observed difference in the amplitude of the received signal even over very short distances.

  Let us consider the time-varying tapped-delay line channel model.

- As either the Tx^r or Rx^r move relative to each other, the channel response **h(t)** will change.
- Movement in the propagation environment will also cause the channel response to change over time.
- This channel response can be thought of as having two dimensions:
  a delay dimension τ & a time dimension t
- Since the channel is highly variant in both the τ & **t** dimensions, in order to be able to discuss what the channel response is we must use statistical methods.
- The most important & fundamental function used to statistically describe broadband fading channels is the two-dimensional auto correlation function, $A(\Delta\tau, \Delta t)$.

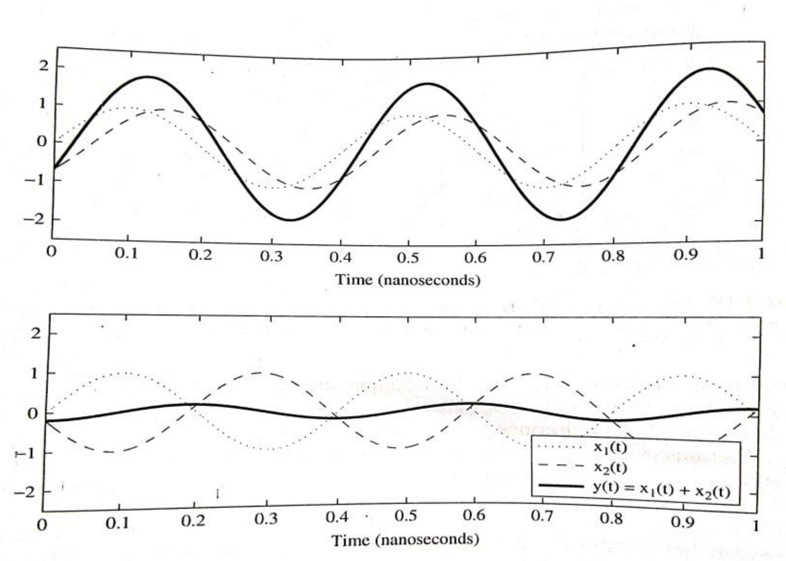

Figure 6:Constructive Interference (top) and destructive interference (bottom)

And it is defined as

$$A(\Delta\tau, \Delta t) = E[h(\tau_1, t_1)h^*(\tau_2, t_2)]$$
$$= E[h(\tau_1, t)h^*(\tau_2, t + \Delta t)]$$
$$= E[h(\tau, t)h^*(\tau + \Delta\tau, t + \Delta t)]$$

- The channels described by this auto correlation function are referred to as **Wide Sense Stationary Uncorrelated Scattering (WSSUS).**
- This is the most popular model for wide band fading channels.
  From the auto correlation function, following wireless channel parameters can be estimated.

1. Delay Spread, τ
2. Coherence Bandwidth, B_c
3. Doppler Spread, f_D

$= \frac{f_c v}{c}$

4. Coherence Time, T_c
5. Angular Spread, θ_{rms}
6. Coherence Distance, D_c

Table1: Summary of Broadband Fading Parameters

Quantity	If "Large"?	If "Small"?	LTE Design Impact
Delay Spread, τ	If $\tau \gg T$, then frequency selective	If $\tau \ll T$, then frequency flat	The larger the delay spread relative to the symbol time, the more severe the ISI.
Coherence Bandwidth, B_c	If $\frac{1}{B_c} \ll T$, then frequency flat	If $\frac{1}{B_c} \gg T$, then frequency selective	Provides a guideline to subcarrier width $B_{sc} \approx B_c/10$, and hence number of subcarriers needed in OFDM: $L \geq 10B/B_c$.
Doppler Spread, $f_D = \frac{f_c \nu}{c}$	If $f_c\nu \gg c$, then fast fading	If $f_c\nu \leq c$, then slow fading	As f_D/B_{sc} becomes non-negligible, subcarrier orthogonality is compromised.
Coherence Time, T_c	If $T_c \gg T$, then slow fading	If $T_c \leq T$, then fast fading	T_c small necessitates frequent channel estimation and limits the OFDM symbol duration, but provides greater time diversity.
Angular Spread, θ_{rms}	Non-LOS channel, lots of diversity	Effectively LOS channel, not much diversity	Multiantenna array design, beamforming vs. diversity.
Coherence Distance, D_c	Effectively LOS channel, not much diversity	Non-LOS channel, lots of diversity	Determines antenna spacing.

Delay Spread and Coherence Bandwidth

- Delay Spread: is the amount of time that elapses between the first arriving path and the last arriving path. It specifies the duration of the channel impulse response h (τ, t)
- τ_{max} = maximum delay spread, intuitively gives the measure of the width or spread of the channel response in time.
- Coherence Bandwidth B_c: is the frequency domain dual of the channel delay spread. It gives the rough measure for the maximum separation between frequency f_1 & frequency f_2

$$|f_1 - f_2| \le B_c \Rightarrow H(f_1) \approx H(f_2)$$
$$|f_1 - f_2| > B_c \Rightarrow H(f_1) \text{ and } H(f_2) \text{ are uncorrelated}$$

For a given channel delay spread, it can be shown that

$$B_c \approx \frac{1}{5\tau_{\text{rms}}} \approx \frac{1}{\tau_{\text{max}}}.$$

Doppler Spread and Coherence Time

- Doppler power spectrum gives the statistical power distribution of the channel versus frequency for a signal transmitted at just one exact frequency.

$$f_D = \frac{\nu f_c}{c},$$

where, f_D is called the maximum Doppler or Doppler spread
υ is the maximum speed between the transmitter and the receiver
c is the speed of light

- The channel coherence time gives the period of time over which the channel is significantly correlated. Mathematically,

$$|t_1 - t_2| \le T_c \Rightarrow \mathbf{h}(t_1) \approx \mathbf{h}(t_2)$$
$$|t_1 - t_2| > t_c \Rightarrow \mathbf{h}(t_1) \text{ and } \mathbf{h}(t_2) \text{ are uncorrelated}$$

The coherence time and Doppler spread are also inversely related,

$$T_c \approx \frac{1}{f_D}.$$

- If the transmitter and receiver are moving fast relative to each other then, the Doppler is large but the coherence time is less. As the channel will change much more quickly compared to when the transmitter and receiver are stationary.

Angular Spread and Coherence Distance

- The rms angular spread of a channel can be denoted as θ_{rms} and refers to the statistical distribution of the angle of the arriving energy. A large θ_{rms} implies that the channel energy is coming from many directions, whereas a small θ_{rms} implies that the received channel energy is more focused.
- A large angular spread generally occurs when there is a lot of local scattering, this results more statistical diversity in the channel.
- Whereas more focused energy results in less statistical diversity.
- The dual of the angular spread is coherence distance D_c as the angular spread increases the coherence distance decreases.
- A coherence distance of d means that any physical positions separated by d have an essentially uncorrelated received signal amplitude and phase.

$$D_c \approx \frac{.2\lambda}{\theta_{rms}}$$

- For the case of Rayleigh fading

$$D_c \approx \frac{9\lambda}{16\pi}.$$

Modelling Broadband Fading Channels

- In order to design and benchmark wireless communication systems, it is important to develop channel models that incorporate their variations in time, frequency and space.
- The two main classes of models are **Statistical model** & **Empirical model.**
- Statistical models are simpler and are useful for analysis & simulations.

- The empirical models are more complicated, but usually represent a specific type of channel more accurately.

A Pedagogy for Developing Statistical Models

The methods for modelling wireless channels are broken into three steps:

Step 1 : First consider just a single channel sample corresponding to a single principle path between the Tx^r & Rx^r, that is

$$h(\tau, t) \rightarrow h_0\delta(\tau, t)$$

Attempt to quantify: How is the value of $|h_0|$ statistically distributed?

Step2 : Next consider how this channel sample h_0 evolves over time, that is:

$$h(\tau, t) \rightarrow h_0(t)\delta(\tau)$$ Attempt

to quantify: How does the value $|h_0|$ change over time?

Step 3 : Finally, $h(\tau, t)$ is represented as a general time varying function.

Statistical Channel Models

- The received signal in a wireless system is the superposition of numerous reflections or multi path components.
- In this section, we will overview statistical methods that can be used to characterize the amplitude & power of received signal $r(t)$ when all the reflections arrive at about the same time.
- The following statistical models are considered in this section:
  1. Rayleigh Fading Model
  2. Line-of-Sight Channels - The Rician Distribution
  3. A more general model: Nakagami - m Fading

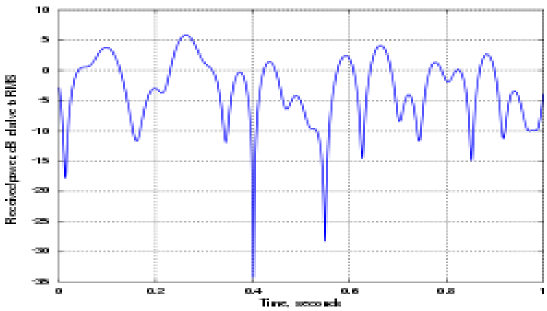

Figure 7: One second of Rayleigh fading with a maximum Doppler shift of 10 Hz.

Rayleigh Fading Model

- Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver.
- The in-phase (cosine) and quadrature (sine) components of received signal r(t) follow two independent time - correlated Gaussian random processes.
  - The distribution of the envelope amplitude

$|r| = \sqrt{r_I^2 + r_Q^2}$ is Rayleigh distribution.

- The received power $|r|^2 = r_I^2 + r_Q^2$ is exponentially distributed

$$f_{|r|}(x) = \frac{2x}{P_r} e^{-x^2/P_r}, \quad x \geq 0,$$

and

$$f_{|r|^2}(x) = \frac{1}{P_r} e^{-x/P_r}, \quad x \geq 0,$$

- Where P_r is the average received power due to shadowing and pathloss.
- This phase is **uniformly distributed** from 0 to 2π, or equivalently from $[-\pi, \pi]$

LoS Channels - The Rician Distribution

- An important assumption in the Rayleigh fading model is that, the arriving reflections have a mean of zero.
- For LoS signal, the received envelope distribution is more accurately modelled by a Rician distribution.
- It is given by

$$f_{|r|}(x) = \frac{x}{\sigma^2} e^{-(x^2+\mu^2)/2\sigma^2} I_0\left(\frac{x\mu}{\sigma^2}\right), \quad x \geq 0,$$

where μ^2 is the power of the LoS component and
I_0 is the 0^{th} order, modified Bessel function of the first kind.

- The Rician phase distribution θ_r is not uniform in $[0,2\pi]$ and is not distributed by a straight forward expression.
- It is more generalization of the Rayleigh distribution.

A More General Model: Nakagami - m Fading

- The Nakagami distribution is relatively new, being first proposed in 1960.
- It has been used to model attenuation of wireless signals traversing multiple paths and to study the impact of fading channels on wireless communications.
- The Probability Density Function (PDF) of Nakagami - m fading is parameterized by m and is given as

$$f_{|r|}(x) = \frac{2m^m x^{2m-1}}{\Gamma(m) P_r^m} e^{-mx^2/P_r}, \quad m \geq 0.5.$$

- The power distribution for Nakagami fading is

$$f_{|r|^2}(x) = \left(\frac{m}{P_r}\right)^m \frac{x^{m-1}}{\Gamma(m)} e^{-mx/P_r}, \quad m \geq 0.5.$$

Empirical Channel Model

- Actual environments are too complex to model accurately.
- In practice, most simulation studies use empirical models that have been developed based on measurements taken in various real environments.
- In 1968, **Okumura** conducted extensive measurements of base station to mobile signal attenuation throughout Tokyo and developed a set of curves giving median attenuation relative to free space path loss.
- To use this model one needs to use the empirical plots given in his paper. This is not very convenient to use.
- So in 1980, **Hata** developed closed-form expressions for Okumura’s data.

LTE Channel Models for Path Loss : Hata Model

According to **Hata model** the path loss in an urban area at a distance d is:

$$L_U = 69.55 + 26.16log_{10}(f_c) - 13.82log_{10}(h_B) - a(h_r) + [44.9 - 6.55log_{10}(h_B)]log_{10}(d)$$

where
L_U = Path loss in Urban areas (dB) h_B = Height of BS antenna (meters) f_c = Carrier Frequency (MHz)
$a(h_r)$ = Antenna height correction factor
d = Distance between BS & MS (Kms)

4.2 COST Hata Model

- Hata model is intended for large cells with BS being placed higher than the surrounding rooftops.
- Both Okumura & Hata models are designed for **150-1500 MHz** and are applicable to the first generation cellular systems.
- The European Cooperative for Scientific and Technical (COST) research extended the Hata model to 2 GHz as follows:

$$P_{L,Urban} = 46.3 + 33.9log_{10}(f_c) - 13.82log_{10}(h_t) - a(h_r) + [44.9 - 6.55log_{10}(h_t)]log_{10}(d) + C_m$$

- This model is restricted to the following range of parameters:

Carrier Frequency	1.5 GHz to 2 GHz
Base Antenna Height	30 m to 300 m
Mobile Antenna Height	1 m to 10 m
Distance d	100 m to 20 Km

- COST Hata model is designed for large and small macro-cells, i.e., base station antenna heights above rooftop levels adjacent to base station.

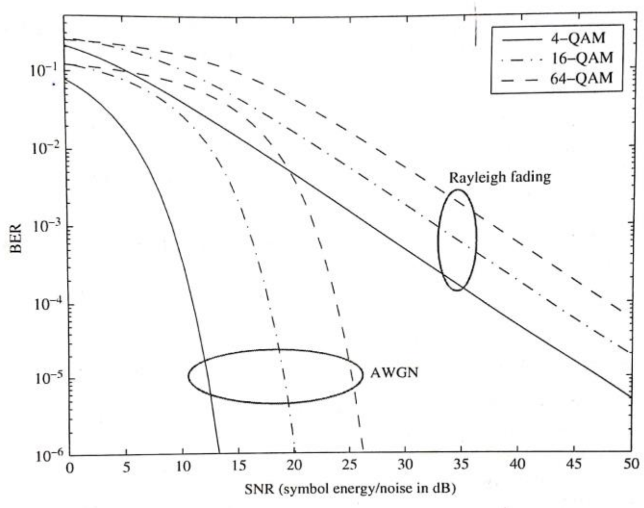

Figure 8: SNR vs. BER

Mitigation of Narrowband Fading

The Effects of Unmitigated Fading

- The probability of bit error (BER) is the principle metric of interest for the physical (PHY) layer of a communication system.
- For a QAM - based modulation system, the BER in an AWGN (no fading) can be approximated by the following bound:
  $P_b \leq 0.2e^{-1.5SNR/(M-1)}$
- The BER decreases rapidly (exponentially) with SNR.
- So decreasing SNR linearly causes the BER to increase exponentially.

Techniques to mitigate fading

The following techniques are used to mitigate the effects of fading.

1. Diversity - Spatial Diversity
2. Coding and Interleaving - Using ECCs or FECs
3. Automatic Repeat Request (ARQ)
4. Adaptive Modulation and Coding (AMC)

Spatial Diversity

- Diversity is the key to overcome performance loss from fading channels.
- Spatial diversity is a powerful form of diversity, and particularly desirable since it does not include redundancy in time or frequency.
- It is usually achieved by having two or more antennas at the receiver and / or the transmitter.
- The simplest form of space diversity consists of two receive antennas, where the stronger of the two signals is selected.
- This type of diversity is called as **Selection Diversity.**

Mitigation of Broadband Fading

- Since the data rate R is proportional to 1/T, high data rate systems almost invariably have multi path delay spread & hence experience very serious inter symbol interference (ISI).
- Choosing a technique to effectively reduce ISI is a central design decision for any high data rate system.
- OFDM is the most popular choice for reducing ISI in high rate systems, including WiFi, WiMAX and LTE.

Adaptive Modulation & Coding (AMC)

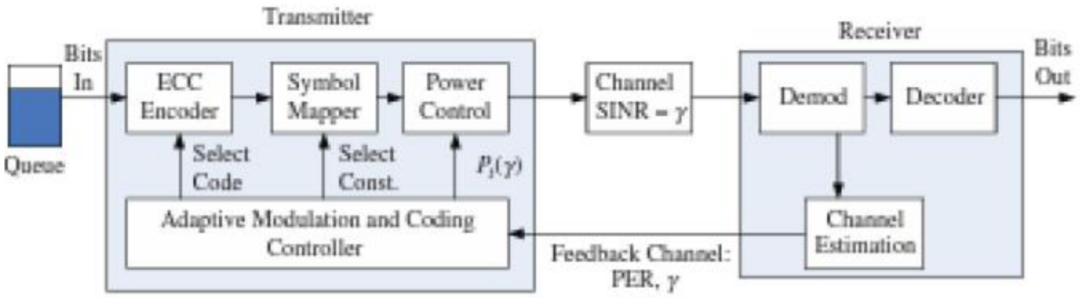

Figure 9: Adaptive Modulation & Coding Block Diagram

- LTE systems employ AMC in order to take advantage of fluctuations in the channel over time and frequency.
- The basic idea is to transmit as a high a data rate as possible where the channel is good and transmit at a lower data rate where the channel is poor.
- To perform AMC the transmitter must have knowledge of the instantaneous channel gain, then it can choose the modulation technique that will achieve the highest possible data rate, while maintaining the packet error rate (PER) requirement.

- Lower data rates through QPSK and low rate error correcting codes such as 1/3 turbo codes

- Higher data rates through 64 QAM and less robust error correcting codes such as ¾ codes.

- Tuning the Adaptive Modulation & Coding Controller:
    1. **PER and Received SINR**
       -The Tx needs only the statistics of the instantaneous SINR to determine optimum coding/modulation.
       - But the PER should be carefully monitored as the final word on whether data rate has to be increased or decreased

    2. **Automatic Repeat Request (ARQ)**
       - Hybrid-ARQ increases the ideal PER operating point by a factor of 10

    3. **Power Control**
       - In theory more power is allocated to strong channels and less power to weak channels
       - But in practice the opposite approach called the channel inversion is used, as it is a sensible goal to use as little power as possible to achieve a given target rate and reliability.

    4. **Adaptive Modulation in OFDMA**
       - In OFDMA each user is allocated a block of subcarriers, each with varying SINR. Hence care needs to be taken as to which modulation and coding set to be used.

Module 2

Multicarrier Modulation - Part 1

An OFDM Communication System

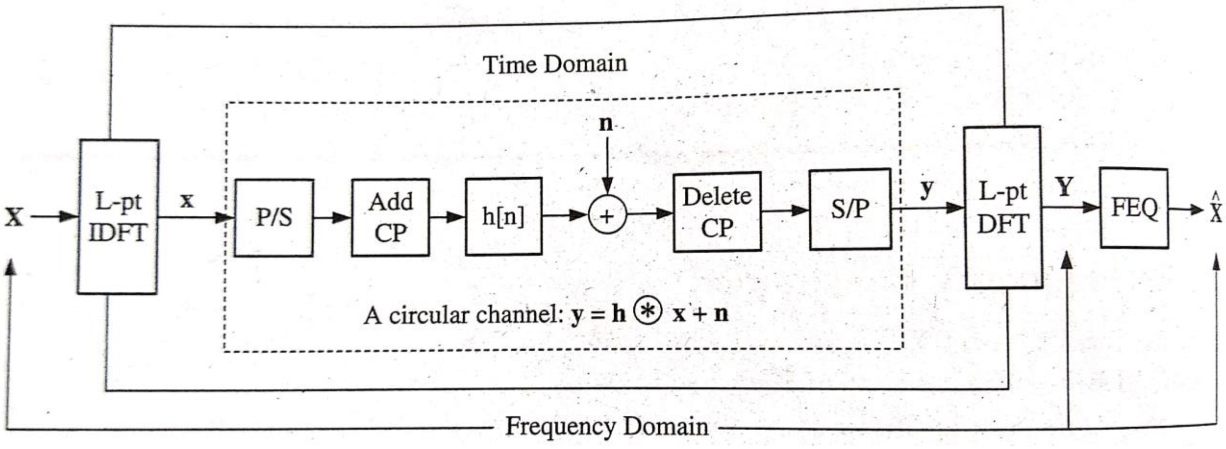

Fig 2.1: An OFDM system in vector notation. Encoding and decoding is done in the frequency domain, where X, Y, and $\hat{X}$ are the L transmitted, received and estimated symbols.

The Key steps in OFDM Communication System are:

1. A wideband signal of bandwidth B is divided into L narrowband signals (subcarriers) of bandwidth B/L each. These subcarriers are ISI free if a cyclic prefix that exceeds the delay spread is used. The L subcarriers in an OFDM symbol are represented by the vector X.

2. In order to use a single wideband radio instead of L independent narrow band radios, the subcarriers are created digitally using IFFT operation.

3. In order for the IFFT/FFT to decompose the ISI channel into orthogonal subcarriers, a cyclic prefix of length v is added after the IFFT operation. These L+v channels are sent in serial through wideband channel.

4. At the receiver the cyclic prefix is discarded, and the L received symbols are demodulated using an FFT operation, which results in L data symbols, each of form $Y_l = H_l X_l + N_l$ for subcarrier l.

5. Each subcarrier is then equalized via FEQ (Frequency Domain Equalizer) by simply dividing by the complex channel gain H[i] for that subcarrier. This results in the estimated symbol $\hat{X}_l = X_l + N_l/H_l$

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OFDM in LTE

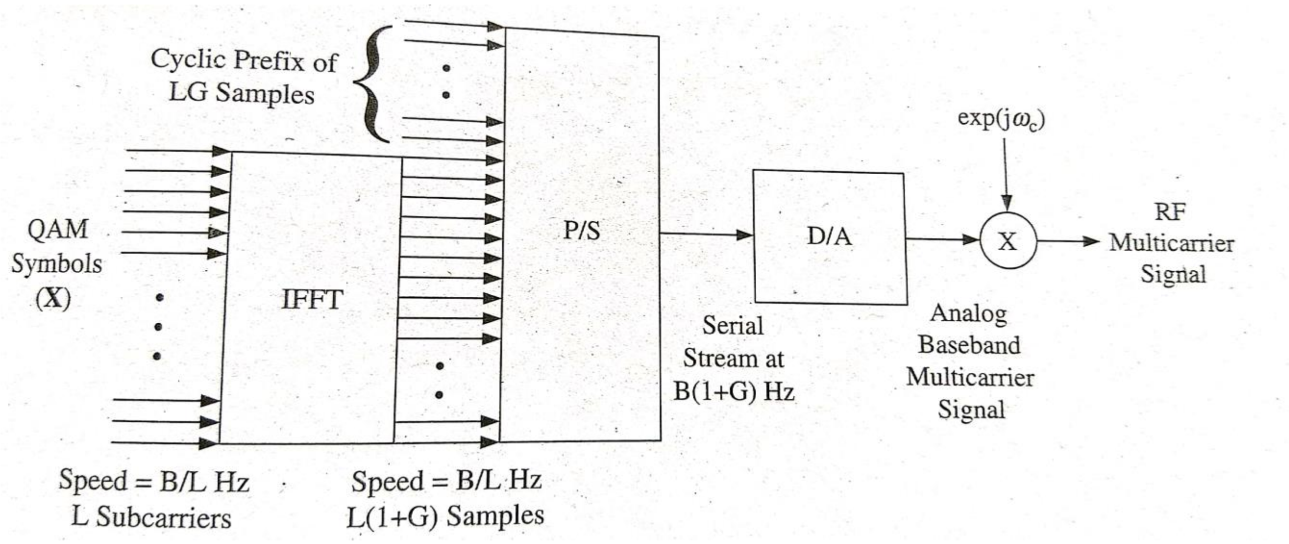


Fig 2.2: A close-up of the OFDM baseband to passband transmitter

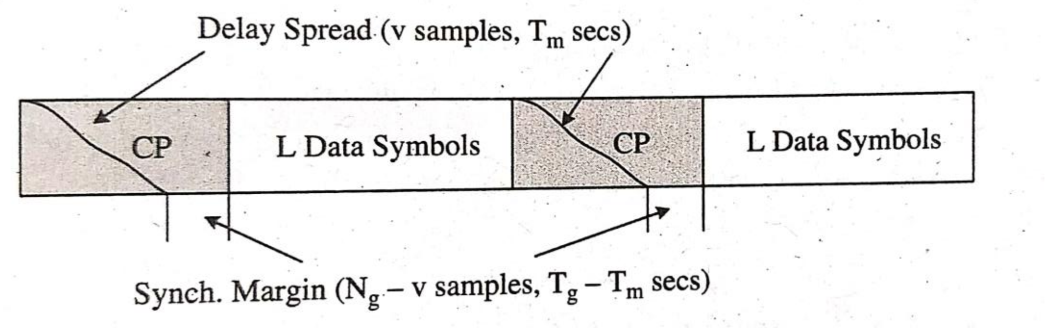
- The above figure shows an up-close view of a passband OFDM modulation engine. The inputs to this figure are L independent QAM symbols (vector X)
- The L-point IFFT creates a time domain L-vector x, that is cyclic extended to have length L(1+G) where G is the fractional overhead.
- This vector is then parallel-to-serial (P/S) converted into wideband digital signal that can be amplitude modulated with a single radio at carrier frequency of $f_c = w_c/ 2\pi$

Timing & Frequency Synchronization

In order to demodulate an OFDM signal there are two important synchronization tasks that need to be performed by the receiver.

1) *Timing Synchronization*: the timing offset of the symbol and the optimal timing instants need to be determined.
2) *Frequency Synchronization:* the receiver must align its frequency as closely as possible with the transmitted frequency.

Timing Synchronization



- The effect of timing errors in symbol synchronization is somewhat relaxed in OFDM due to the presence of a cyclic prefix.
- In case that perfect synchronization is not maintained, it is still possible to tolerate a timing offset of τ seconds without any degradation in performance as long as $0 \leq \tau \leq T_g - T_m$, where T_g is the guard time and T_m is the maximum delay spread
- If $\tau < 0$ corresponds to sampling earlier than at the ideal instant, whereas $\tau > 0$ is later than the ideal instant.
- As long as τ remains constant, the channel estimator includes it as a fixed phase offset and can be corrected by FEQ without any loss in performance. This acceptable range of τ is referred to as the timing synchronization margin.
- If τ is not within this window $0 \leq \tau \leq T_g - T_m$, ISI occurs regardless of phase-shift appropriation.

Frequency Synchronization

- OFDM achieves a high degree of bandwidth efficiency compared to other wideband systems. The subcarrier packing is extremely tight compared to conventional modulation techniques.
- Due to this high bandwidth efficiency, the multicarrier signals shown in fig below are very sensitive to frequency offsets.
- As long as the frequency offset δ=0 there is no interference between the subcarriers.
- In practice however the frequency offset is not always zero.

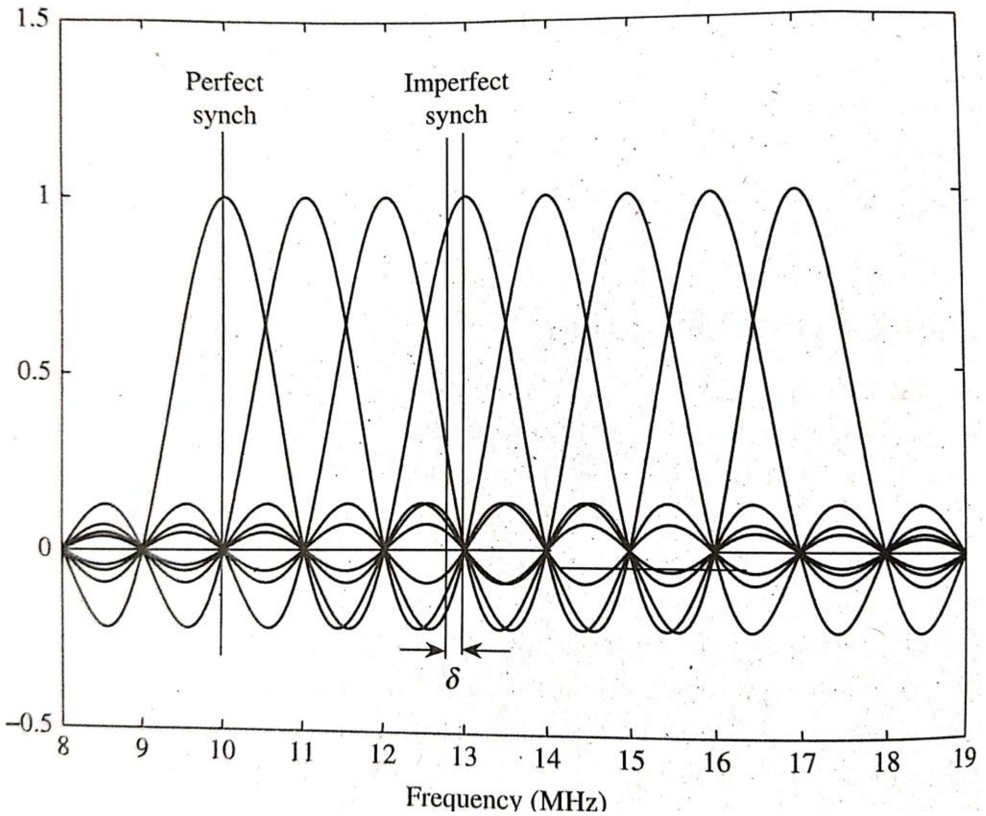


Figure: OFDM synchronization in frequency, here eight subcarriers are shown.

The Peak-to-Average Ratio

- OFDM signals have higher peak-to-average ratio (PAR) or peak-to-average power ratio (PAPR)
- As in the time domain a multicarrier signal is the sum of many narrow band signals, at some times this sum is large at other times it is small. Hence the peak value is substantially larger than the average
- This reduces the efficiency of the RF power amplifier

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The PAR Problem

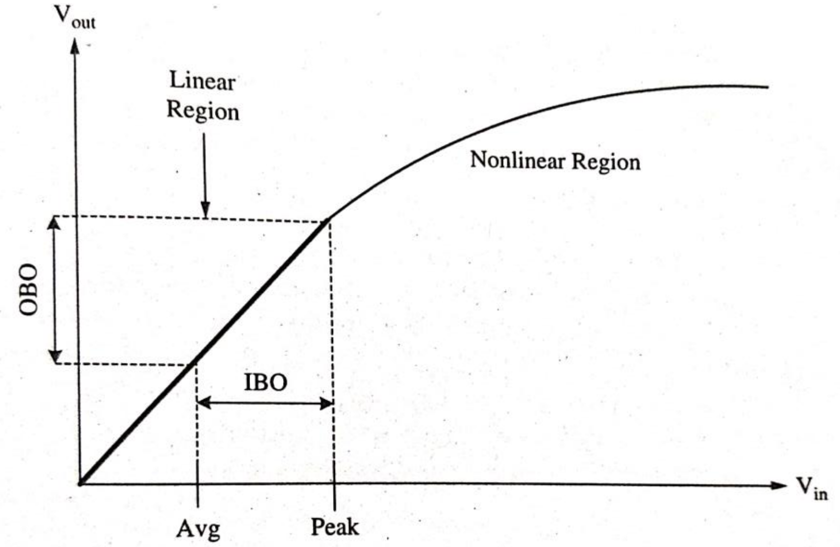

Figure 3.11 A typical power amplifier response. Operation in the linear region is required in order to avoid distortion, so the peak value must be constrained to be in this region, which means that on average, the power amplifier is underutilized by a "backoff" amount.

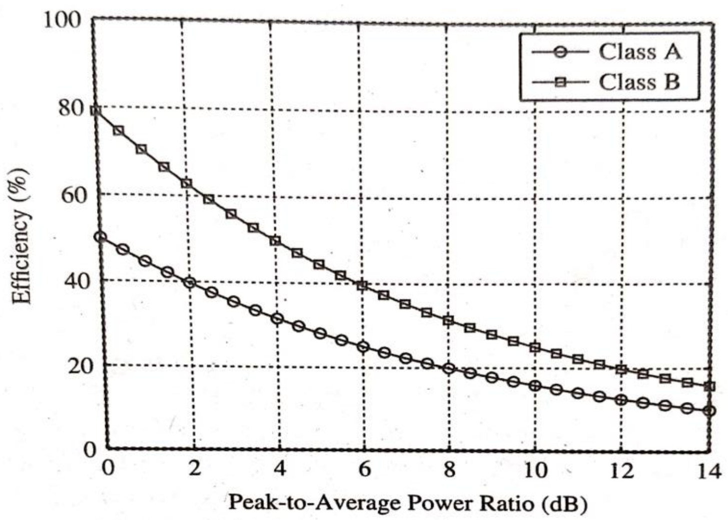

Figure 3.12 Theoretical efficiency limits of linear amplifiers [22]. A typical OFDM PAR is in the 10 dB range, so the PA efficiency is 50–75% lower than in a single-carrier system.

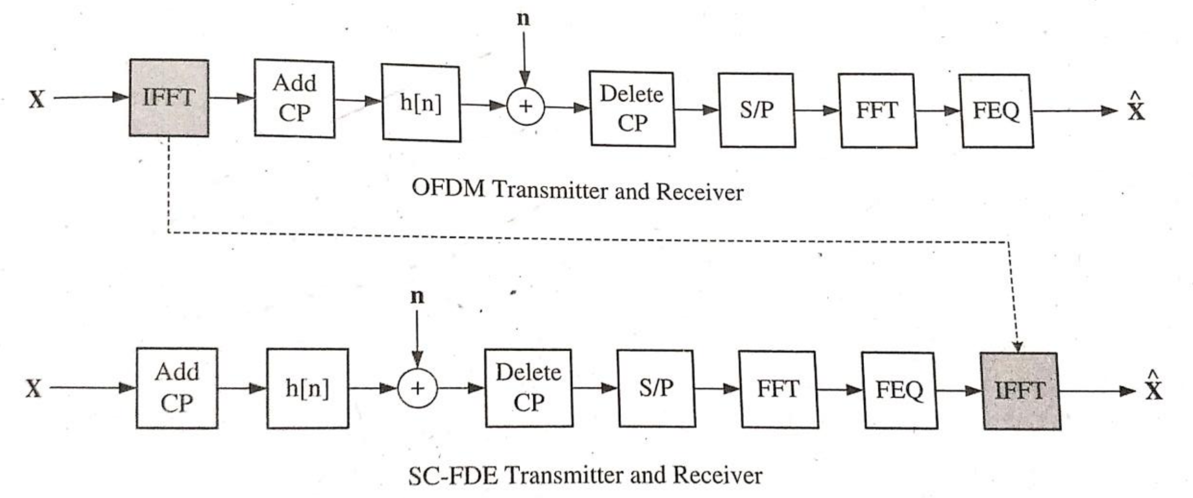

Figure 3.17 Comparison between an OFDM system and an SC-FDE system. The principle difference is that the IFFT formerly in the transmitter is in the SC-FDE receiver.

- The only difference is that the IFFT is moved to the end of the receive chain rather than operating at the transmitter to create multicarrier waveform as in OFDM.
- SC-FDE system also utilizes a cyclic prefix as long as the channel delay spread, but the transmitted signal is simply a sequence of QAM symbols, which have low PAR, of the order 4-5 dB

OFDMA and SC-FDMA [Module 2 - Part 2]

Multiple Access for OFDM Systems

- OFDM is not a multiple-access strategy, but a technique for mitigating frequency selectivity(ISI)
- OFDM does create many parallel streams of data that can in principle be used by different users, but previous OFDM systems such as DSL can be called "single-user OFDM" where all subcarriers are used by a single user.
- All the concepts of OFDM and OFDMA are equivalent for SC-FDMA

Frequency Division Multiple Access (OFDM-FDMA)

- FDMA can be readily implemented in OFDM systems by assigning different users their own set of subcarriers.
- Simplest method is the static allocation of subcarriers to each user, For eg: In a 64-subcarrier OFDM system, user 1 could take subcarriers 1-16, with users 2, 3 and 4 using subcarriers 17-32, 33-48, and 49-64 respectively
- The subcarriers are allocated with a multiplexer before the IFFT operation, high data rate

users can be allocated more subcarriers than lower rate users. Such a system can be referred to as OFDMA.

- In LTE dynamic subcarrier allocation is used to mitigate frequency selective fading

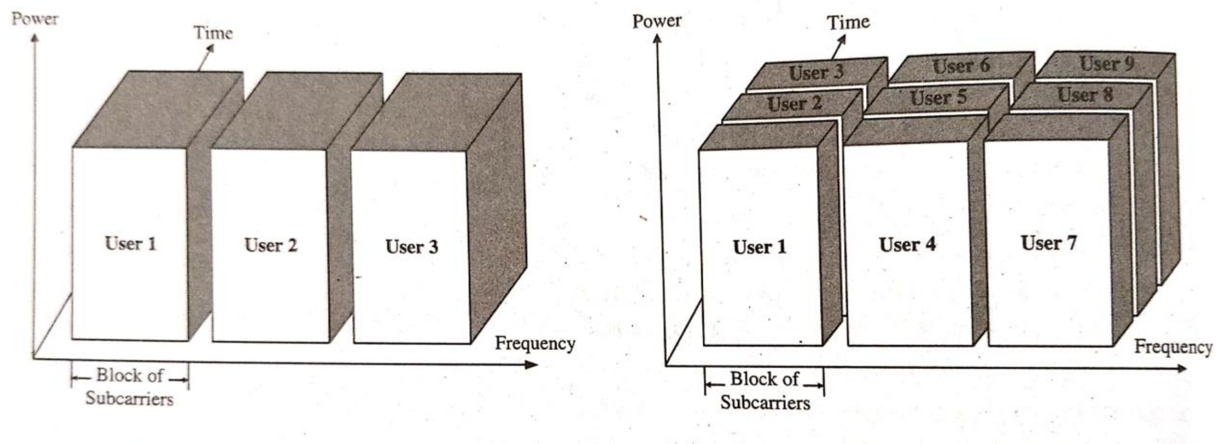

Figure 4.1 FDMA (left) and a combination of FDMA with TDMA (right).

Time Division Multiple Access (OFDM-TDMA)

- Multiple users can also be accommodated with TDMA, all wireless TDMA systems employ both FDMA and TDMA at some level since the electromagnetic spectrum must be shared with many other users
- Static TDMA, shown in fig. above is appropriate for constant data-rate applications like voice and streaming video, users often will not have data to send so it is important that subcarriers be dynamically allocated in order to avoid waste

Code Division Multiple Access (OFDM-CDMA or MC-CDMA)

- CDMA is the dominant multiple access technique for 3G cellular systems, but is not appropriate for high-speed data since a bandwidth much larger than the data rate is used to suppress the interference
- OFDM and CDMA can be combined together to create a Multicarrier CDMA (MC-CDMA)

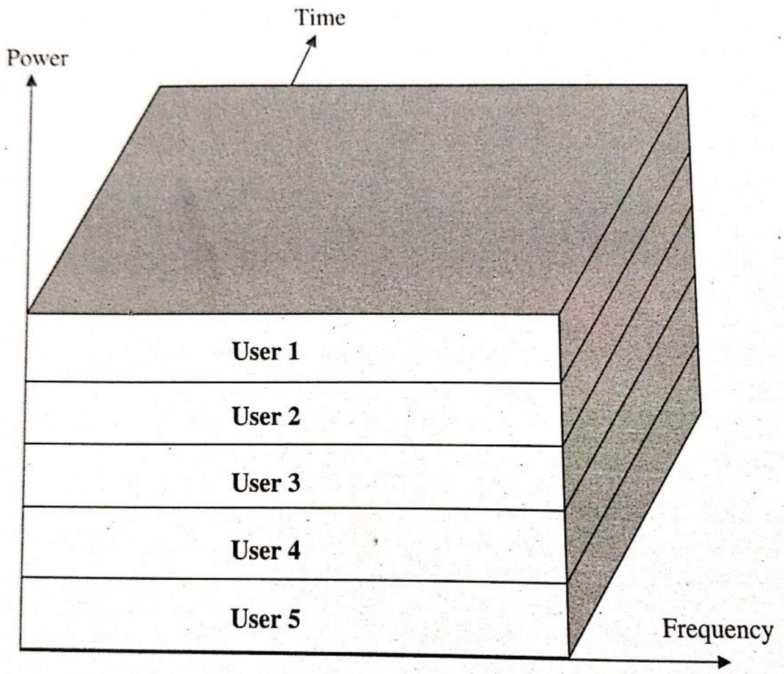

Figure 4.2 CDMA's users share time and frequency slots but employ codes that allow the users to be separated by the receiver.

Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA systems allocate users time-frequency slices consisting of M subcarriers, the M subcarriers can be :

1) Distributed/Comb/Diversity Allocation: Spread out over the band
   - achieves frequency diversity over the entire band, would typically rely on interleaving and coding to correct errors caused by poor subcarriers

2) Band AMC/Localized/Grouped Allocation: Bunched together in M contiguous subcarriers
   - uses subcarriers where the SINR is roughly equal, and choose the best coding and modulation scheme for that SINR

Table 4.1 OFDMA Notation

K	Number of active users
L	Total number of subcarriers
M_k, M	Number of subcarriers per active user k
$h_{k,l}$	Envelope of channel gain for user k in subcarrier l
$P_{k,l}$	Transmit power allocated for user k in subcarrier l
σ^2	AWGN power spectrum density
P_{tot}	Total transmit power available at the base station
B	Total transmission bandwidth

OFDMA

- *OFDMA Downlink Transmitter:* The basic flow is very similar to an OFDM system except for now K users share the L subcarriers, with each user being allocated M_k subcarriers
- Forward Error Correction (FEC) is applied to the OFDM symbols of a particular user, they are then modulated using QAM by the adaptive modulation and coding block of the transmitter.
- These OFDM symbols are allocated to various subcarriers
- Each subcarrier has only one user allocated to it

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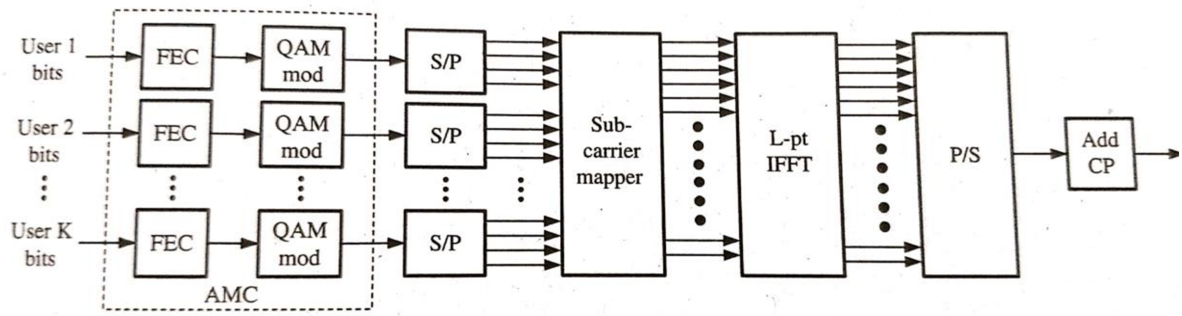

Figure 4.3 OFDMA downlink transmitter.

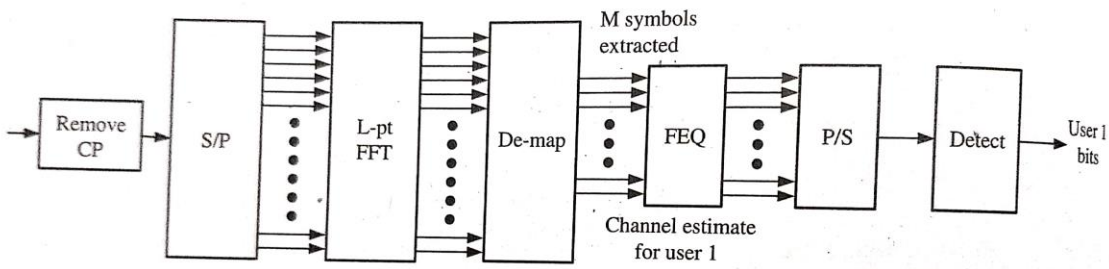

Figure 4.4 OFDMA downlink receiver for user 1. Each of the K active users—who by design have orthogonal subcarrier assignments—have a different receiver that only detects the M_k subcarriers intended for it.

- *OFDMA Downlink Receiver:* At each receiver the user cares only about its own M_k subcarriers, but still L point FFT is applied in order to extract the desired subset of subcarriers, the receiver should know which time and frequency resources is allocated to it.
- Thus, the OFDMA down link receiver must demodulate the entire waveform which is wasteful of power
- Digital separation of users is simple and inter user interference is low compared to either CDMA or conventional FDMA where analog filters are used to separate the users

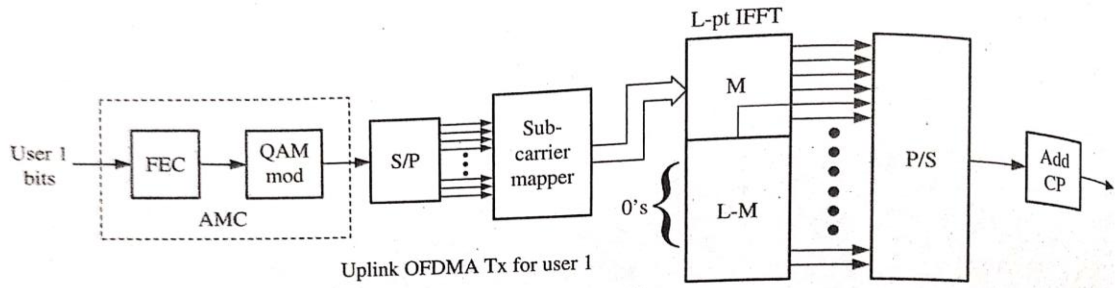

Figure 4.5 OFDMA uplink transmitter for user 1, where user 1 is allocated subcarriers 1, 2,.. *M* of *L* total subcarriers.

- *OFDMA Uplink Transmitter:* Although OFDMA is not used in LTE uplink, OFDMA uplink Tx and Rx block diagrams are shown to illuminate the differences and similarities of OFDMA and SC-FDMA (FEC = forward error correction)
- The uplink transmitter modulates just the particular user's bits. Here user 1 is occupying subcarriers 1,2….M of the total L subcarriers
- All the users' signals collide at the receiver's antenna and are collectively demodulated using the receiver's FFT
- *OFDMA Uplink Receiver:* The signals that arrive at the receiver offset slightly in time and frequency in the uplink as it is asynchronous. If these offsets become large, they can lead to considerable self-interference and can severely degrade the orthogonality across all subcarriers.
- Frequency and timing synchronization for the uplink is achieved relative to the downlink.

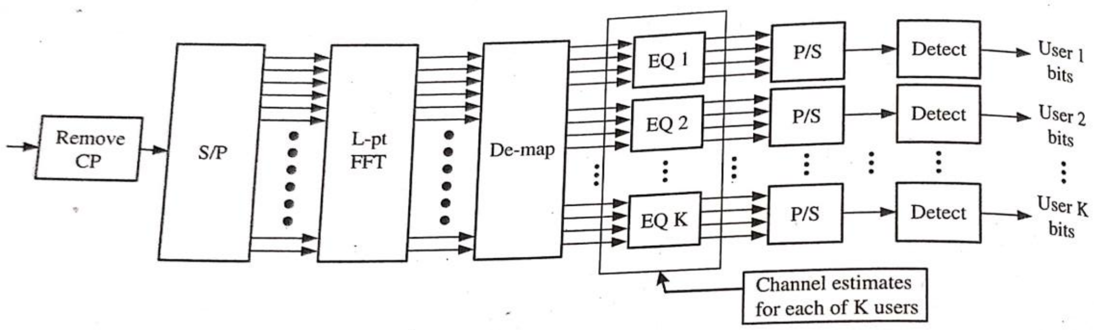

Figure 4.6 OFDMA uplink receiver. All *K* active users—who by design have orthogonal subcarrier assignments—are aggregated at the receiver and demultiplexed after the FFT.

- A higher-level view of OFDMA is shown in the figure 4.7 below. Here, a base station is transmitting a band AMC-type OFDMA waveform to four different devices simultaneously. The dotted arrows indicate the control signaling that must happen in order for band AMC-type OFDMA to work .
- First the mobile measure and send channel state information (CSI) to the base station, usually CSI is an SINR measurement.
- The base station would then allocate subcarriers to the four users and send the subcarrier allocation information to the four users.
- Finally, the actual data is transmitted to the four users over the subcarriers assigned to them.

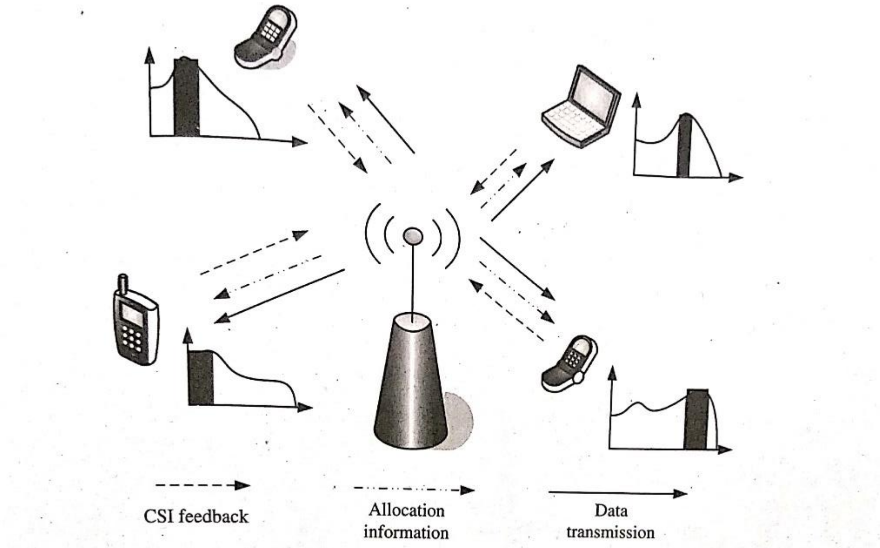

Figure 4.7 In OFDMA, the base station allocates each user a fraction of the subcarriers, preferably, in a range where they have a strong channel.

Single-Carrier Frequency Division Multiple Access (SC-FDMA)

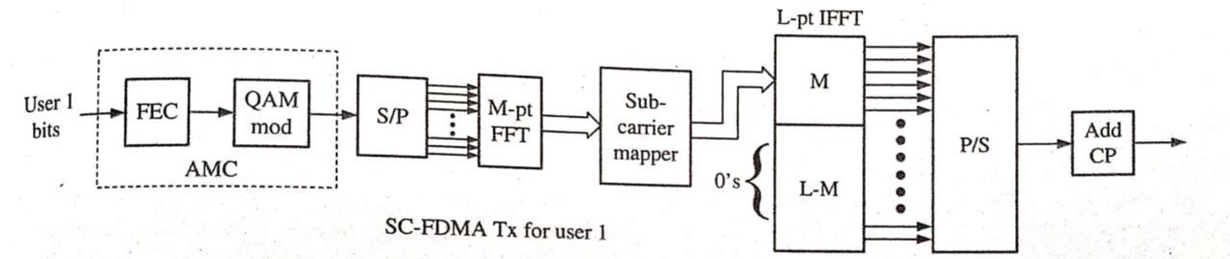

Figure 4.8 SC-FDMA uplink transmitter for user 1, where user 1 is allocated subcarriers 1, 2, . . . , M of L total subcarriers.

- SC-FDMA is employed in uplink LTE, even though SC-FDMA has conceptually evolved from SC-FDE single carrier frequency division multiple access it closely resembles OFDMA as it still requires an IFFT operation at the transmitter to separate the users
- The goal of SC-FDMA is to take the low peak-to-average ratio (PAR) properties of SC-FDE and achieve them in an OFDMA type system
- *SC-FDMA Uplink Transmitter:* Clearly it is very similar to the OFDMA uplink transmitter, the only big difference is that the user's M_k complex symbols are pre-processed with an FFT of size M_k
- The FFT operation creates a frequency domain signal X[m] from x[n] so that when IFFT is applied later, the output corresponds to the phase-shifted version of the original time-domain signal x[n]
- Hence the transmitted SC-FDMA signal is an oversampled single-carrier signal, rather than multiple subcarrier signal transmitted in OFDMA

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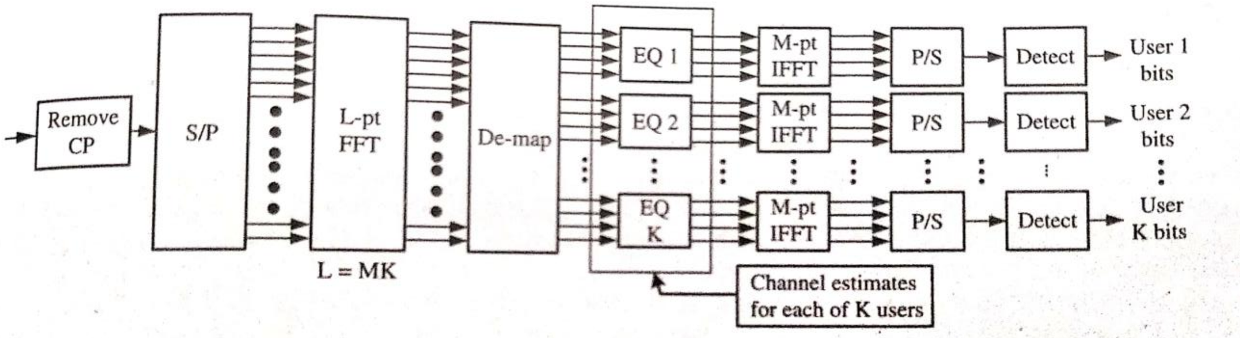

Figure 4.9 SC-FDMA uplink receiver. Much like the OFDMA receiver, here we explicitly assume that each user occupies a fraction *M/L* of the spectrum.

- *SC-FDMA Uplink Receiver:* This is also very similar to the OFDMA uplink receiver, the difference being for each user's M_k subcarriers an additional small IFFT is applied to bring them back to the time domain.

OFDMA Advantages

- Low Complexity
- Dynamic, flexible and efficient bandwidth allocation is possible
- Lower data rates and bursty data are handled more efficiently
- Time-frequency resource allocation can be adapted dynamically to meet arbitrary throughput, delay and possibly other QoS constraints.

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Multiple Antenna Transmission and Reception [Module 2 - Part 3]

Multiple antennas techniques can be grouped into roughly three different categories: *(I) Diversity, (II) Interference suppression, and (III) Spatial multiplexing.* All these three different techniques are often collectively referred to as multiple input-multiple output (MIMO) communication.

(I) SPATIAL DIVERSITY

- Spatial Diversity is exploited through two or more antennas, which are separated by enough distance so that fading is approximately decorrelated between them.
- The cost and space of additional antenna is negligible if the gains are significant enough to warrant the space expense

a) Array Gain

- Array gain achieves performance enhancement by coherently combining the energy of each of the antennas to gain advantage against the noise in each antenna which is uncorrelated.
- Due to array gain, even if the channels are completely correlated the received SNR increases linearly with the number of receive antennas, N_r

For a $N_t \times N_r$ system, the array gain is N_r, which can be seen for a $1 \times N_r$ as follows. In correlated flat fading, each antenna $i \in (1, N_r)$ receives a signal that can be characterized as:

$$y_i = h_i x + n_i = hx + n_i, \tag{5.1}$$

where $h_i = h$ for all the antennas since they are perfectly correlated. Hence, the SNR on a single antenna is

$$\gamma_i = \frac{|h|^2}{\sigma^2}, \tag{5.2}$$

where the noise power is σ^2 and we assume unit signal energy ($\mathcal{E}_x = E|x|^2 = 1$). If all the receive antenna paths are added, the resulting signal is

$$y = \sum_{i=1}^{N_r} y_i = N_r hx + \sum_{i=1}^{N_r} n_i, \tag{5.3}$$

and the combined SNR, assuming that just the noise on each branch is uncorrelated, is

$$\gamma_\Sigma = \frac{|N_r h|^2}{N_r \sigma^2} = \frac{N_r |h|^2}{\sigma^2}. \tag{5.4}$$

Hence, the received SNR also increases linearly with the number of receive antennas even if those antennas are correlated. However, because the channels are all correlated in this case (in fact, identical), there is no diversity gain.

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b) Diversity Gain

- Diversity Gain results from the creation of multiple independent channels between the transmitter and the receiver.

- In additive noise, the bit error probability(BEP) can be written for any modulation scheme as:

$$P_b \approx c_1 e^{-c_2 \gamma}, \quad \text{----------------(1)}$$

Where, c_1 and c_2 are constants that depend on the modulation type and γ is the received SNR.

- As the error probability is exponentially decreasing with SNR, a modestly high SNR dramatically reduces the BEP.
- In contrast, with fading the SNR becomes a random variable and so the BEP is also a random variable.
  Without diversity, the average BEP decreases very slowly and is given by:

$$\bar{P}_b \approx c_3 \gamma^{-1} \quad \text{----------------(2)}$$

- If N_t transmit antennas and N_r receive antennas that are sufficiently spaced are added to the system, it is said that the *diversity order* is $N_d = N_r N_t$, Since that is the number of uncorrelated channels between the transmitter and the receiver. Since the probability of all the $N_d$uncorrelated channels having low SNR, is very small, the average BEP improves to:

$$\bar{P}_b \approx c_4 \gamma^{-N_d}, \quad \text{----------------(3)}$$

- On the other hand, if only array gain was possible (i.e. the antennas are not sufficiently placed), the average BEP would only decrease from (2) to:

$$\bar{P}_b \approx c_5 (N_d \gamma)^{-1} \quad \text{----------------(4)}$$

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1) RECEIVE DIVERSITY

- The most prevalent form of spatial diversity
- Places no particular requirements on the transmitter, but requires receiver that processes N_r received streams and combines them in some fashion.
- Since no requirements on the transmitter, receive diversity techniques are not specified in the LTE standard, but most certainly used in nearly all LTE handsets and base stations
- The two most widely used combining algorithms to achieve receive diversity are:
  i) Selection Combining (SC)

ii) Maximal Ratio Combining (MRC)

i) Selection Combining

- Selection Combining is the simplest type of combiner: it simply estimates the instantaneous strengths of each of the N_r streams, and selects the highest one.
- Since SC ignores the useful energy on the other streams, it is suboptimal, but its simplicity and reduced hardware and power requirements make it attractive for narrowband channels.
- In a wideband channel, different coherence bands will have different SNRs, hence to use selection diversity, it would require all antennas to be active for at least one band, if all the antennas and RF chains have to be active, it is usually better to use MRC

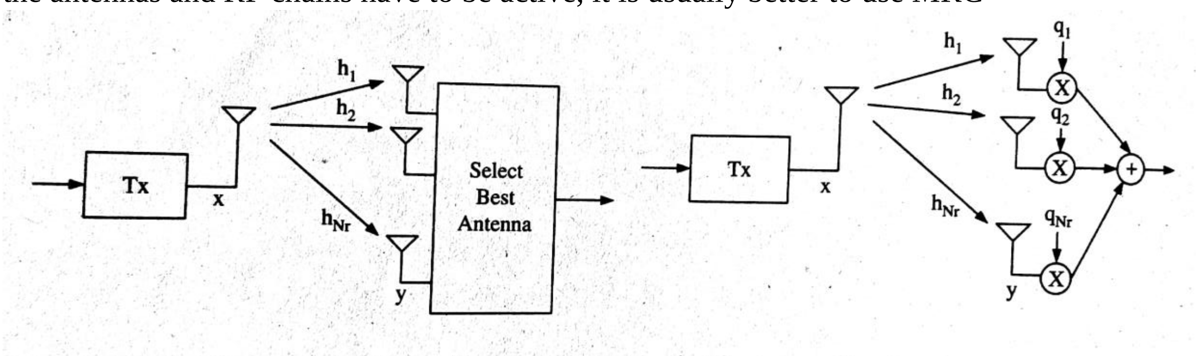

Figure 5.2 Receive diversity: selection combining (left) and maximal ratio combining (right).

ii) Maximal Ratio Combining

- Maximal Ratio Combining (MRC) combines the information from all the received branches in order to maximize the ratio of signal-to-noise power.
- MRC works by weighting each branch with a complex factor $q_i = |q_i|e^{j\emptyset_i}$ and then adding up the N_r branches as shown in figure 5.2
- The received signal on each branch is $x(t)\ h_i$, where $h_i = |h_i|e^{j\emptyset_i}$ represents the flat fading in the *i*th branch

2) TRANSMIT DIVERSITY

- Signals sent from different transmit antennas interfere with one another at the receiver and additional signal processing is required at both the transmitter and the receiver.

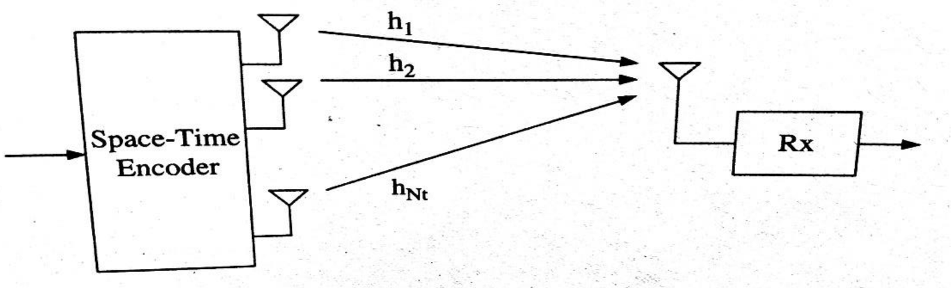

Figure 5.4 Open-loop transmit diversity (no feedback).

- Transmit diversity is particularly useful in the downlink

- Multiple antenna transmit schemes are classified into two classes:
  i) Open Loop: does not require knowledge of the channel at the transmitter
  ii) Closed Loop: require channel knowledge at the transmitter.

i) Open-Loop Transmit Diversity: 2 x 1 Space-Frequency Block Coding

The most popular open-loop transmit diversity scheme is space-time (space-frequency in LTE) coding, where a particular code known to the receiver is applied at the transmitter. The receiver must know only the channel to decode (this is not a large burden as the receiver must know the channel for other decoding operation also).

The simplest space-frequency block code (SFBC) corresponds to two transmit antennas and a single receive antenna. If two symbols s_1 and s_2 are to be transmitted then the *Alamouti code* sends the following over two subcarriers f_1 and f_2:

		Antenna	1	2
Subcarrier	f_1		s_1	s_2
	f_2		$-s_2^*$	s_1^*

The 2x1 Alamouti SFBC is referred to as a rate 1 code, since the data rate is neither increased nor decreased; two symbols are sent over two adjacent subcarriers.

Assuming a flat fading channel on each subcarrier (which efficiently suppresses ISI) and an additional assumption that the channel is constant over the two adjacent subcarriers, the channel can be represented as $h_1(f_1) = h_2(f_2) = h_1$ and the received signal r(f) can be written as:

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$$\begin{aligned} r(f_1) &= h_1 s_1 + h_2 s_2 + n(f_1), \\ r(f_2) &= -h_1 s_2^* + h_2 s_1^* + n(f_2), \end{aligned} \tag{5.18}$$

where $n(\cdot)$ is a sample of white Gaussian noise. The following diversity combining scheme can then be used, assuming the channel is known at the receiver:

$$\begin{aligned} y_1 &= h_1^* r(f_1) + h_2 r^*(f_2), \\ y_2 &= h_2^* r(f_1) - h_1 r^*(f_2). \end{aligned} \tag{5.19}$$

Hence, for example, it can be seen that:

$$\begin{aligned} y_1 &= h_1^*(h_1 s_1 + h_2 s_2 + n(f_1)) + h_2(-h_1^* s_2 + h_2^* s_1 + n^*(f_2)), \\ &= (|h_1|^2 + |h_2|^2) s_1 + h_1^* n(f_1) + h_2 n^*(f_2), \end{aligned} \tag{5.20}$$

and proceeding similarly that:

$$y_2 = (|h_1|^2 + |h_2|^2) s_2 + h_2^* n(f_1) - h_1 n^*(f_2). \tag{5.21}$$

Hence, this very simple decoder that just linearly combines the two received samples $r(f_1)$ and $r^*(f_2)$ is able to eliminate all the spatial interference. The resulting SNR can be computed as:

$$\begin{aligned} \gamma_\Sigma &= \frac{(|h_1|^2 + |h_2|^2)^2}{|h_1|^2\sigma^2 + |h_2|^2\sigma^2} \frac{\mathcal{E}_x}{2}, \\ &= \frac{(|h_1|^2 + |h_2|^2)}{\sigma^2} \frac{\mathcal{E}_x}{2}, \\ &= \frac{\sum_{i=1}^{2} |h_i|^2}{\sigma^2} \frac{\mathcal{E}_x}{2}. \end{aligned} \tag{5.22}$$

NOTE: Alamouti Code (also called orthogonal space-time block code[OSTBC]) is a simple code named after its inventor. It is a popular means of achieving transmit diversity, due to its ease of implementation

ii) Open-Loop Transmit Diversity with More Antennas

a) 2x2 SFBC

The 2x2 SFBC uses the same transmit encoding scheme as for 2x1 transmit diversity. The channel description (still flat fading and constant over two symbols) can be represented as a 2x2 matrix rather than a 2x1 vector.

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}.$$

The resulting signals at subcarriers f_1 and f_2 on antennas 1 and 2 can be represented as:

$$\begin{aligned} r_1(f_1) &= h_{11} s_1 + h_{21} s_2 + n_1(f_1), \\ r_1(f_2) &= -h_{11} s_2^* + h_{21} s_1^* + n_1(f_2), \\ r_2(f_1) &= h_{12} s_1 + h_{22} s_2 + n_2(f_1), \\ r_2(f_2) &= -h_{12} s_2^* + h_{22} s_1^* + n_2(f_2). \end{aligned} \tag{5.23}$$

b) 4x2 Stacked STBCs

Two data streams can be sent using a double space-time transmit diversity (DSTTD) scheme, which consists of two 2x1 Alamouti code systems in parallel.

DSTTD also called “stacked STBCs” combines transmit diversity and maximal ratio combining techniques along with a form of spatial multiplexing as shown in fig 5.5

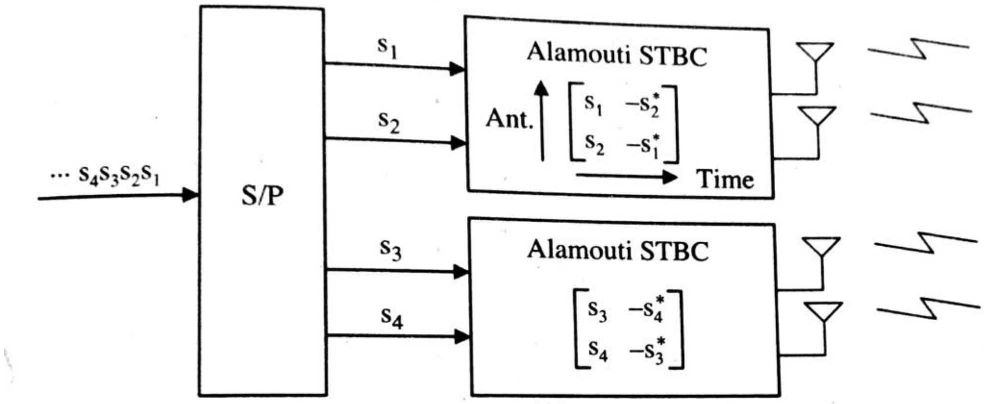

Figure 5.5 4 × 2 stacked STBC transmitter.

The time dimension can be used interchangeably with frequency to create stacked SFBCs

$$\begin{bmatrix} r_1(f_1) \\ r_1^*(f_2) \\ \hline r_2(f_1) \\ r_2^*(f_2) \end{bmatrix} = \left[\begin{array}{cc|cc} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{12}^* & -h_{11}^* & h_{14}^* & -h_{13}^* \\ \hline h_{21} & h_{22} & h_{23} & h_{24} \\ h_{22}^* & -h_{21}^* & h_{24}^* & -h_{23}^* \end{array}\right] \begin{bmatrix} s_1 \\ s_2 \\ \hline s_3 \\ s_4 \end{bmatrix} + \begin{bmatrix} n_1(f_1) \\ n_1^*(f_2) \\ \hline n_2(f_1) \\ n_2^*(f_2) \end{bmatrix}.$$

Then, the equivalent matrix channel model of DSTTD can be represented as:

$$\begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{H}_{11} & \mathbf{H}_{12} \\ \mathbf{H}_{21} & \mathbf{H}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{s}_1 \\ \mathbf{s}_2 \end{bmatrix} + \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \end{bmatrix}.$$

c) 4x2 in LTE

This is a combination of SFBC and frequency switched transmit diversity (FSTD). This is a rate1 diversity scheme, i.e., four modulation symbols are sent over four OFDM symbols using the following space-frequency encoder, where columns represent the subcarrier index and the rows represent the transmit antenna.

$$\frac{1}{\sqrt{2}} \begin{bmatrix} s_1 & s_2 & 0 & 0 \\ 0 & 0 & s_3 & s_4 \\ -s_2^* & s_1^* & 0 & 0 \\ 0 & 0 & -s_4^* & s_3^* \end{bmatrix}$$

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iii) Transmit Diversity vs Receive Diversity

The manner in which improvement is achieved is different for transmit and receive diversity

iv) Closed Loop Transmit Diversity

If feedback is added to the system then the transmitter will have knowledge of the channel between it and the receiver. There is substantial gain in many cases from possessing channel state information (CSI) at the transmitter

The basic configuration for closed-loop transmit diversity is shown in fig 5.7

a) Transmit Selection Diversity

It is the simplest form of transmit diversity, only a subset $N^* < N_t$ of the total N_t antennas are used at a given time. The selected subset typically corresponds to the best channels between the transmitter and the receiver.

Some advantages are: (1) hardware cost and complexity are reduced
(2) spatial interference is reduced as fewer transmit signals are sent
(3) Diversity order is still $N_r N_t$ even though N^* $of\ the\ N_t$ antennas are used

The main drawback of antenna selection is that wideband channels have multiple coherence bands so the gain from selecting the best antenna is likely to be small.

b) Linear Diversity Precoding

-Linear Precoding is a general technique for improving the data rate or link reliability by exploiting the CSI at the transmitter.

-Linear Precoder at the transmitter and a linear Post coder at the receiver are applied only to improve the link reliability.

-The received data vector z can be written as $\mathbf{z} = \mathbf{G}\mathbf{y} = \mathbf{G}(\mathbf{H}\mathbf{F}\mathbf{x} + \mathbf{n})$.

-The size of the transmitted vector x is M x 1 and the received vector y is Nr x 1.

-The post coder matrix G is M x Nr, the channel matrix H is Nr x Nt, the pre coder matrix F is Nt x M, the noise vector n is Nr x 1 and received data vector z is M x 1.

-M is the number of spatial data “streams” sent in general case.

-For case of pure diversity pre coding only one data symbol is sent at a time where M=1 and the SNR maximizing pre coder F and post coder G are the right and left singular vectors of H corresponding to its largest singular value $\sigma_{\max}$.

-The equivalent channel model after pre coding and post coding for a transmitted data symbol x becomes y = hx + n.

-The received SNR is $\gamma = \frac{\mathcal{E}_x}{\sigma^2}\sigma^2_{\max}$ where is σ^2 the noise variance.

-SNR is bounded as $\frac{\|\mathbf{H}\|^2_{\mathbf{F}}}{N_t} \cdot \frac{\mathcal{E}_x}{\sigma^2} \leq \gamma \leq \|\mathbf{H}\|^2_{\mathbf{F}} \cdot \frac{\mathcal{E}_\mathbf{x}}{\sigma^2}$.

$\|\cdot\|_{\mathbf{F}}$ denotes the Frobenius norm which is just the total sum of all the powers of each spatial channel defined as $\|\mathbf{H}\|_{\mathbf{F}} = \sqrt{\sum_{i=1}^{N_t}\sum_{j=1}^{N_r} h_{ij}^2}$.

-SNR for the case of STBC is given as $\gamma_{\mathrm{STBC}} = \frac{\|\mathbf{H}\|^2_{\mathbf{F}}\mathcal{E}_\mathbf{x}}{N_t\sigma^2}$.

-To employ linear diversity pre coding, CSI is required at the transmitter.

(II) INTERFERENCE SUPPRESSION

DOA based Beam steering

-Electromagnetic waves can be physically steered to create beam patterns at either transmitter or receiver.

-At the transmitter, this causes energy to be sent predominantly in a desired direction while only a small amount of residual energy is leaked in other directions.

-The most common and simple form is static pattern gain beam steering which is known as **sectoring**.

-Each DOA can be estimated using signal processing techniques such as MUSIC, ESPRIT and MLE algorithms.

-From the acquired Direction of Arrival (DOA), a beam former extracts a weighting vector for the antenna elements and uses it to transmit or receive the desired signal of a specific user while suppressing the undesired interference signals.

-When the plane wave arrives at the d-spaced Uniform Linear Array (ULA) with Angle of Arrival (AOA) θ, the wave at the first antenna element travels an additional distance of dsinθ to arrive at the second element.

-The difference in propagation distance between the adjacent antenna elements can be formulated as an arrival time delay τ = d/c sinθ.

-The signal arriving at the second antenna can be expressed in terms of the signal at the first antenna element as

$$\begin{aligned} y_2(t) &= y_1(t)\exp(-j2\pi f_c \tau) \\ &= y_1(t)\exp(-j2\pi \frac{d\sin\theta}{\lambda}) \end{aligned}$$

-For an antenna element with Nr elements all spaced by d, the resulting received signal vector can be expressed as

$$\begin{aligned} \mathbf{y}(t) &= [y_1(t)\ y_2(t)\ \ \ldots\ \ y_{N_r}(t)]^T \\ &= y_1(t)\underbrace{[1\ \ \exp(-j2\pi\frac{d\sin\theta}{\lambda})\ \ \ldots\ \ \exp(-j2\pi(N_r-1)\frac{d\sin\theta}{\lambda})]^T}_{\mathbf{a}(\theta)} \end{aligned}$$

where a(θ) is the array response vector.

-Considering a 3 element ULA with d=λ/2 spacing between the antenna elements and assuming that the desired user's signal is received with an AOA of θ1=0 and 2 interfering signals are received with AOAs of θ2=π/3 and θ3=-π/6, the array response vectors are given by

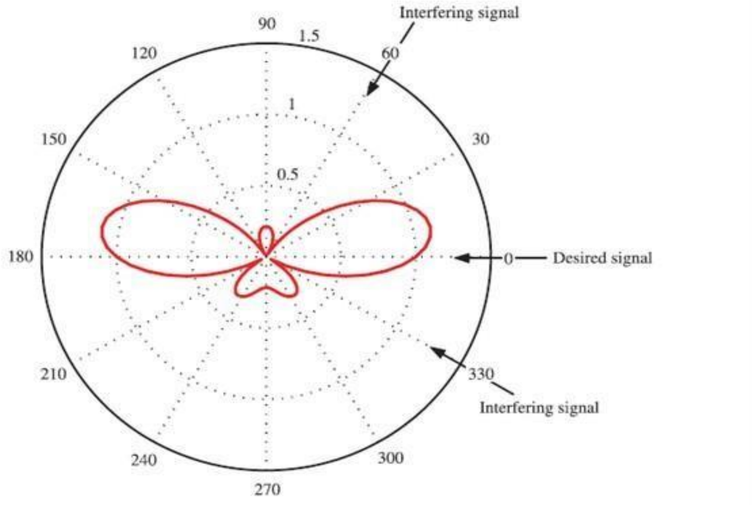
$$\begin{aligned} \mathbf{a}(\theta_1) &= [1\ \ 1\ \ 1]^T \\ \mathbf{a}(\theta_2) &= \left[1\ \ e^{-j\frac{\sqrt{3}}{2}\pi}\ \ e^{-j\sqrt{3}\pi}\right]^T \\ \mathbf{a}(\theta_3) &= \left[1\ \ e^{j\frac{\pi}{2}}\ \ e^{j\pi}\right]^T \end{aligned}$$

-The beam forming weight vector $\mathbf{w} = [w_1\ w_2\ w_3]^T$ should increase the antenna gain in the direction of desired user while simultaneously minimizing the gain in the directions of interferers.

-The weight vector should satisfy the criterion $\mathbf{w}^* \left[\mathbf{a}(\theta_1) \;\; \mathbf{a}(\theta_2) \;\; \mathbf{a}(\theta_3)\right] = [1 \;\; 0 \;\; 0]^T$.

-A unique solution for the weight vector is obtained as

$$\mathbf{w} = [0.3034 + j0.1966 \;\; 0.3932 \;\; 0.3034 - j0.1966]^T$$



Null-steering beam pattern for the DOA-based beamforming using three-element ULA with $\lambda/2$ spacing at transmit antennas. The AOAs of the desired user and two interferers are 0, $\pi/3$, and $-\pi/6$, respectively

-The null steering beam former (DOA based beam former) can be designed to completely null out interfering signals only if the number of such signals is strictly less than the number of antenna elements i.e. if the number of receive antennas is Nr, then Nr-1 independent interferers can be cancelled.

-The disadvantage of DOA based beam former is that a null is placed in the direction of the interferers and so the antenna gain is not maximized at the direction of the desired user.

Linear Interference Suppression

1) By complete knowledge of Interference Channels

- Considering a single transmitter with Nt antennas trying to communicate to a receiver with Nr >Nt antennas in the presence of one or more L_I interfering transmitters each with $N_{t,i}$ antennas, the total number of interfering sources is $L = \sum_{i=1}^{L_I} N_{t,i}$.
- With L = 1, Nt = 1 and Nr = 2, we have a total of 2 transmitted streams to a 2 antenna receiver.

- The received signal model is y = Hx + n.
- Assuming the receiver knows not only its channel vector but the interfering channel as well, a ZF receiver $\mathbf{G} = \mathbf{H}^{-1}$ would produce $\mathbf{z} = \mathbf{x} + \mathbf{H}^{-1}\mathbf{n}$.
- If the transmitters are independent rather than co-located, it is known as uplink multiuser MIMO or uplink SDMA since 2 users are supported simultaneously.

2)By statistical knowledge of Interference Channels

- Allowing the transmitter to pre code its signal with a Ntx1 beam forming vector $\mathbf{w}_t$, the Nr dimensional received signal vector at the receiver is $\mathbf{y} = \mathbf{H}\mathbf{w}_t x + \mathbf{H}_I \mathbf{x}_I + \mathbf{n}$ where x is the desired symbol with energy $\mathcal{E}_x$

  $\mathbf{x}_I = [x_1 \; x_2 \; \cdots \; x_L]^T$ is the interference vector

  n is the noise vector with covariance matrix $\sigma^2 \mathbf{I}$

  H is Nr x Nt channel gain matrix for the desired user

  $\mathbf{H}_I$ is the Nr x L channel gain matrix for the interferers

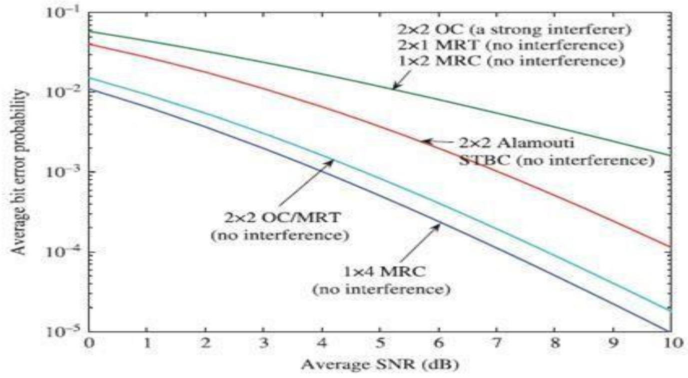
  $\mathbf{w}_t$ is the eigen vector corresponding to the largest eigen value $\lambda_{\max}(\mathbf{H}^*\mathbf{R}^{-1}\mathbf{H})$ and $\mathbf{w}_r = \alpha \mathbf{R}^{-1}\mathbf{H}\mathbf{w}_t$ where α is an arbitrary constant

  $\mathrm{R} = \sigma^2 \mathrm{I} + \mathbb{E}[\mathrm{H}_I \mathrm{x}_I \mathrm{x}_I^* \mathrm{H}_I^*]$ is the interference plus noise covariance matrix

  $\lambda_{\max}(\mathbf{A})$ is the largest eigen value of A.
- The maximum output SINR is $\gamma = \mathcal{E}_x \lambda_{\max}(\mathbf{H}^*\mathbf{R}^{-1}\mathbf{H})$.
- The transmit power is focused on the largest eigen channel among the $\min(N_t, N_r)$ eigen channels in order to maximize post beam forming SINR and this beam forming approach is termed as Optimum eigen beam former, interference aware beam forming and/or Optimum Combiner (OC).
- If the interference terms are ignored, $\mathrm{R} \to \sigma^2 \mathrm{I}$ and $\mathrm{w}_r \to \mathrm{G}$ and $\mathrm{w}_t \to \mathbf{F}$.
- In the absence of interference, the output SNR of optimum beam former with Nt> 1 can be upper and lower bounded as

$$\gamma^{STBC}_{N_t \times N_r} = \frac{\mathcal{E}_x}{N_t \sigma^2} ||\mathbf{H}||^2_{\mathbf{F}} < \gamma^{MRT}_{N_t \times N_r} = \frac{\mathcal{E}_x}{\sigma^2} \lambda_{\max}\left(\mathbf{H}^H \mathbf{H}\right) \leq \frac{\mathcal{E}_x}{\sigma^2} ||\mathbf{H}||^2_{\mathbf{F}} = \gamma^{MRC}_{1 \times N_t N_r}$$

- To increase the system capacity using the acquired transmits CSI, up to $\mathrm{rank}(\mathrm{H}) = \min(N_t, N_r)$ eigen channels can be used for transmitting multiple data streams.



Performance comparison between optimal combining/beamforming and diversity approaches. MRT and MRC have the same performance for the same number of antennas

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(III) SPATIAL MULTIPLEXING

Spatial Multiplexing refers to breaking the incoming high rate data streams into M parallel data streams as shown in fig 5.11, for $M = N_t$ and $N_t \leq N_r$. This increases the spectral efficiency by a factor of M the streams are successfully decoded. This implies that, this can increase the data rate without increasing the bandwidth.

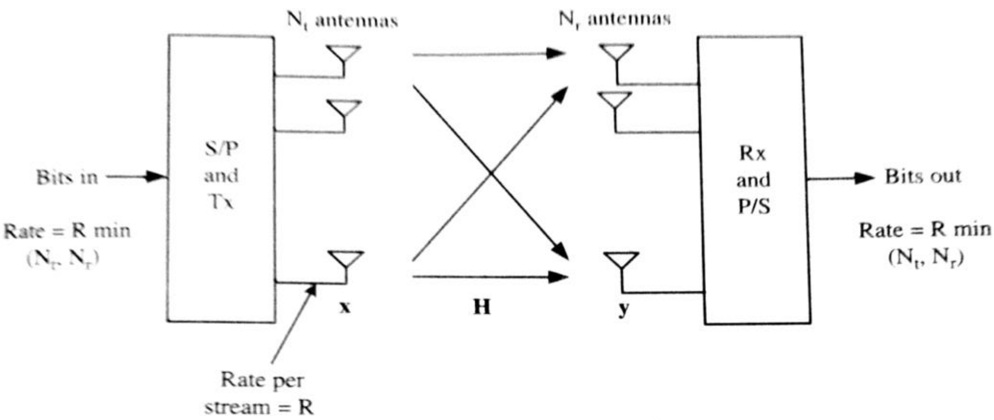

Figure 5.11 A spatial multiplexing MIMO system transmits multiple substreams to increase the data rate.

Introduction to Spatial Multiplexing

The standard mathematical model used for spatial multiplexing is very similar to that used for linear precoding and interference suppression,

$$y = Hx + n$$

where, y = the received signal (vector of size 1 x N_r)

x = the transmitted signal (vector of size 1 x N_t)

n = additive noise

H = is the channel response which is given by the matrix of size N_r x N_t

$$\mathrm{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_t} \\ h_{21} & h_{22} & \cdots & h_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r1} & h_{N_r2} & \cdots & h_{N_rN_t} \end{bmatrix},$$

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It is assumed that spatial channels all experience uncorrelated Rayleigh fading and Gaussian noise. This model enables rich framework for mathematical analysis for MIMO systems based on random matrix theory.

Open-Loop MIMO: Spatial Multiplexing Without Channel Feedback

Similar to diversity techniques, spatial multiplexing can also be performed with or without channel knowledge. The open-loop techniques for spatial multiplexing attempt to suppress the interference that results from all $N_t$streams received by each N_r antenna. These techniques are:

i) Optimum Decoding: Maximum Likelihood Detection
ii) Linear Detectors
iii) BLAST

i) Optimum Decoding: Maximum Likelihood Detection
This method estimates the most likely input vector $\hat{x}$ via a minimum distance criterion:

$$\hat{x} \;=\; \arg\min ||\mathrm{y} - \mathrm{H}\hat{x}||^2$$

An exhaustive search must be made over all M^{N_t} possible input vectors. The computational complexity is very large even with a small number of antennas.
Lower complexity ML detectors such as sphere decoder have some potential for high-performance

ii) Linear Detectors
Linear detectors such as the zero-forcing detector is used to recover the transmitted vector x. It sets receiver equal to the inverse of the channel $G_{zf} = H^{-1}$when $N_t = N_r$ or its pseudoinverse:

$$\mathbf{G}_{zf} = (\mathbf{H}^*\mathbf{H})^{-1}\mathbf{H}^*. \tag{5.59}$$

As the name implies, the zero-forcing detector completely removes the spatial interference from the transmitted signal, giving an estimated received vector:

$$\hat{\mathbf{x}} = \mathbf{G}_{zf}\mathbf{y} = \mathbf{G}_{zf}\mathbf{H}\mathbf{x} + \mathbf{G}_{zf}\mathbf{n} = \mathbf{x} + (\mathbf{H}^*\mathbf{H})^{-1}\mathbf{H}^*\mathbf{n}. \tag{5.60}$$

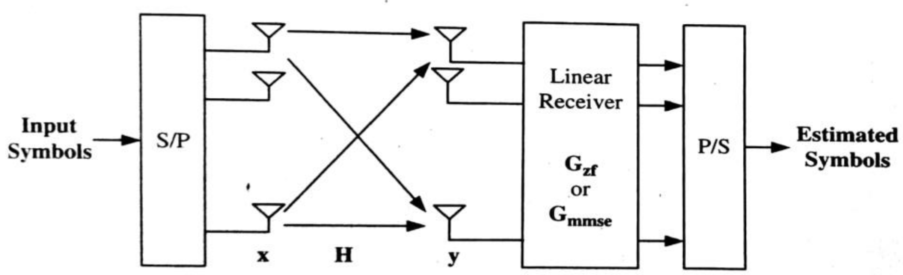

Figure 5.13 Spatial multiplexing with a linear receiver.

Because the G_{zf} inverts the eigen values of H, it can severely amplify the noise in n and hence is not a practical option in LTE.

A logical alternative is the MMSE receiver, which simply minimizes the distortion and hence strikes a balance between spatial interference suppression and noise enhancement.

$$\mathbf{G}_{mmse} = \arg\min_{\mathbf{G}} \mathrm{E}||\mathbf{Gy} - \mathbf{x}||^2, \tag{5.61}$$

which can be derived using the well-known orthogonality principle as:

$$\mathbf{G}_{mmse} = \left(\mathbf{H}^*\mathbf{H} + \frac{\sigma_z^2}{P_t}\mathbf{I}\right)^{-1}\mathbf{H}^*, \tag{5.62}$$

where P_t is the transmitted power. In other words, as the SNR grows large, the MMSE detector converges to the ZF detector, but at low SNR it prevents the worst eigenvalues from being inverted.

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iii) BLAST

The earliest spatial multiplexing receiver was invented and prototyped by Bell Labs and is called *Bell labs LAyered Space-Time (BLAST).* BLAST consists of parallel “layers” supporting multiple simultaneous data streams. The layers (substreams) are separated by interference cancellation techniques that decouple the overlapping data streams. The two most important techniques are the original *diagonal BLAST*(D-BLAST) and its later version *vertical BLAST* (V-BLAST)

(a) D-BLAST:

Structure: It groups the transmitted symbols into “layers”, which are coded in time independently of other layers. These layers are then sent to the different transmit antennas in a cylindrical manner, resulting in each layer being transmitted in a *diagonal* of space and time.
Each symbol achieves diversity in time via coding and in space as it rotates among all different antennas.
Technique(working): This layered D-BLAST structure is detected by decoding one layer at a time.
Each layer is detected by nulling the layers that have not yet been detected, and cancelling the layers that have already been detected. In fig 5.14 layer-1 is already detected and hence it is cancelled (subtracted) from the received signal and the layers to the right are nulled by using knowledge of the channel.
Drawback: the decoding process is iterative and complex, and the diagonal layering structure wastes space-time slots at the beginning and end of a D-BLAST block.

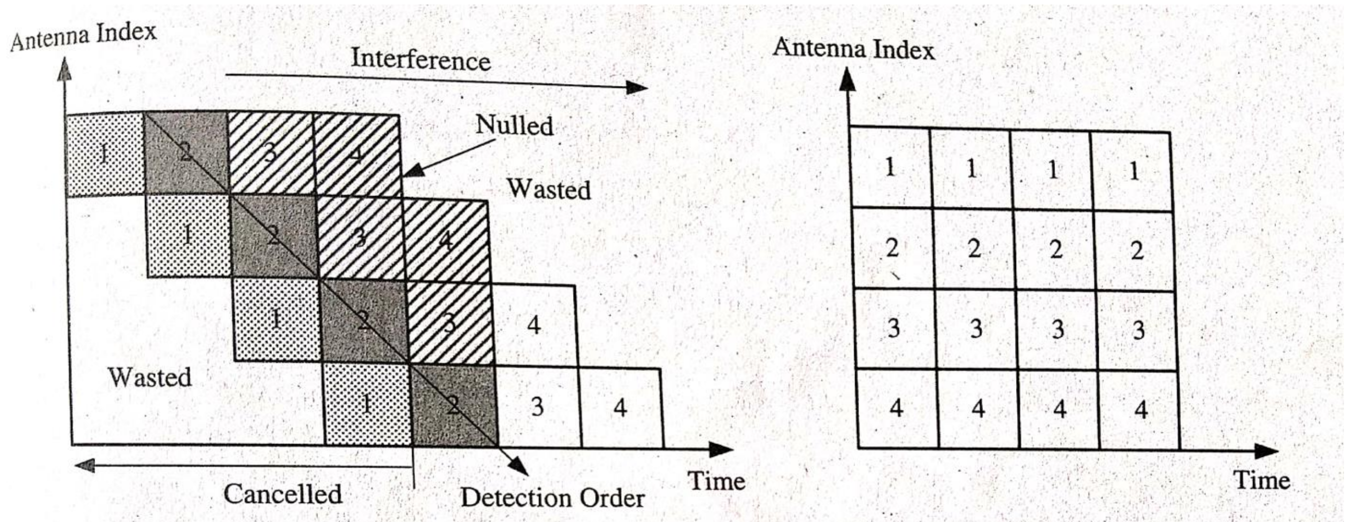

Figure 5.14 (Left) D-BLAST detection of layer 2 of 4. (Right) V-BLAST encoding. Detection is done dynamically; the layer (symbol stream) with the highest SNR is detected first and then cancelled.

(b) V-BLAST:

Simpler than D-BLAST, here each antenna simply transmits an independent symbol stream(for example QAM symbols). A variety of techniques can be used at the receiver such as ZF and MMSE to separate the various symbol streams from each other.

The post detection SNR for the *i*th stream is

$$\gamma_i = \frac{\mathcal{E}_x}{\sigma^2 ||\mathbf{w}_{r,i}||^2} \quad i = 1, \cdots, N_t,$$

Where $w_{r,i}$ is the ith row of the zero-forcing(ZF) or MMSE receiver G

The essence of V-BLAST is to combine a linear receiver with ordered successive interference cancellation. Instead of detecting all N_t streams in parallel, the strongest symbol stream is detected and subtracted from the composite received signal. Then the second strongest signal is detected and so on. Hence the *i*th detected stream experiences interference from only $N_t - i$ of the total transmitted streams.

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2) Closed Loop MIMO

i) Singular Value Decomposition (SVD) Pre coding and Post coding

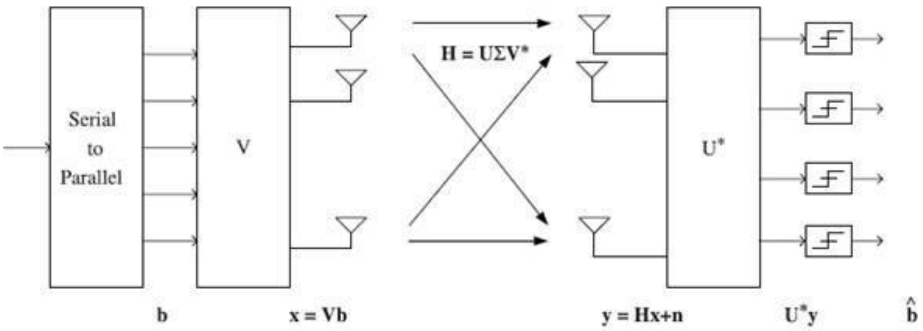
- Generalized eigen value decomposition of the channel matrix H is $\mathbf{H} = \mathbf{U}\Sigma\mathbf{V}^*$

where U and V are unitary and Σ is a diagonal matrix of singular values.

- The decision vector d should be close to input symbol vector b and can be written
- systematically as $\mathbf{d} = \mathbf{U}^*\mathbf{y}$

$$\begin{aligned} &= \mathbf{U}^*(\mathbf{Hx} + \mathbf{n}) \\ &= \mathbf{U}^*(\mathbf{U}\Sigma\mathbf{V}^*\mathbf{V}\mathbf{b} + \mathbf{n}) \\ &= \mathbf{U}^*\mathbf{U}\Sigma\mathbf{V}^*\mathbf{V}\mathbf{b} + \mathbf{U}^*\mathbf{n} \\ &= \Sigma\,\mathbf{b} + \mathbf{U}^*\mathbf{n} \end{aligned}$$

- $\mathbf{U}^*\mathbf{n}$ has the same variance as n.
- The singular value approach does not result in noise enhancement.
- The complexity of finding the SVD of an Nt x Nr matrix is on the order of $O(N_r N_t^2)$ if $N_r \geq N_t$.



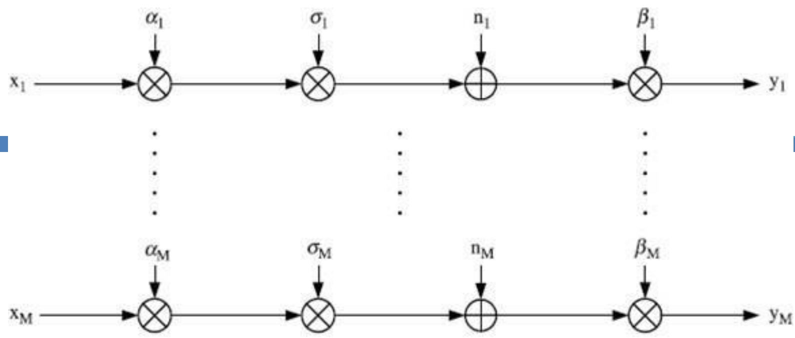
A MIMO system that has been diagonalized through SVD precoding

ii) Linear Pre coding and Post coding

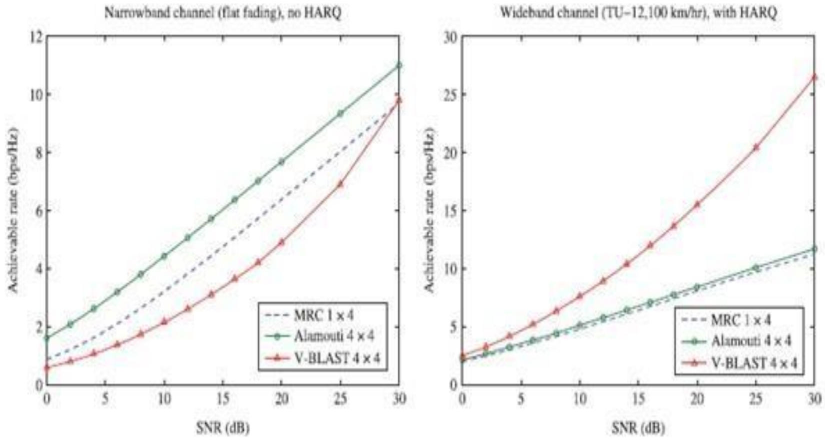
- The received symbol for the ith sub channel can be expressed as

$$y_i = \alpha_i \sigma_i \beta_i x_i + \beta_i n_i, \qquad i = 1, \ldots, M$$

- σ_i are the singular values of H, α_i and β_i are the pre coder and post coder weights and n_i is the noise per subchannel.
- The number of sub channels is bounded by $1 \leq M \leq \min(N_t, N_r)$



Spatial subchannels resulting from linear precoding and postcoding



The Diversity-Multiplexing Tradeoff, for a narrowband system with no other forms of diversity (left) and for a wideband system with ARQ (right)

Module 3

Overview and Channel Structure of LTE - Part 1

The LTE radio interface aims for a long-term evolution hence it is designed with a clean slate approach unlike the High-Speed Packet Access (HSPA), which was designed as an add-on to UMTS.

This part of the module describes,
i) an overview of the LTE standard including design principles, the network architecture, and radio interface protocols;
ii) the hierarchical channel structure and the purpose of each channel type, the mapping between channels at various protocol layers;
iii) the downlink OFDMA and the uplink SC-FDMA including frame structures, physical resource blocks, resource allocation and the supported MIMO modes.

Introduction to LTE

LTE was designed primarily for high-speed data services; hence it is a packet switched network from end-to-end and has no support for circuit-switched services, but it can emulate a circuit switched network on top of the packet-switched framework.

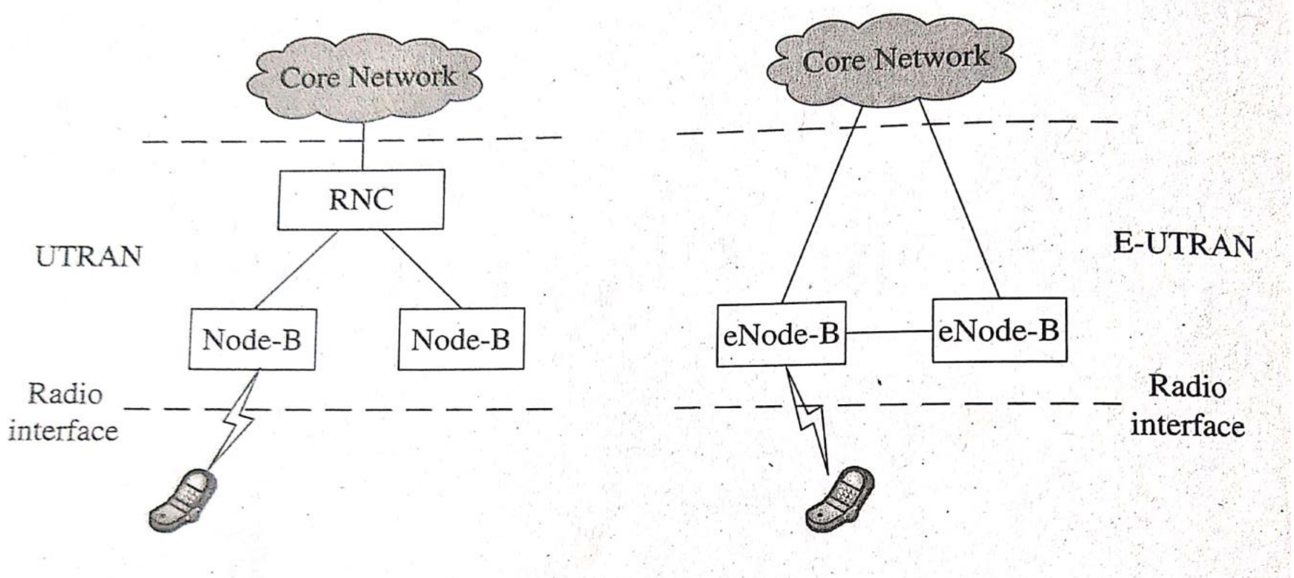


Figure 6.1 Radio interface architectures of UTRAN and E-UTRAN.

Design Principles

The LTE standard was designed as a completely new standard, with new numbering and documentation.

Earlier elements were brought in only if there was a compelling reason for them to exist in the new standard. The basic design principles followed in 3GPP to design LTE include:

1. **Network Architecture**

   - Supports packet switching for high data rate services from the start, unlike previous generations of networks such as UMTS/HSPA where packet switched traffic was achieved through subsequent add-ons; for example: HSPA was built on top of the release 99 UMTS network, hence it carried unnecessary burdens of a circuit -switched network

   - The LTE radio access network E-UTRAN was designed to have minimum number of network elements and still provide efficient packet switched transport.

2. **Data Rate and Latency**

   - The target downlink and uplink peak data rates for LTE are 100Mbps and 50 Mbps respectively, when operating at 20MHz frequency division duplex (FDD) channel size.

   - The user plane latency: is defined as the time it takes to transmit a small IP packet from the UE (User Equipment or mobile terminal) to the edge node. The target for one-way latency in the user plane is 5ms in an unloaded network (only a single UE is present in the cell)

   - The control plane latency: the target transition time from camped state to active state is less than 100ms and the target transition time between dormant state and active state is less than 50ms

3. **Performance Requirements**

   The target performance requirements are:

   - Spectrum efficiency: the downlink data rate and spectrum efficiency target is 3 to 4 times that of HSDPA network. Similarly, the uplink target is 2 to 3 times that of HSUPA.

   - Mobility: Support handoff/mobility at different terminal speeds. Maximum performance at lower terminal speeds of 0 to 15 km/hr, minor degradations up to 120 km/hr. Sustain a connection for terminal speeds up to 350 km/hr with significant degradations.

   - Coverage: the above performance targets should be met up to 5 km. For cell ranges up to 30 km, a slight degradation of the user throughput & spectrum efficiency is tolerated but mobility requirements should be met. Cell ranges up to 100km should be allowed by the specifications.

   - MBMS Service: LTE should also provide enhanced support for the multimedia Broadcast and Multicast Service (MBMS) compared to UTRA operation

4. **Radio Resource Management**

   - Enhanced support for end-to-end QoS, efficient support for transmission of higher layers, and support for load sharing and policy management across different radio access technologies.

5. **Deployment Scenario and co-existence with 3G**
   LTE supports the following two deployment scenarios:-
   - Standalone deployment scenario: LTE is deployed with no previous network deployed in the area, no interworking requirement with existing UTRAN/GERAN (GSM EDGE radio access network)
   - Interworking with existing UTRAN/ GERAN networks: where the operator already has either a UTRAN /GERAN network deployed in the same geographical area.
6. **Flexibility of Spectrum and Deployment**
   - Service providers in different geographical regions often have different spectrums in terms of the carrier frequency and the total available bandwidth from 1.4 MHz to 20 MHz
   - To accommodate flexible duplexing options, LTE was designed to operate in both frequency division duplex (FDD) and time division duplex (TDD) modes
7. **Interoperability with 3G and 2G Networks**
   - LTE terminals should be able to support measurement of, and handover from and to, both 3GPP UTRAN and 3GPP GERAN systems with acceptable terminal complexity and network performance.

Network Architecture

The LTE network architecture is composed two newly defined components of the Release 8 network of the 3GPP specifications:
I)The radio access network (E-UTRAN)
II) The core network (EPC)
Unlike the UMTS which defined a new radio access network but used the same core network as the previous generation.

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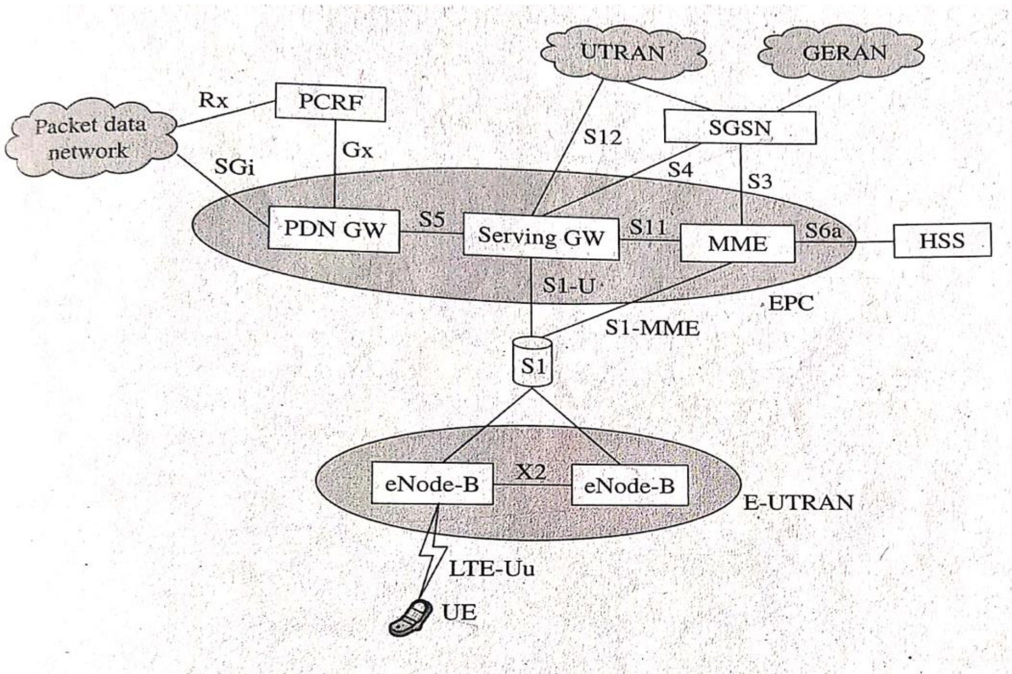

Figure 6.2 LTE end-to-end network architecture.

The main components of the E-UTRAN and EPC are

1) **UE**
   - The mobile terminal (user equipment)

2) **eNode-B**
   -also called as the base station, it terminates the air interface protocol, and is the first point of contact for the UE.
   - The eNode-B is the only logical node in the E-UTRAN, so it includes some functions in RNC of the UTRAN, such as uplink and downlink radio resource management and data packet scheduling, and mobility management

3) **Mobility Management Entity(MME)**
   - It manages mobility aspects in 3GPP access such as gateway selection and tracking area list management.

4) **Serving Gateway (Serving GW)**
   - It terminates the interface toward E-UTRAN and routes data packets between E-UTRAN and EPC.
   - It also acts as the local mobility anchor point for inter-eNode-B handovers and inter-3GPP mobility.

- Other responsibilities include lawful intercept, charging, and policy enforcement.
- The Serving GW and MME may be implemented in one physical node or separate physical nodes.

5) **Packet Data Network Gateway (PDN GW)**
   - It routes data packets between the EPC and the external PDN, and is the key node for policy enforcement and charging data collection
   - It also provides the anchor point for mobility with non-3GPP accesses.

6) **S1 Interface**
   - It separates the E-UTRAN and the EPC
   - It is split into two parts: i) the S1-U, which carries traffic data and
   ii) the S1-MME, which is the signaling only interface between the
   ………………. eNode-B and the MME

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7) **X2 Interface**
   - It is the interface between eNode-Bs
   - It consists of two parts: i) X2-C is the control plane interface between eNode-Bs
   ii) X2-U is the user plane interface between eNode-Bs

Radio Interface Protocols

The LTE radio interface is designed based on the layered protocol stack, which can be divided into control plane and user plane protocol stacks as shown in fig 6.3, the packet flow in the user plane is shown in fig 6.4

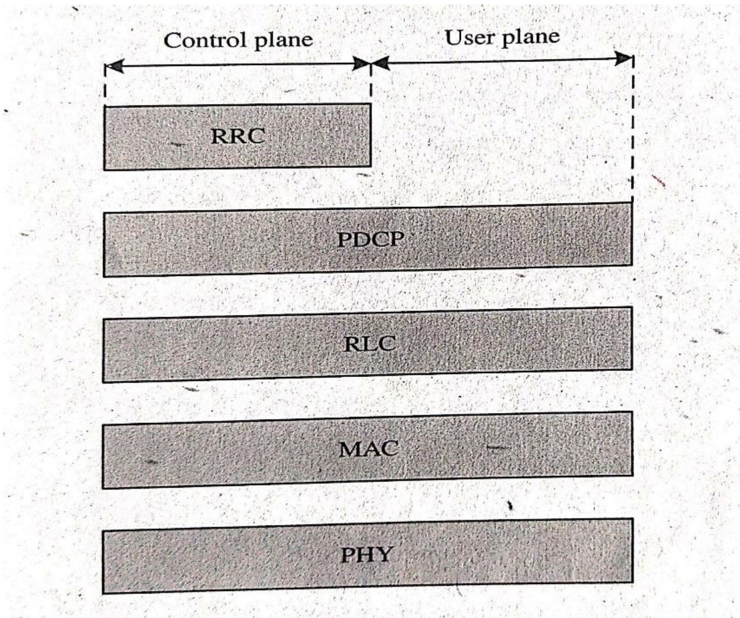

Figure 6.3 The LTE radio interface protocol stack.

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The LTE radio interface protocol is composed of the following layers:

1) **Radio Resource Control (RRC):** performs control plane functions including paging, maintenance, release of an RRC connection, security handling, mobility management, and QoS management
2) **Packet Data Convergence Protocol (PDCP):** the main functions of the PDCP sublayer are
   - IP packet header compression and decompression based on the RObust Header Compression (ROHC) protocol
   - ciphering of data and signaling, and integrity protection for signaling.

3) **Radio Link Control (RLC):** performs segmentation and concatenation of data units, error correction through the Automatic Repeat request (ARQ) protocol and in-sequence delivery of packets to the higher layers. It operates in three modes:
   - *The Transparent Mode (TM):* It is the simplest mode, without RLC header addition, data segmentation, or concatenation and it is used for specific purposes such as random access.

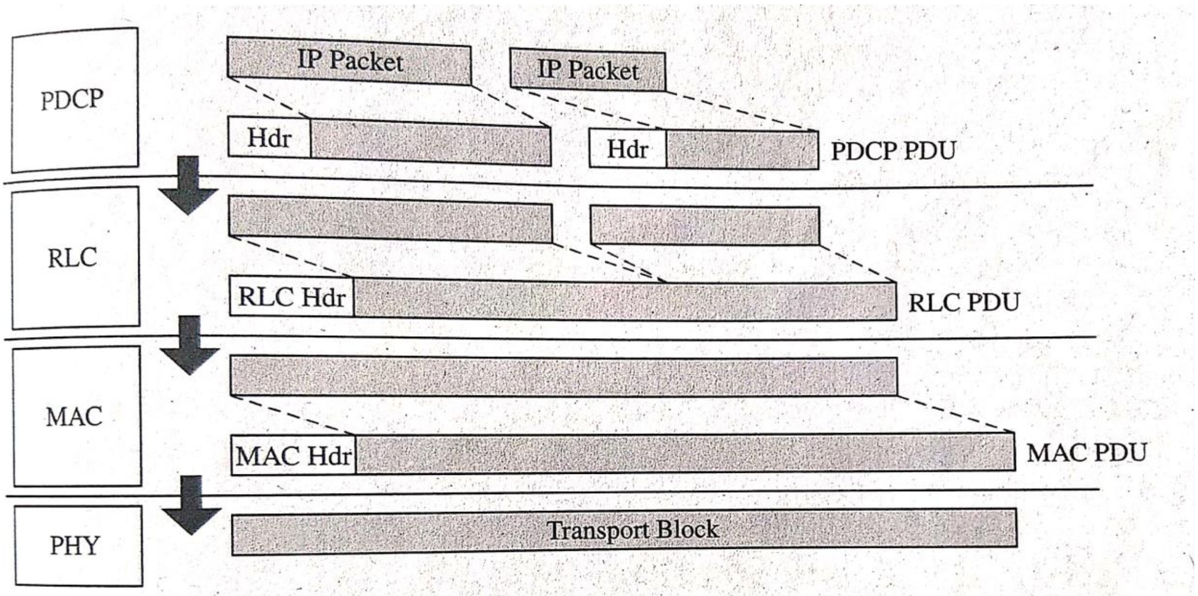

Figure 6.4 The packet flow in the user plane.

- *The Unacknowledged Mode (UM):*This mode allows the detection of packet loss and provides packet reordering and reassembly, but does not require retransmission of missing protocol data units(PDUs).
- *The Acknowledged Mode (AM):*It is the most complex mode and it is configured to request retransmission of the missing PDUs along with the features in the UM mode.

4) **Medium Access Control (MAC):** Its main functions include error correction through the Hybrid-ARQ(H-ARQ) mechanism, mapping between logical channels and transport channels, multiplexing/demultiplexing of RLC PDUs on to transport blocks, priority handling between UEs
-It is also responsible for transport format selection of scheduled UEs such as selection of modulation format, code rate, MIMO rank, and power level.
- There is only one MAC entity at the eNode-B and one MAC entity at the UE

5) **Physical Layer (PHY):** actual transmission and reception of data in forms of transport blocks
- Also responsible for various control mechanisms such as signaling of H-ARQ feedback, signaling of scheduled allocations and channel measurements.

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Hierarchical Channel Structure of LTE

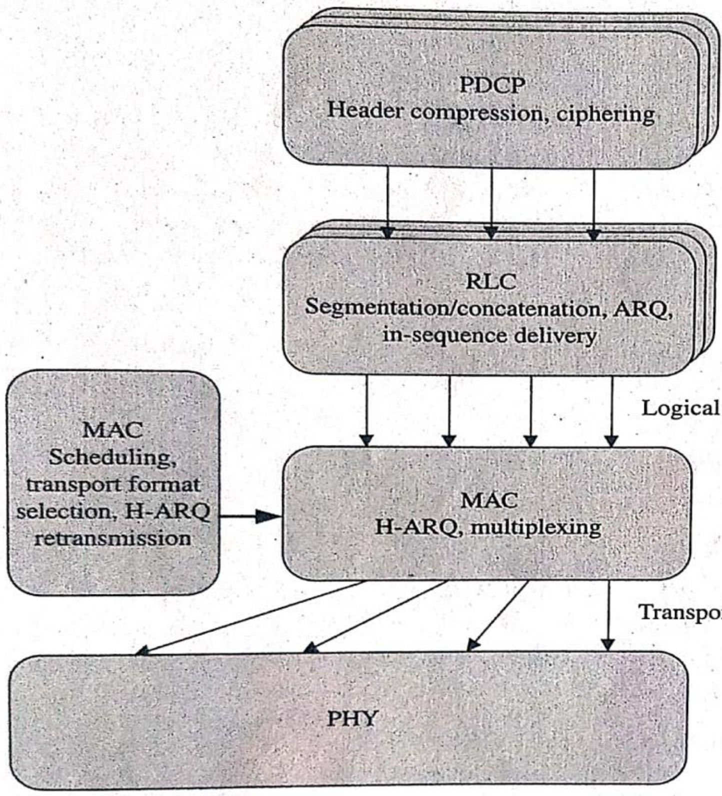

Figure 6.5 The radio interface protocol architecture and the SAPs between different layers.

-LTE adopts a hierarchical channel structure to provide efficient support to QoS (Quality of Services).
-There are three different channel types defined in LTE – logical channels, transport channels, and physical channels, each is associated with a service access point (SAP) between different layers.
-The lower layers of the protocol stack use these channels to provide services to the higher layers.
-Logical channels provide services at the SAP between MAC and RLC layers;
Transport channels provide services at the SAP between MAC and PHY layers;
Physical channels are the actual implementation of transport channels over radio interface.

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1) Logical Channels: What to transmit

- Logical channels are used by the MAC to provide services to the RLC
- Depending in the service they provide there are two categories of logical channels depending on the service they provide: a) logical control channels and b) logical traffic channels

a)Logical Control Channel: used to transfer control plane information, they include the following types:

i) Broadcast Control Channel (BCCH):
- It is a common downlink channel which is used to broadcast the system control information to all the UEs in the Cell
- such as downlink system bandwidth, antenna configuration, and reference signal power
- Due to the large amount of information it is mapped to two different transport channels: the Broadcast Channel (BCH) and the Downlink Shared Channel (DL-SCH)
ii) Multicast Control Channel (MCCH):
- It is a point-to-multipoint downlink channel used for transmitting control information to UEs in the cell
- It is used by UEs that receive multicast/broadcast services
iii) Paging Control Channel (PCCH):
- It is a downlink channel that transfers paging information to registered UEs in the cell. (a paging information includes a system change information)
iv) Common Control Channel (CCCH):
- It is a bidirectional channel for transmitting control information between the network and UEs when no RRC connection is available i.e. when the UE is in idle state or during a random-access procedure
v) Dedicated Control Channel (DCCH):
- It is a point-to-point, bi-directional channel that transmits dedicate control information between the UE and the network
- This is used when the RRC connection is available, i.e. the UE is attached to the network.

b) Logical Traffic Channels: are used to transfer user plane information, they include:

i) Dedicated Traffic Channel (DTCH):
- A point-to-point, bi-directional channel used between a given UE and the network
- exists in both uplink and down link

ii) Multicast Traffic Channel (MTCH):
- A unidirectional, point-to-multipoint data channel that transmits traffic data from the network to UEs
- It is associated with multicast/broadcast service

2) Transport Channels: How to transmit

- Used by the PHY to offer services to the MAC
- how and with what characteristics(coding scheme, modulation scheme, and antenna mapping) data is transferred over the radio interface
- The two MAC entities (one in UE and one in E-UTRAN) handles the following downlink/uplink transport channels

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Downlink Transport Channels

i) Downlink Shared Channel (DL-SCH):

- used for transmitting the downlink data (both control and traffic), hence is associated with both logical control and logical traffic channels

- It supports H-ARQ, dynamic link adaption, dynamic resource allocation, multicast/broadcast transmission

- The shared channel transmission maximizes throughput by allocating the radio resources to the optimum number of UEs

ii)Broadcast Channel (BCH):

- it is a downlink channel associated with the BCCH logical channel and is used to broadcast system information over the entire cell.

iii)Multicast Channel (MCH):

- associated with MCCH and MTCH logical channels

- It supports *Multicast/ Broadcast Single Frequency Network (MBSFN)* transmission, which transmits the same information on the same radio resource from multiple synchronized base stations to multiple UEs

iv)Paging Channel (PCH):

- associated with the PCCH logical channel

- is required for broadcast over the entire cell coverage area

- it is transmitted on the physical downlink Shared Channel (PDSCH), and supports UE discontinuous reception

Uplink Transport Channels

i) Uplink Shared Channel (UL-SCH):

- associated with CCCH, DCCH and DTCH logical channels

- It supports H-ARQ, dynamic link adaption, dynamic resource allocation

ii) Random Access Channel (RACH):

-It is a specific transport channel that is not mapped to any logical channel

-It transmits relatively small amounts of data for initial access or in case of RRC state changes

Transport Block: the data in each transport channel is organized into transport blocks

Transmission Time Interval (TTI): the transmission time of each transport block is called Transmission Time Interval, and it is 1ms in LTE. It is also the minimum time for link adaption and scheduling decision.

Control Information (defined in the MAC layer): These are important for physical layer procedures

i) Downlink Control Information (DCI):

-Carries information related to downlink/uplink scheduling assignment, modulation & coding scheme, and Transmit Power Control (TPC) Command and is sent over the Physical Downlink Control Channel (PDCCH)

- The DCI supports 10 different formats, shown in table 6.1
- Format 0 is for signaling uplink transmission allocation
- Format 3 and 3A are for TPC
- remaining formats are for signaling downlink transmission allocation.

Table 6.1 DCI Formats

Format	Carried Information
Format 0	Uplink scheduling assignment
Format 1	Downlink scheduling for one codeword
Format 1A	Compact downlink scheduling for one codeword and random access procedure
Format 1B	Compact downlink scheduling for one codeword with precoding information
Format 1C	Very compact downlink scheduling for one codeword
Format 1D	Compact downlink scheduling for one codeword with precoding and power offset information
Format 2	Downlink scheduling for UEs configured in closed-loop spatial multiplexing mode
Format 2A	Downlink scheduling for UEs configured in open-loop spatial multiplexing mode
Format 3	TPC commands for PUCCH and PUSCH with 2-bit power adjustments
Format 3A	TPC commands for PUCCH and PUSCH with 1-bit power adjustments

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ii) Control Format Indicator (CFI):

It indicates how many symbols the DCI spans in that subframe. CFI = 1,2,or 3 is sent over the Physical Control Format Indicator Channel (PCFICH)

iii)H-ARQ Indicator (HI):

It carries H-ARQ acknowledgement in response to uplink transmissions and is sent over the Physical Hybrid ARQ Indicator Channel

3) Physical Channels: Actual Transmission

-The basic entities that make a physical channel are resource elements and resource blocks
-A resource element is a single sub-carrier over one OFDM symbol, that carries one (two with spatial multiplexing) modulated symbol.
-A resource block is a collection of resource elements; this is the smallest quanta of resources that can be allocated in the frequency domain

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Downlink Physical Channels
i) Physical Downlink Control Channel (PDCCH):
-carries information about transport format and resource allocation, H-ARQ information
ii) Physical Downlink Shared Channel (PDSCH):
-carries user data and higher level signaling
iii) Physical Broadcast Channel (PBCH):
-corresponds to BCH and carries system information
iv) Physical Multicast Channel (PMCH):
-carries multicast/broadcast information for the MBMS service
v) Physical Hybrid-ARQ Indicator Channel (PHICH):
-carries H-ARQ ACK/NAK associated with the uplink data transmission
vi) Physical Control Format Indicator Channel (PCFICH):
-It informs the UE about the number of OFDM symbols used for the PDCCH

Uplink Physical Channels
i) Physical Uplink Control Channel (PUCCH):
-carries the uplink control information, including Channel quality Indicators, ACK/NAK for H-ARQ in response to downlink transmission and uplink scheduling requests
ii) Physical Uplink Shared Channel (PUSCH):
- carries user data and higher level signaling
iii) Physical Random Access Channel (PRACH):
-carries the random-access preamble sent to UEs

Physical Signals: besides these physical channels, there are signals embedded in the downlink and the uplink physical layer, which do not carry any information, they are:
i) Reference Signal:
- for channel estimation, to enable coherent demodulation and channel quality measurement for user scheduling

- There are three reference signals in the downlink:
a) Cell-specific reference signal, for non-MBSFN (non-broadcast) transmission
b) MBSFN reference signal, for MBSFN (broadcast) transmission

c) UE- specific signals

-There are two reference signals in the uplink:
a) Demodulation reference signal, for transmission of PUSCH or PUCCH
b) Sounding reference signal, to support uplink channel-dependent scheduling

ii) Synchronization Signal:
-only in the down link, for acquisition of symbol timing and precise frequency of the downlink channel
-split into primary and secondary synchronization signal

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Channel Mapping

-From the description of different channels, we understand that there exists a good correlation in the purpose and content between channels in different layers.

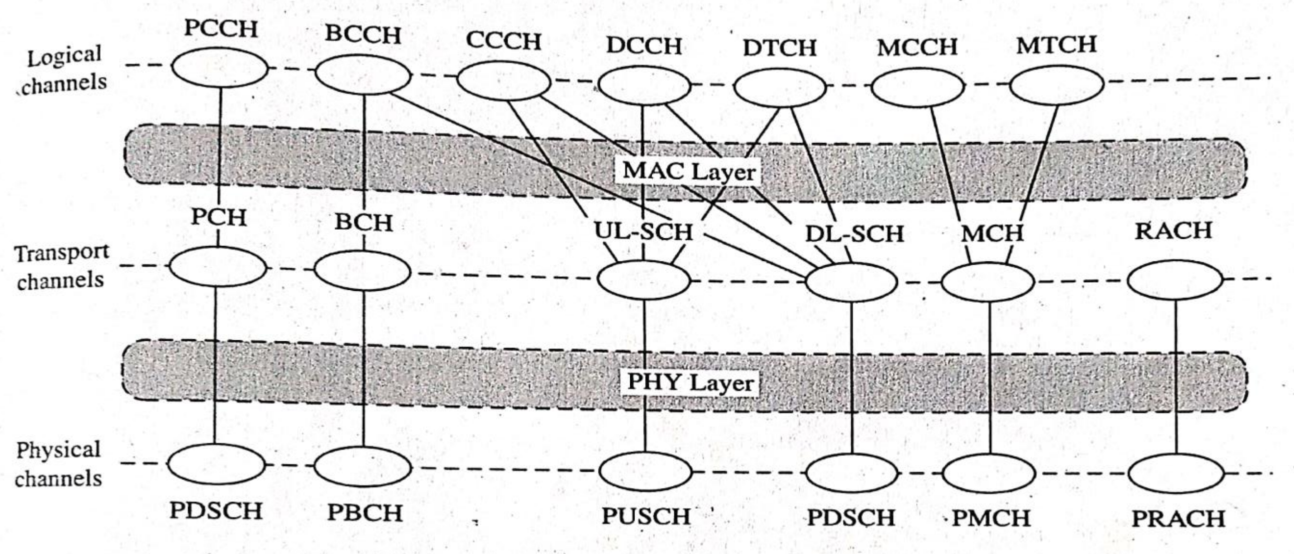

Figure 6.6 Mapping between different channel types.

-This requires mapping between logical channels and transport channels at the MAC SAP and a mapping between transport channels and physical channels at the PHY SAP.

-This channel mapping cannot be random, the allowed mapping between different channel types is shown in fig 6.6, similarly the mapping between the control information and the physical channels is shown in fig 6.7

-Multiple channels can be mapped to a single channel, for example different logical control channels and logical traffic channels are mapped to the DL-SCH transport channel

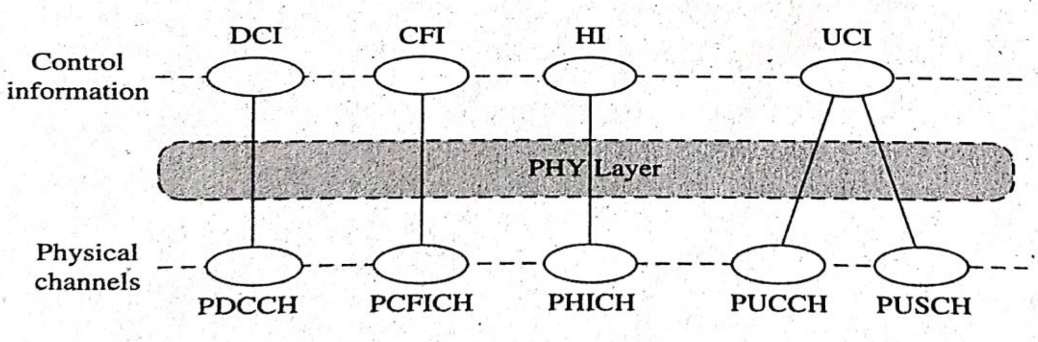

Figure 6.7 Mapping of control information to physical channels.

Downlink OFDMA Radio Resources

In LTE, the downlink and uplink use different transmission schemes due to different considerations
A scalable OFDM transmission is used in the downlink and a scalable SC-FDMA transmission is used in the uplink.
-The downlink transmission is based on OFDM with a cyclic prefix (CP)

Frame Structure

The frame structure in time domain is common element in both the downlink and the uplink
- In LTE, the size of elements in the time domain is expressed as a number of time units

$$T_s = 1/(15000\text{x}2048) \text{ seconds}$$

- T_s can be regarded as the sampling time of an FFT-based OFDM transmitter/receiver implementation with FFT size $N_{\text{FFT}} = 2048$
-the subcarrier spacing is $\Delta f = 15kHz$, hence the sampling frequency which equals $\Delta f \; x \; N_{\text{FFT}}$ is a multiple of the UTRA/HSPA chip rate of 3.84MHz
-Also, a reduced subcarrier spacing of 7.5 kHz is defined for MBSFN (Multicast/Broadcast Single Frequency Network) cells
- In Time Domain the downlink and the uplink multiple TTIs are organized into radio frames with duration $T_f = 307200 \,.T_s = 10\text{ms}$
- LTE supports both FDD and TDD modes, most of the design parameters are common to FDD and TDD in order to reduce the terminal complexity and maximize reuse
- LTE supports two kinds of frame structures:
 i) Frame structure Type 1 for FDD mode
 ii)Frame structure Type 2 for TDD mode

Frame Structure Type 1 (For FDD mode)

It is applicable to both full duplex and half duplex FDD. There are three different kind of units specified for this frame structure,

i) Slot: It is the smallest one of length $T_{slot} = 15360.T_s = 0.5$ms

where $T_s = {}^{1}/_{(15000x2048)}$ seconds

ii) Subframe: Two consecutive slots are defined as a subframe of length 1ms

iii) Radio Frame: 20slots, numbered from 0 to 19, constitute a radio frame of 10ms

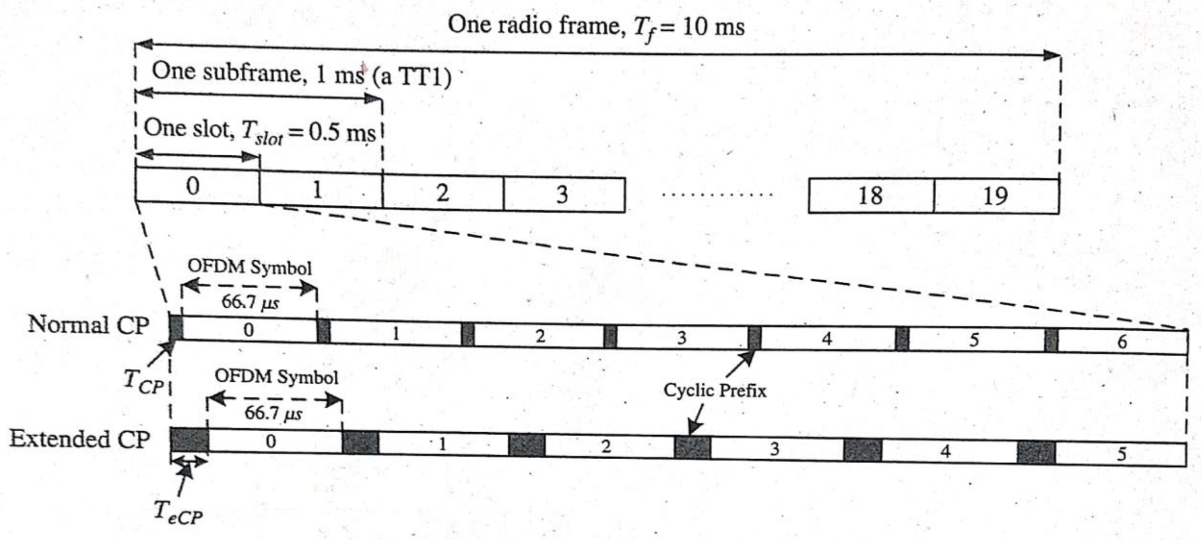

Figure 6.8 Frame structure type 1. For the normal CP, $T_{CP} = 160 \cdot T_s \approx 5.2\mu s$ for the first OFDM symbol, and $T_{CP} = 144 \cdot T_s \approx 4.7\mu s$ for the remaining OFDM symbols, which together fill the entire slot of 0.5 ms. For the extended CP, $T_{eCP} = 512 \cdot T_s \approx 16.7\mu s$.

- Each slot consists of seven to six OFDM symbols including CPs (Cyclic Prefix), CP is a guard interval to combat inter-OFDM-symbol interference, it should be larger than the delay spread
- Normal CP and extended CP are defined in LTE, extended CP is for multicell multicast/broadcast
- For FDD uplink and downlink transmissions are separated in the frequency domain, each with 10 subframes
- In half-duplex FDD operation, the UE cannot transmit and receive at the same time, while there are no such restrictions in full-duplex FDD operation
- But full-duplex FDD terminals need high quality and expensive RF duplex-filters to separate uplink and downlink channels
- half-duplex FDD allows hardware sharing between uplink and downlink, which offers cost sharing at

the expense of reducing data rates by half, they are preferred when the separation between uplink and downlink is relatively small

Frame Structure Type 2 (For TDD mode)

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- It is designed for coexistence with legacy systems such as 3GPP TD-SCDMA base standard

- Each radio frame is of length $T_f = 307200 . T_s = 10$ms, which consists of two half-frames of length 5ms each

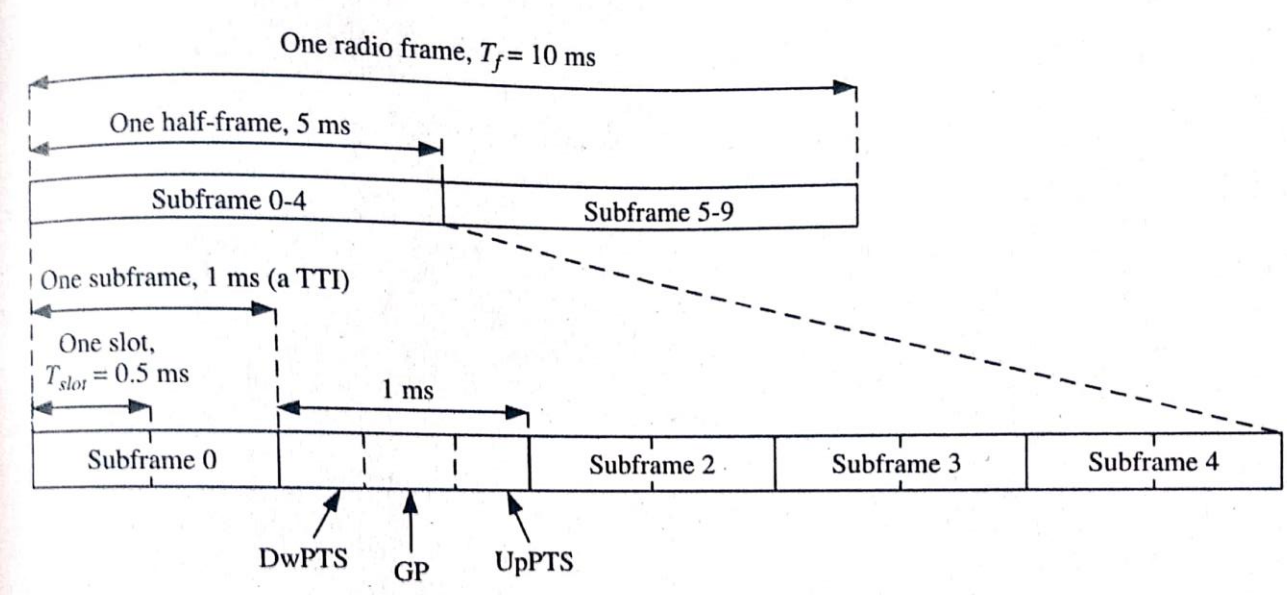

Figure 6.9 Frame structure type 2.

- Each half frame is divided into five subframes with 1ms duration. There are special subframes, which consist of three fields:

i) The Downlink Pilot TimeSlot (DwPTS) field: This is the downlink part of the special subframe. Its length can vary three up to twelve OFDM symbols

ii) The Uplink Pilot TimeSlot (UpPTS) field: This is the uplink part of the special subframe and has a short duration with one or two OFDM symbols. It is used for transmission of uplink sounding reference signals and random-access preambles

iii) The Guard Period (GP) field: The remaining symbols in the special subframe , that have not been allocated to DwPTS or UpPTS are allocated to the GP field, which is used to provide the guard period for the downlink-to-uplink switch and vice versa. GP can vary from two to ten OFDM symbols, sufficient for cell size up to and beyond 100km.

Table 6.2 Typical Parameters for Downlink Transmission

Transmission bandwidth [MHz]	1.4	3	5	10	15	20
Occupied bandwidth [MHz]	1.08	2.7	4.5	9.0	13.5	18.0
Guardband [MHz]	0.32	0.3	0.5	1.0	1.5	2.0
Guardband, % of total	23	10	10	10	10	10
Sampling frequency [MHz]	1.92 $1/2 \times 3.84$	3.84	7.68 2×3.84	15.36 4×3.84	23.04 6×3.84	30.72 8×3.84
FFT size	128	256	512	1024	1536	2048
Number of occupied subcarriers	72	180	300	600	900	1200
Number of resource blocks	6	15	25	50	75	100
Number of CP samples (normal)	9×6 10×1	18×6 20×1	36×6 40×1	72×6 80×1	108×6 120×1	144×6 160×1
Number of CP samples (extended)	32	64	128	256	384	512

All other subframes are defined as two slots, each with length $T_{slot} = 0.5$ms. Fig 6.9 only shows the detail structure of the first half-frame. The Second Half-frame has the similar structure. LTE supports 7 uplink-downlink configurations with either 5ms or 10ms Downlink-to-Uplink Switch-Point Periodicity, this is shown in the table below

Table 6.3 Uplink-Downlink Configurations for the LTE TDD Mode

Uplink-Downlink Configuration	Downlink-to-Uplink Switch-Point Periodicity	Subframe Number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Physical Resource Blocks for OFDMA

- The physical resource in the downlink in each slot is described by a time-frequency grid, called a *resource grid*
- The smallest time-frequency unit in a resource grid is denoted as a *resource element.*
- Each resource grid consists of a number of *resource blocks*, which describe the mapping of certain physical channels to resource elements

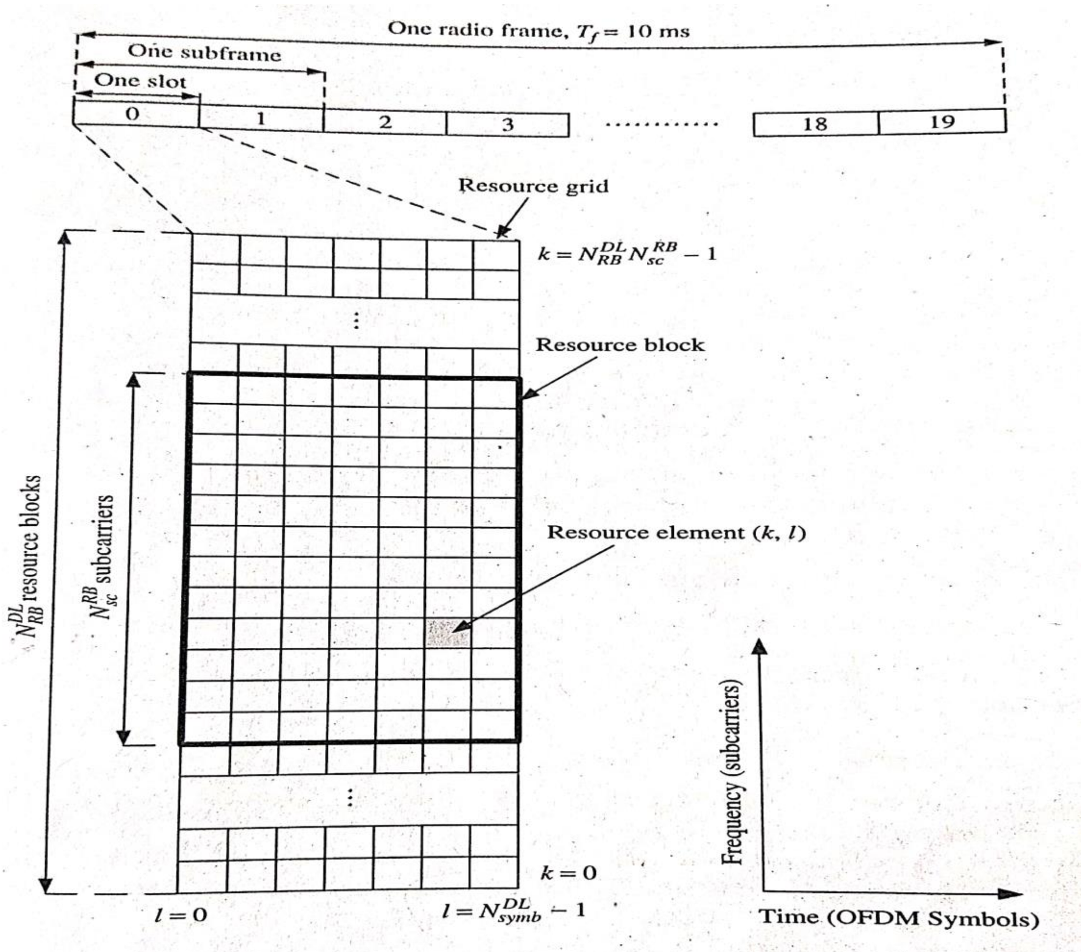

Figure 6.10 The structure of the downlink resource grid.

Resource Grid

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The structure of each resource grid is characterized by the following three parameters

i) The number of downlink resource blocks (N_{RB}^{DL}):

-It depends on the transmission bandwidth and shall fulfil $N_{RB}^{min,DL} \leq N_{RB}^{DL} \leq N_{RB}^{max,DL}$, where $N_{RB}^{min,DL} = 6$ and $N_{RB}^{max,DL} = 110$ for smallest and largest downlink channel bandwidth respectively

ii) The number of subcarriers in each resource blocks (N_{SC}^{RB}):

-It depends on subcarrier spacing Δf, satisfying $N_{SC}^{RB}\, \Delta f = 180kHz$, i.e. each resource block is 180kHz wide in the frequency domain.

-The values of N_{SC}^{RB} for different subcarrier spacings are shown in table 6.4

-There are a total of $N_{RB}^{DL}\ x\ N_{SC}^{RB}$subcarriers in each resource grid

ii) The number of OFDM symbols in each block (N_{symb}^{DL}):

- It depends on both the CP length and the subcarrier spacing, specified in Table 6.4

Therefore, each downlink resource grid has $N_{RB}^{DL}\ x\ N_{SC}^{RB}\ x\ N_{\text{symb}}^{DL}$ resource elements. For example, with 10MHz bandwidth and $\Delta f\ = 15kHz$, and normal CP we get N_{RB}^{DL}= 50 from table 6.2, $N_{SC}^{RB}\ = \mathbf{12}\ \boldsymbol{and}$ $N_{\text{symb}}^{DL} = 7$ from table 6.4

- In case of multiantenna transmission, there is one resource grid defined per antenna port

Resource Element:

Each resource element in the resource grid is identified by the index pair (k,l) in a slot,

Where, k=0,1,… $N_{RB}^{DL}\ N_{SC}^{RB}\ - \mathbf{1}$ the indices in the frequency domain

l=0,1,….. $N_{\text{symb}}^{DL}\ - 1$ are the indices in the time domain

Resource Block:

It is the basic element for radio resource allocation

-The minimum size of radio resource that can be allocated is the minimum TTI in the time domain, that is one subframe of 1ms

- The size of each resource block is the same for all bandwidths, which is 180kHz in the frequency domain

- There are two types resource blocks defined in LTE: physical and virtual resource blocks

Table 6.4 Physical Resource Block Parameters for the Downlink

Configuration		N_{sc}^{RB}	N_{symb}^{DL}
Normal CP	$\Delta f = 15\text{kHz}$	12	7
Extended CP	$\Delta f = 15\text{kHz}$	12	6
	$\Delta f = 7.5\text{kHz}$	24	3

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Resource Allocation:

Resource Allocation's role is to dynamically assign available time-frequency resource blocks to different UEs in an efficient way to provide good system performance.

-LTE supports channel-dependent scheduling, and transmission is based on the shared channel structure where the radio resource is shared among different UEs

-Multiuser Diversity is exploited by assigning resource blocks to the UEs with favorable channel qualities

-LTE is able to exploit channel variations in both time and frequency domain, unlike HSPA which can exploit only time-domain variations, this provides higher multi-user diversity gain and is especially beneficial for slow-time varying channels

-In OFDMA downlink resource allocation, each resource block is assigned exclusively to one UE.

- Physical Resource Blocks (PRBs) and Virtual Resource Blocks (VRBs). The VRB is introduced to support both block-wise transmission (localized\consecutive subcarriers) and transmission on non-consecutive subcarriers (distributed) as a means to maximize frequency diversity.
-The LTE downlink supports three resource allocation types: type 0,1,2
- The downlink scheduling is performed at the eNode-B based on the channel quality information fed back from UEs, this downlink resource assignment information is sent to UEs on the PDCCH channel
-A PRB is defined as N_{symb}^{DL} consecutive OFDM symbols in the time domain and N_{SC}^{RB} consecutive subcarriers in the frequency domain, and each PRB corresponds to one slot in the time domain(0.5ms) and 180kHz in the frequency domain
- The PRB number n_{PRB} of a resource element (k,l) in a slot is given by: $n_{PRB} = \left\lfloor \frac{k}{N_{SC}^{RB}} \right\rfloor$

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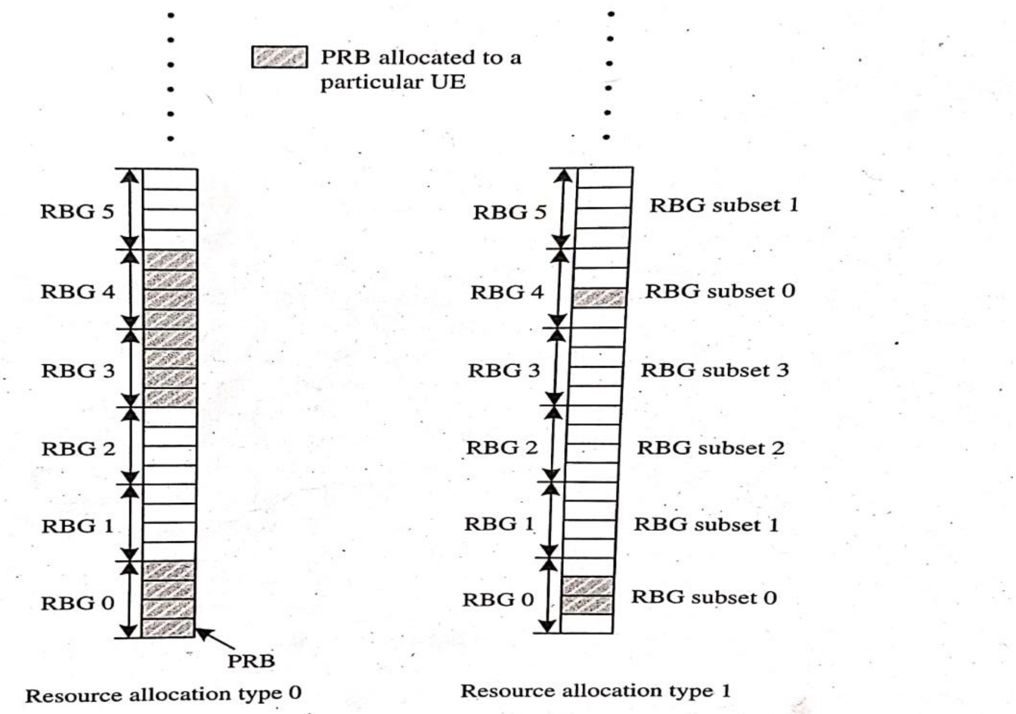

Figure 6.11 Examples of resource allocation type 0 and type 1, where the RBG size $P = 4$.

Type 0 Resource Allocation:
Several consecutive PRBs constitute a resource block group (RBG), and the resource allocation is done in units of RBGs
- A bitmap indicating the RBG is sufficient for resource assignment

-the allocated RBGs to a UE need not be adjacent to each other, this provides frequency diversity
- the RBG size P, that is, the number of PRBs in each RGB, depends on the bandwidth and is specified in table 6.5
- An example of type 0 resource allocation is shown in fig 6.11, where P=4 and RBGs 0,3,4 are allocated to a particular UE

Type 1 Resource Allocation:
-All the RBGs are grouped into a number of RBG subsets, and certain PRBs inside a selected RBG subset are allocated to the UE. There are a total of P RBG subsets, where P is the RBG size.
-The resource assignment information consists of three fields: i)the selected RBG subset ii) indicates whether an offset is applied iii)the bitmap indicating the PRBs inside the selected RBG subset

Type 2 Resource Allocation:
-PRBs are not directly allocated instead VRBs are allocated, which are then mapped onto PRBs, A VRB is the same size as a PRB
-There are two types of VRBs: localized type and the distributed type
-For both types of VRB, a pair of VRBs over two slots in a subframe are assigned together with a single VRB number n_{VRB}
-VRBs of localized type are mapped directly to PRBs such that $n_{PRB} = n_{VRB}$
-For VRBs of distributed type, the VRB numbers are mapped to PRB numbers according to rules specified in LTE

MIMO modes supported by the downlink OFDMA radio resources
- It supports both single-user MIMO (SU-MIMO) and multi-user MIMO (MU-MIMO)

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Uplink SC-FDMA Radio Resources

For, LTE uplink transmission SC-FDMA with CP is adopted, it possesses most of the advantages of OFDM along with a lower PAR. A lower PAR leads to less expensive power amplifiers, which is needed at UEs
Frame structure:- The uplink frame is similar to that of downlink, here we have SC-FDMA symbols and SC-FDMA subcarriers. Frame structure type 1 and 2 are similar to OFDMA
Physical resource blocks are also similar to that in OFDMA
Resource Allocation:- supports shared-channel transmission and channel-dependent scheduling

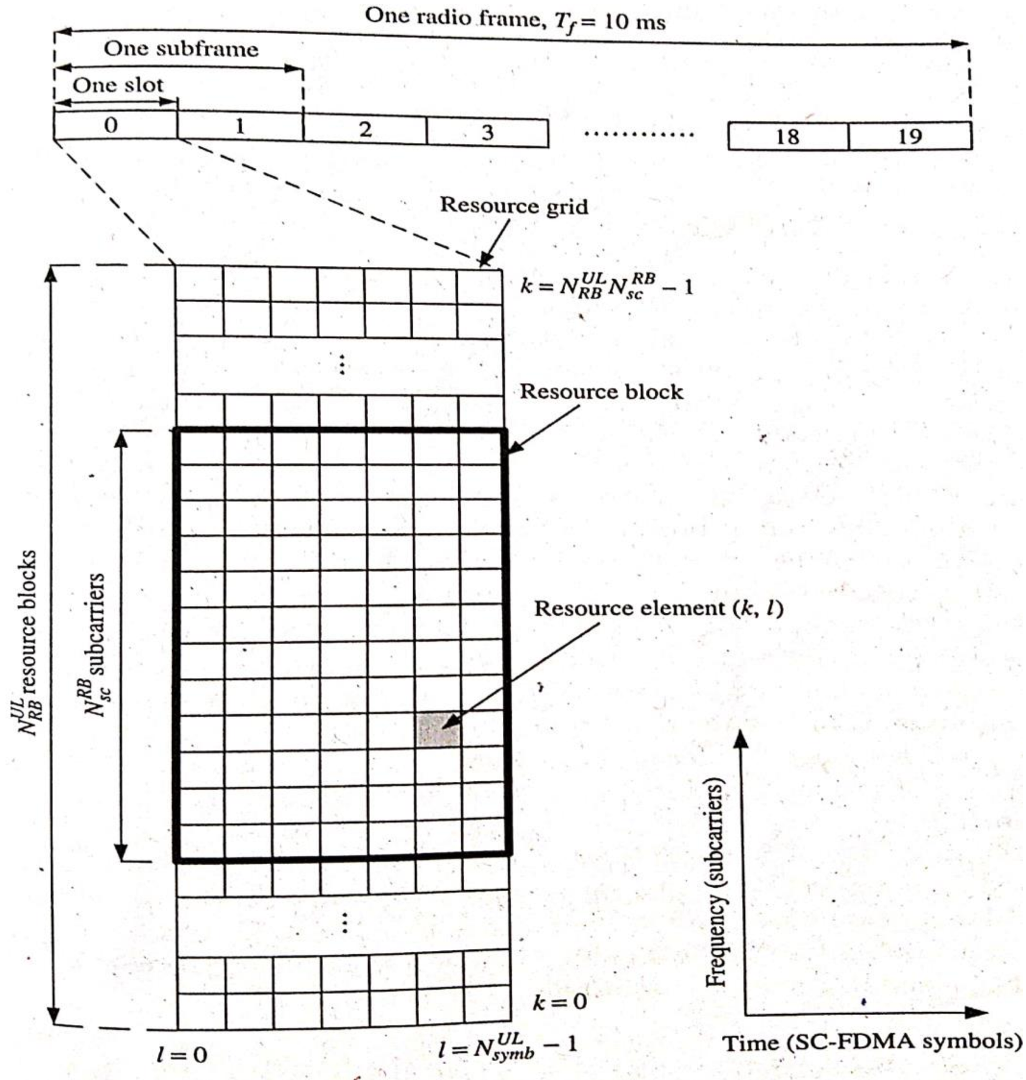

Figure 6.12 The structure of the uplink resource grid.

-uplink resource allocation is also performed at the eNode-B, based on channel quality measured on uplink sounding reference signals

Table 6.6 Physical Resource Block Parameters for Uplink

Configuration	N_{sc}^{RB}	N_{symb}^{UL}
Normal CP	12	7
Extended CP	12	6

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Downlink Transport Channel Processing – [Module 3 Part 2]

Downlink Transport Channel Processing Overview

-The downlink physical layer processing mainly consists of channel coding and modulation, fig 7.1
-Channel coding involves mapping the incoming transport blocks from the MAC layer into different codewords
-Modulation generates complex valued OFDM baseband signals for each antenna port, which are then upconverted to the carrier frequency

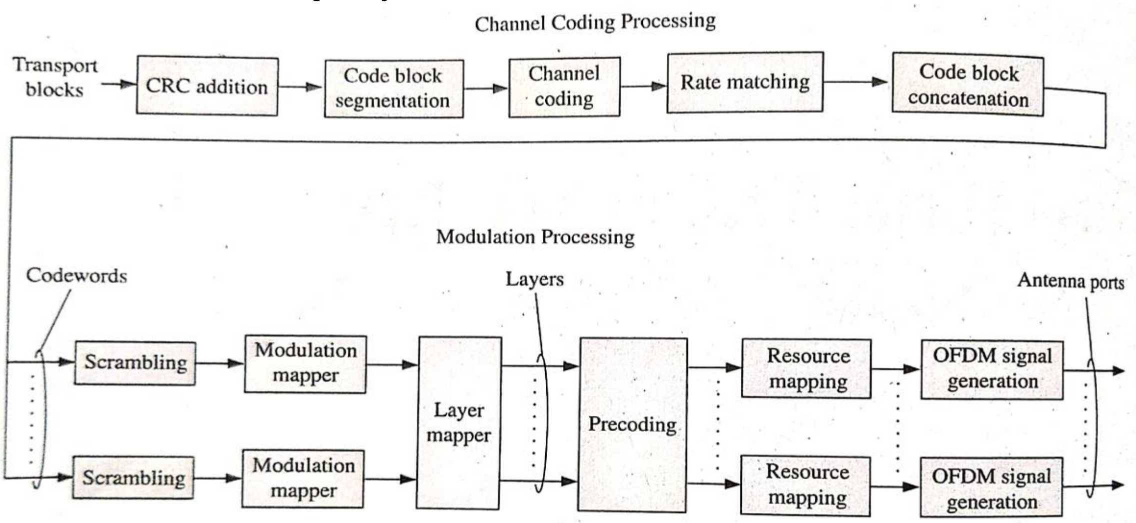

Figure 7.1 Overview of downlink transport channel processing.

1)Channel Coding Processing

The fig 7.2 shows an example of the generic procedures during channel coding, they include a)an error-control mechanism for data transmission using forward error correction (FEC) code and b) error detection based on cyclic redundancy check (CRC)
-For shared channel, the error control mechanism is coupled with the retransmission mechanism using Hybrid-ARQ (H-ARQ) protocol
-In LTE, the coding rate of the channel encoder is fixed, and different effective coding rates for the whole transport block are achieved by repetition/puncturing during rate matching procedure

i) CRC Addition

- The CRC provides error detection on the transport blocks
- It generates parity bits by cyclic generator polynomial
-The number of parity bits can be 8, 16, 24
- The 24-bit CRC is the baseline for the downlink shared channel

ii) Code Block Segmentation

- It is performed if the number bits in the sequence after CRC attachment is larger than the maximum code block size of the turbo encoder, which is z=6144

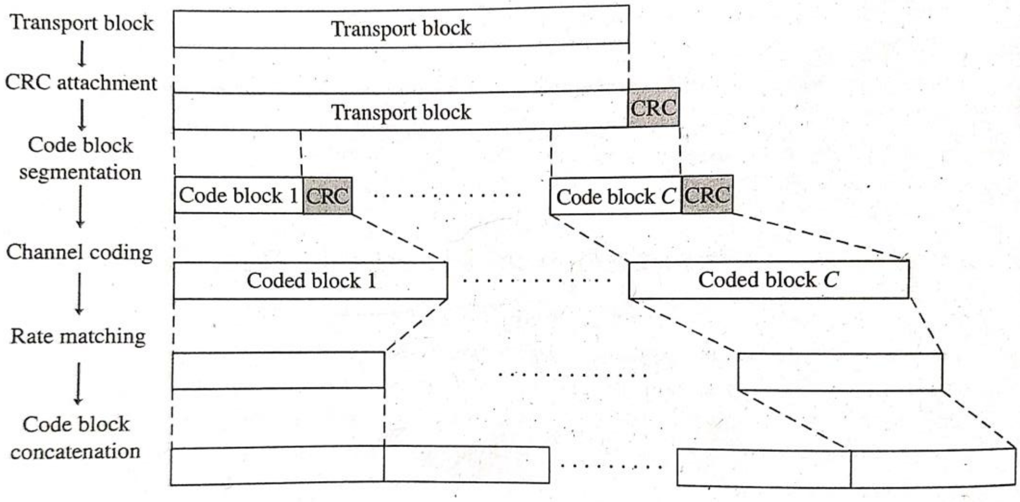

Figure 7.2 Channel coding processing.

-It breaks long sequence into C code blocks and adds an additional 24-bit CRC sequence to each block, where C is given by

$$C = \begin{cases} 1 & \text{if} \quad B \le Z \\ \lceil B/(Z-L) \rceil & \text{if} \quad B > Z, \end{cases}$$

Where, L is the number of parity bits

C is the number of code blocks

B is the number of bits in each code block after segmentation

(if B<40, which is the min code block size of the turbo encoder, filler bits are added)

-Each code block is encoded independently, to prevent excessive complexity and memory requirement for decoding at the receiver

iii) Channel Coding

The channel encoders applied to transport channels are tail-biting convolutional coding and convolutional turbo coding. The usage of channel coding schemes and coding rates for different downlink transport channels is shown in Table 7.1 and for control information is shown in Table 7.2

Table 7.1 Channel Coding Schemes and Coding Rates for Downlink Transport Channels

Transport Channel	Coding Scheme	Coding Rate
DL-SCH, PCH, MCH	Turbo coding	1/3
BCH	Tail-biting convolutional coding	1/3

Table 7.2 Channel Coding Schemes and Coding Rates for Downlink Control Information

Control Information	Coding Scheme	Coding Rate
DCI	Tail-biting convolutional coding	1/3
CFI	Block coding	1/16
HI	Repetition coding	1/3

a) Tail-Biting Convolutional Coding:

-The convolution encoder used in LTE is a rate 1/3 encoder with a constraint length of 7, as shown in fig 7.3

-Trellis termination must be performed at the end of each code block in order to restore the state of the encoder to the initial state for the next code block

-Two of the most common approaches for trellis termination are padding and tail biting.

-In case of padding, the end of the code block is padded with zeros, this forces the encoder to state'0' at the end of the code block.

- The main drawback of this method is that additional bandwidth is wasted due to the extra zeros that are added to the end of each code block.

- A more efficient method for trellis termination is tail biting, where the information bits from the end of each code block are appended to the beginning of the code block, once the appended bits are passed through the encoder, it ensures that the start and end states of the encoder are the same.

- For example, if the input bit sequence is $c_0, c_1, \ldots, c_{k-1}$, the initial value of the shift register shall be set to $[s_0, s_1, s_2, s_3, s_4, s_5] = [c_{k-1}, c_{k-2}, c_{k-3}, c_{k-4}, c_{k-5}, c_{k-6}]$ and then the initial and final states of the shift register are the same, the parity bits generated from the appended bits in the beginning of the code block are discarded and not used for transmission.

- With tail biting all input bits have the same amount of error protection, and there is no code rate loss compared to zero padding

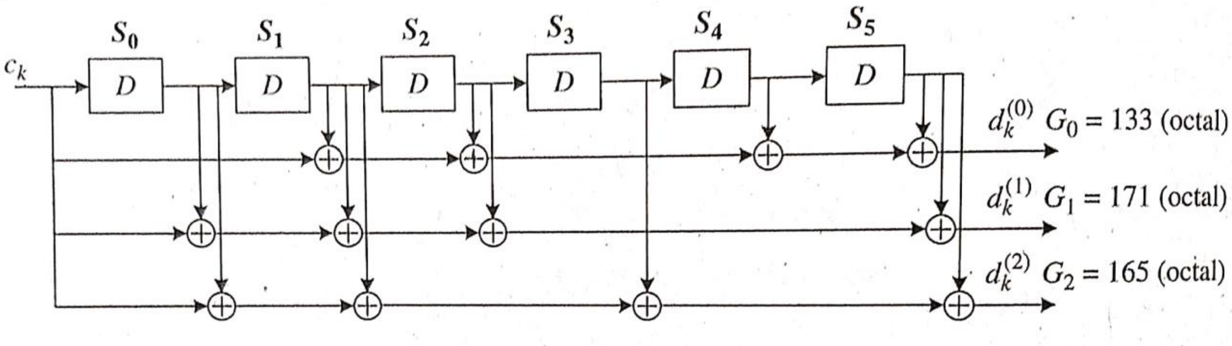

Figure 7.3 Rate 1/3 tail-biting convolutional encoder.

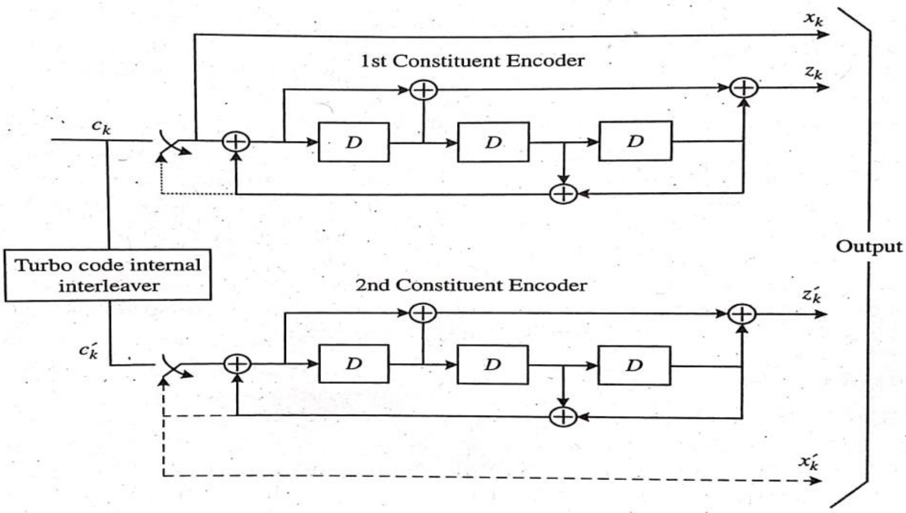

Figure 7.4 Structure of rate 1/3 turbo encoder (dotted lines apply for trellis termination only).

b) Convolution Turbo Coding:

The turbo encoder in LTE is similar to the one in HSPA, It is a Parallel Concatenated Convolutional Code (PCCC) with two eight-state constituent encoders and one turbo code internal interleaver, with a coding rate of 1/3

-Unlike the convolutional codes, the encoder used for the turbo codes is systematic and therefore recursive in nature

-LTE employs a new contention free internal interleaver based on Quadrature Permutation Polynomial (QPP), this allows highly flexible parallelization. The structure of the encoder is shown in fig 7.4

-The transfer function of the eight-state constituent code for the PCCC is

$$G(D) = \left[1, \frac{g_1(D)}{g_0(D)}\right], \tag{7.2}$$

where

$$g_0(D) = 1 + D^2 + D^3,$$
$$g_1(D) = 1 + D + D^3.$$

The initial values of the shift registers shall be all zeros when starting to encode the input bits.

The input bits to the turbo code QPP-based internal interleaver, $c_0, c_1, \cdots, c_{K-1}$, are mapped to the output bits $c'_0, c'_1, \cdots, c'_{K-1}$, according to the following relationship:

$$c'_i = c_{\Pi(i)}, \quad i = 0, 1, \ldots, K-1, \tag{7.3}$$

Where л(i) is a quadratic permutation polynomial given as л(i) = $(f_1.i + f_2.i^2)$mod K, where K is the number of input bits

-Instead of tail biting, the termination is performed by taking the recursive bit and performing modulo 2 addition with itself
-the output of the turbo encoder consists of three K-bit data streams: one systematic bit stream and two parity bit streams

iv) Rate Matching

-It performs interleaving as well as repetition or puncturing, in order to generate a transport block that fits the payload size determined by the modulation scheme

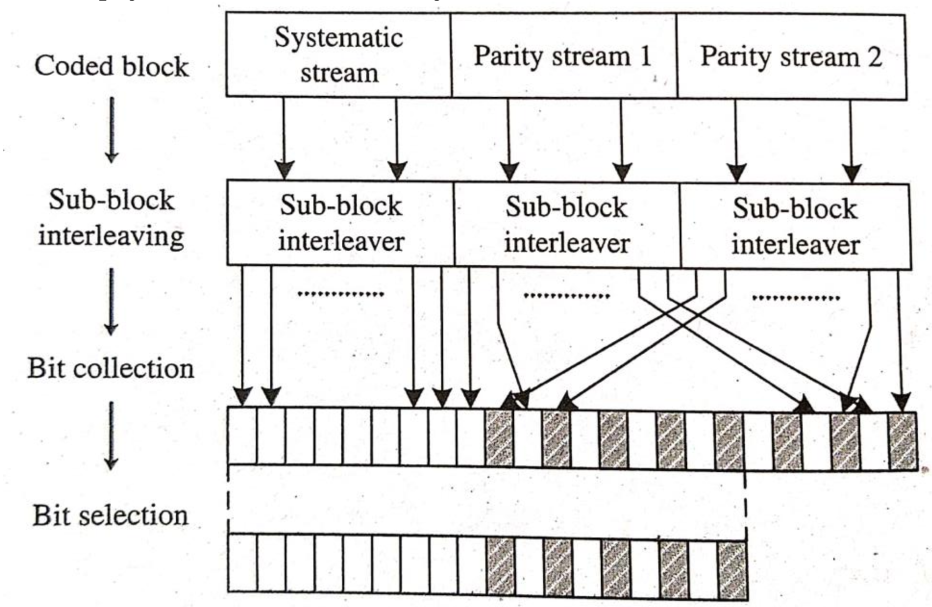

Figure 7.5 Rate matching for coded transport channels.

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-Rate matching per coded block consists of the following stages:

a) Sub-block Interleaving: in order to spread out the occurrence of bursty errors across the code block, which improves the overall performance of the decoder
-It is performed independently for each bit steam, using a block interleaver with inter-column permutations.

b) Bit Collection: Since interleaving is performed separately for the systematic and parity bits, a bit collection stage is required to place the systematic and parity bits in the right order as needed by the decoder
-A virtual cyclic buffer is formed by collecting bits from the interleaved streams.
-The systematic bits are placed in the beginning, followed by bit-by-bit interlacing of the two interleaved parity streams, as shown in fig 7.5
-The interlacing guarantees that the equal number of parity1 and parity 2 bits are transmitted.

c) Bit Selection: the bit selection stage is required in order to repeat or puncture some of the parity bits to create the required payload
-To select the output bit sequence, the sequence length L should be first determined, this depends on the number of allocated resource blocks, modulation scheme, MIMO mode
- Then the L bits are read from the virtual circular buffer, the starting point of the bit selection depends on the redundancy version of the current transmission. The redundancy version indicates the number of parity bits that are punctured or repeated for that H-ARQ transmission.
- During bit selection if the end of the buffer is reached, the reading continues by wrapping around to the beginning of the buffer, this way puncturing or repetition is achieved using a unified method
-In fig 7.5 puncturing is achieved
-The effective coding rate of K/L is used to achieve any continuum of coding rate,
where K is the number of input bits to the channel encoder and L is the sequence length

v) Code Block Concatenation
- Consists of sequentially concatenating the rated matching outputs for different code blocks
- This forms the input to the modulation processing
- This is needed only for turbo coding when the number of code blocks is larger than one

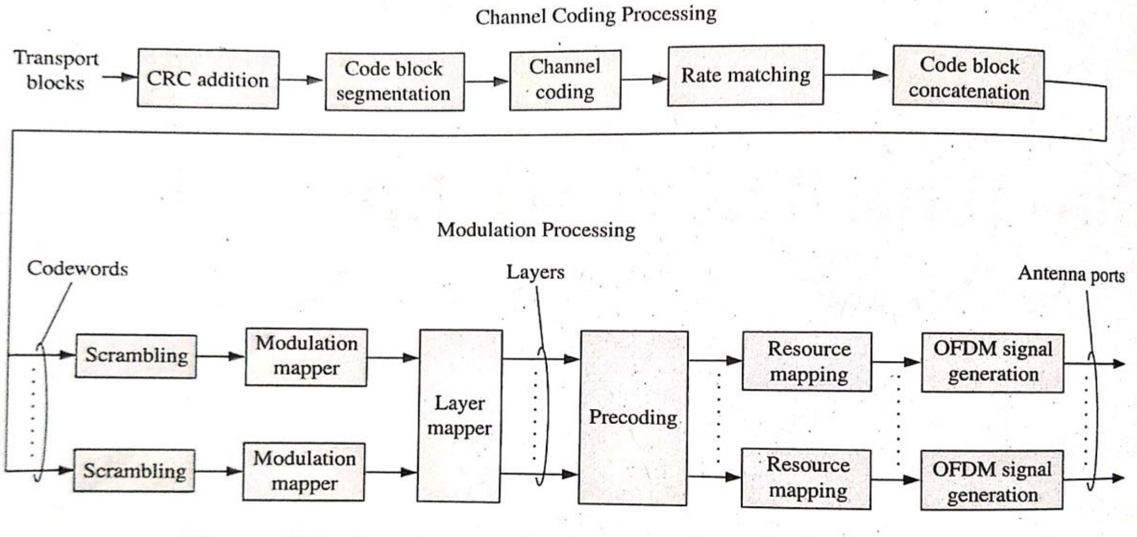

Figure 7.1 Overview of downlink transport channel processing.

2) Modulation Processing

Modulation takes in one or two codewords (two if spatial multiplexing is used), and converts them to complex valued OFDM baseband signals for each antenna port
The modulation process consists of 1)Scrambling, 2) Modulation Mapping 3) MIMO related multi antenna processing 4) Resource Mapping 5)OFDM signal generation

i) Scrambling

Before modulation, the codeword generated through channel coding processing is first scrambled by a bit-level scrambling sequence. The block of bits for codeword q is denoted as $b^{(q)}(0), \ldots, b^{(q)}(M_b^{(q)} - 1)$, where $M_b^{(q)}$ is the number of bits transmitted in one subframe. The scrambling sequence $c^{(q)}$ is a pseudo-random sequence defined by a length-31 Gold sequence [3]. The scrambled bits are generated using a modulo 2 addition as:

$$\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i)\right) \bmod 2, \quad i = 0, 1, \ldots, M_b^{(q)} - 1.$$

Up to two codewords can be transmitted in the same subframe, so $q = 0$ if spatial multiplexing is not used or $q \in \{0, 1\}$ if spatial multiplexing is used.

- Except for multicast channel, for all other downlink transport channels, the scrambling sequences are different for neighboring cells so that inter-cell interference is randomized

ii) Modulation Mapping

For each codeword q, the block of scrambled bits $\tilde{b}^{(q)}(0), \ldots, \tilde{b}^{(q)}(M_b^{(q)} - 1)$ are modulated into a block of complex-valued modulation symbols $d^{(q)}(0), \ldots, d^{(q)}(M_s^{(q)} - 1)$, where $M_s^{(q)}$ is the number of the modulation symbols in each codeword and depends on the modulation scheme. The relation between $M_s^{(q)}$ and $M_b^{(q)}$ is as follows:

$$M_s^{(q)} = \frac{M_b^{(q)}}{Q_m},$$

where Q_m is the number of bits in the modulation constellation, with $Q_m = 2$ for QPSK, $Q_m = 4$ for 16QAM, and $Q_m = 6$ for 64QAM.

Table 7.3 Modulation Schemes for Different Physical Channels

Physical Channel	Modulation Schemes
PDSCH	QPSK, 16QAM, 64QAM
PMCH	QPSK, 16QAM, 64QAM
PBCH	QPSK
PCFICH	QPSK
PDCCH	QPSK
PHICH	BPSK

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iii) Layer Mapping and Precoding

- Both layer mapping and precoding are associated with multi antenna transmission and reception (MIMO)

- These two steps map the incoming codewords to up to four transmit antennas, as shown in fig 7.6, the layer mapper maps N_c codewords to v spatial layers, while the precoder maps these v layers to P antenna ports

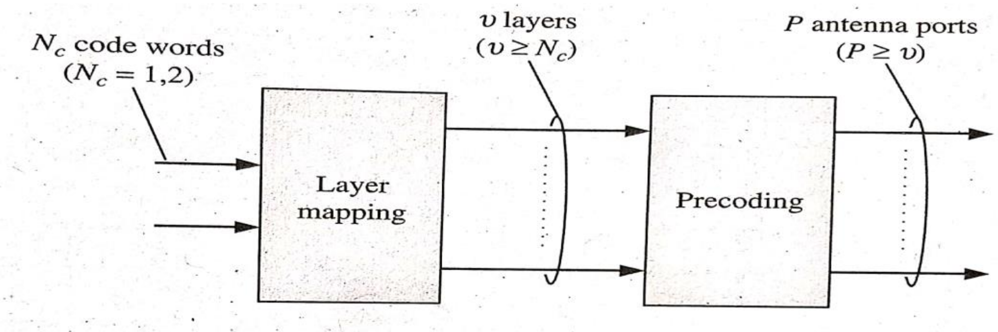

Figure 7.6 Layer mapping and precoding.

Some of the MIMO transmission terminologies are explained below:

A) Codeword: A codeword is defined as the output of each channel coding/rate matching stage associated with a single transport block coming from the MAC layer

- In LTE, although up to four transmit/receive antennas are supported, the number of codewords is limited to two; this is to limit the uplink feedback overhead, as a separate H-ARQ process is operated for each codeword, which requires separate signaling in the uplink

B) Layer: A layer corresponds to the data stream of the spatial multiplexing channel.

- Each codeword is mapped into one or multiple layers, hence $\upsilon \geq N_c$

C) Antenna Port: is defined by its associated reference signal, which is a logical entity and may not correspond to an actual antenna.

-The number of transmit antenna ports at the eNode-B is sent to the UEs through the PBCH channel, (which can be 1,2,or 4 in LTE)

-The antenna ports are divided into three groups:

a) Antenna ports 0-3 are *cell specific*, which are used for downlink MIMO transmission

b) Antenna port 4 is *MBSFN specific* and is used for MBSFN transmission

c) Antenna port 5 is *UE specific*, which is used for beamforming to a single UE using all physical antennas

- Cell specific ports and the UE specific ports cannot be simultaneously used

For a υ-layer transmission, modulation symbols $d^{(q)}(0), \cdots, d^{(q)}(M_s^{(q)}-1)$ for codeword q shall be mapped onto the layers $\mathbf{x}(i) = [x_0(i) \cdots x_{\upsilon-1}(i)]^T$, $i = 0, 1, \ldots, M_s^{\text{layer}}-1$, where M_s^{layer} is the number of modulation symbols per layer. Layer mapping is different for different MIMO modes, described as follows.

i. Single antenna port: one codeword is mapped to a single layer, which is straight forward
ii. Transmit diversity: one codeword is mapped to two or four layers. It is an open-loop MIMO mode
iii. Spatial Multiplexing: N_c codewords are mapped to v layers, where $N_c = 1,2$, v=1,2,3,4 and v $\geq N_c$. The detailed mapping is shown in table 7.4
- The case of a single codeword mapped to two layers only when the initial transmission contains two codewords and a codeword mapped onto two layers needs to be retransmitted
- Both open-loop (OL) and closed-loop (CL) spatial multiplexing modes are supported in LTE

Table 7.4 Codeword-to-Layer Mapping for Spatial Multiplexing

Number of Layers	Codeword 0	Codeword 1
1	Layer 0	
2	Layer 0	Layer 1
2	Layer 0, 1	
3	Layer 0	Layer 1,2
4	Layer 0,1	Layer 2,3

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The precoder takes a block of vectors $\mathbf{x}(i)$ as input, and generates a block of vectors $\mathbf{y}(i) = [y_0(i), \ldots, y_{P-1}(i)]^T, i = 0, 1, \ldots, M_s^{\text{ap}} - 1$ to be mapped onto resources on each of the antenna ports, where $y_p(i)$ is the signal for antenna port p and M_s^{ap} is the number of symbols on each antenna port. The precoder is either fixed or selected from a predefined codebook based on the feedback from UEs. The general form for precoding is

$$\mathbf{y}(i) = \mathbf{W}(i)\mathbf{x}(i),$$

where $\mathbf{W}(i)$ is the precoding matrix of size $P \times v$.

Different physical channels support different MIMO modes, specified in Table 7.5. The PDSCH channel supports all the specified MIMO modes, while the PMCH channel only supports single-antenna-port transmission (antenna port 4).

Shown in Figure 7.7 is the observed block error rate for some of the different modulation and coding rates in an additive white Gaussian noise (AWGN) channel.

Table 7.5 Supported MIMO Modes for Different Physical Channels

Physical Channel	Single Antenna Port	OL Transmit Diversity	Spatial Multiplexing
PDSCH	✓	✓	✓
PDCCH	✓	✓	
PBCH	✓	✓	
PMCH	✓		
PHICH	✓	✓	
PCFICH	✓	✓	

iv) Resource Mapping

For each of the antenna ports used for transmission of physical channels, the block of complex-valued symbols $y_p(0), \ldots\ldots, y_p(M_s^{ap}-1)$ *shall be mapped in sequence* starting with $y_p(0)$, to the resource blocks assigned for transmission

- The mapping of resource element *(k,l)* on antenna port p not reserved for other purposes shall be in increasing order of first the index k and then the index l, starting with the first slot in the subframe

v) OFDM Baseband Signal Generation

The continuous-time signal $s_l^{(p)}(t)$ on antenna port p in OFDM symbol l in a downlink slot is generated as:

$$s_l^{(p)}(t) = \sum_{k=-\lfloor N_{RB}^{DL} N_{sc}^{RB}/2 \rfloor}^{-1} a_{k^{(-)},l}^{(p)} \cdot e^{j2\pi k \Delta f (t - N_{CP,l} T_s)} + \sum_{k=1}^{\lceil N_{RB}^{DL} N_{sc}^{RB}/2 \rceil} a_{k^{(+)},l}^{(p)} \cdot e^{j2\pi k \Delta f (t - N_{CP,l} T_s)} \tag{7.4}$$

for $0 \le t \le (N_{CP,l} + N) \times T_s$, where $k^{(-)} = k + \lfloor N_{RB}^{DL} N_{sc}^{DL}/2 \rfloor$ and $k^{(+)} = k + \lfloor N_{RB}^{DL} N_{sc}^{DL}/2 \rfloor - 1$, and for 20MHz bandwidth the value of N is given by:

$$N = \begin{cases} 2048, & \text{if } \Delta f = 15\text{kHz} \\ 4096, & \text{if } \Delta f = 7.5\text{kHz}. \end{cases} \tag{7.5}$$

The cyclic prefix (CP) length $N_{CP,l}$ depends on the CP type and the subcarrier spacing, listed in Table 7.6.

Table 7.6 Values of $N_{CP,l}$

Configuration		CP Length $N_{CP,l}$
Normal CP	$\Delta f = 15$kHz	160 for $l = 0$ 144 for $l = 1, 2, \ldots, 6$
Extended CP	$\Delta f = 15$kHz	512 for $l = 0, 1, \ldots, 5$
	$\Delta f = 7.5$kHz	1024 for $l = 0, 1, 2$

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- In practice OFDM signal is generated using IFFT digital signal processing
- FFT can be used at the receiver to convert time-domain signal back to frequency domain at the receiver
-The implementation of IFFT and FFT is a major advantage of OFDM due to its computational efficiency
- OFDM signal generation with multiple users is shown in fig 7.8

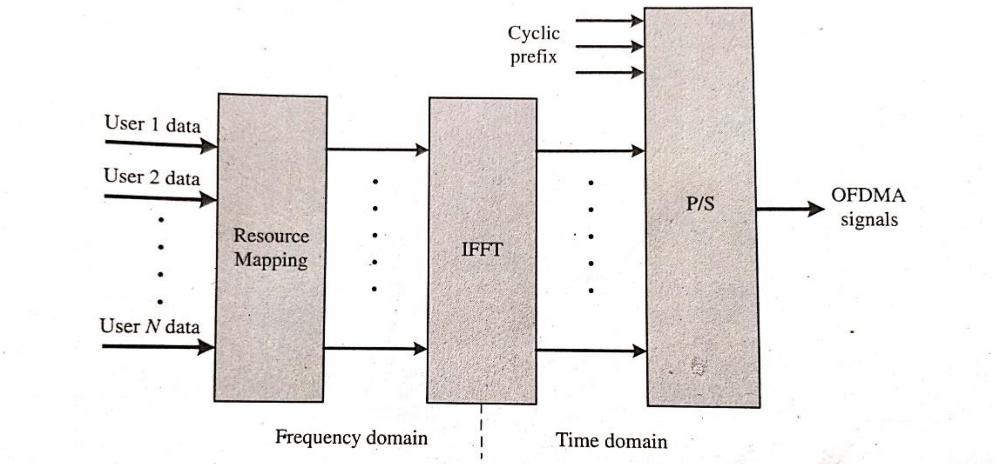

Figure 7.8 OFDMA signal generation with N users, where P/S denotes the parallel-to-serial converter.

Downlink Shared Channel

The physical layer processing for specific transport channels are described, such as for the downlink shared channel, the downlink control channel, the downlink broadcast channel, and the multicast channel

-Although most transport channels implement the various aspects of transport channel processing such as channel coding, rate matching, symbol mapping, MIMO processing, and OFDM modulation, the specifics of each step vary from one transport channel to other

-The DL-SCH is carried on the physical Downlink Shared Channel (PDSCH)

-The DL-SCHs carry both the traffic & control data from the logical channels

-The PDSCH is also used to carry the Paging Channel

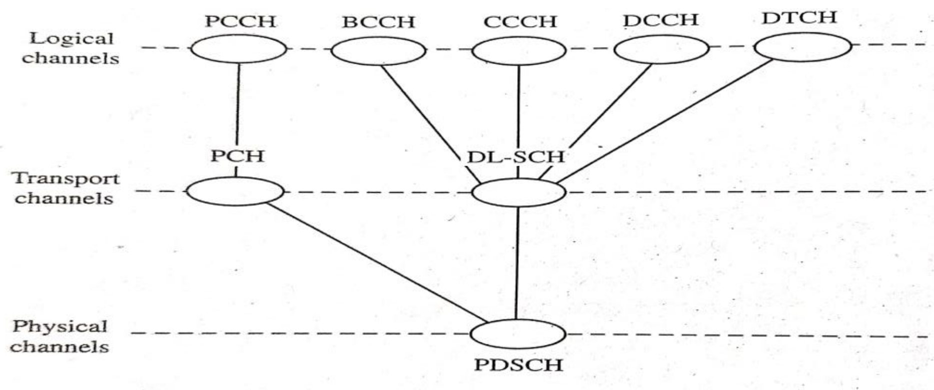

Figure 7.9 Channel mapping around the downlink shared channel.

Channel Encoding and Modulation

The Channel Encoding and Modulation of DL-SCH is explained here:

-It uses the rate 1/3 convolutional turbo code

-Rate matching is used to achieve an *effective channel coding rate* that matches the payload capacity of the given UE and the modulation scheme

-The modulation scheme allowed for DL-SCH includes QPSK, 16QAM, and 64QAM and is chosen based on the Channel Quality Indicator (CQI), size of the transport block, the redundancy version

-The modulation order is indicated in the Downlink Control Information (DCI)

- For MIMO spatial multiplexing (two codewords) different modulation and scheming can be used for each codeword

-The resource mapping of PDSCH physical channel depends on whether UE-specific reference signals are transmitted: ->without reference signal transmission, PDSCH is transmitted on the same set of …………….. antenna ports as the PBCH, which is one of {0},{0,1}, or {0,1,2,3};

->with reference signal transmission, the PDSCH will be transmitted on antenna port ……………. {5}, that is beamforming is applied

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Multiantenna Transmission

The PDSCH supports all the MIMO modes specified in LTE

There are seven different transmission modes defined for data transmission on the PDSCH channel:

i) Single antenna port (port 0) : One transport block is transmitted from a single physical antenna corresponding to antenna port 0.

ii) Transmit diversity: One transport block is transmitted from more than one physical antenna, that is, ports 0 and 1 if two physical antennas are used and ports 0,1,2, and 3 if four physical antennas are used

iii) Open-loop (OL) spatial multiplexing: One or two transport blocks are transmitted from two or four physical antennas, In this case, predefined precoder matrices are used based on the Rank Indicator (RI) feedback. The precoding matrix is fixed and not adapted.

iv) Closed-loop (CL) spatial multiplexing: One or two transport blocks are transmitted from two or four physical antennas. The precoding in this case is adapted based on the Precoding Matrix Indicator (PMI) feedback from the UE.

v) Multiuser MIMO: Two UEs are multiplexed onto two or four physical antennas with one transport block to each UE.

vi) Closed-loop (CL) rank-1 precoding: It is a special case of the CL spatial multiplexing with single-layer transmission, that is, a Px1 precoder is applied

vii) Single-antenna port (port 5): The eNode-B performs beamforming to a single antenna using all physical antennas (hence one transport block is transmitted from two or more physical antennas)

- Here the reference signal is also transmitted using the same beamforming vector used for data symbols

- The beamforming technique used in this mode is transparent to the UEs

- Beamforming is used to improve received signal power, reduce the interference signal power which is important for cell edge users.

Downlink Control Channels

- Downlink Control Channels are carried over the Physical Downlink Control Channel (PDCCH) and they contain Control Information from the MAC layer, including Downlink Control Information (DCI), Control Format Indicator (CFI), and H-ARQ Indicator (HI).

- There is a specific Physical Channel for each type of Control Information.

- On the Physical Layer the PDCCH and the PDSCH are time multiplexed, such that the PDCCH is carried over the first few OFDM symbols of each subframe and the PDSCH is carried over the rest of the OFDM symbols.

- The number of OFDM symbols allocated for PDCCH can vary from one to four and is conveyed by the CFI.

- The CFI is carried on control channel known as the Physical Control Format Indicator Channel (PCFICH), which is always carried in a predetermined format over the first OFDM symbol of each subframe.

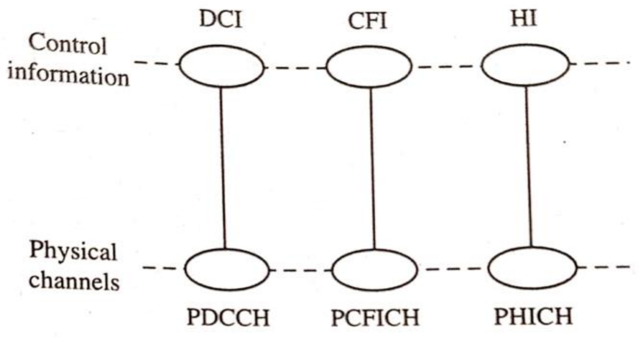

Figure 7.11 Channel mapping for control information in the downlink.

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1. Downlink Control Information (DCI) Formats

- DCI carries detailed Control Information for both Downlink and Uplink transmissions.

- DCI carries the Downlink scheduling assignments, Uplink scheduling grants, power control commands, and other information necessary for the scheduled UEs to decode and demodulate data symbols in the Downlink or encode and modulate data symbols in the Uplink.

- LTE defines ten different DCI formats for different transmission scenarios, summarized as follows:

- **DCI format 0** carries Uplink scheduling grants and necessary Control Information for Uplink transmission.
- **DCI format 1/1A/1B/1C/1D** provides scheduling information for one codeword transmission without Spatial Multiplexing. This category has the largest number of types in order to save signalling resources on the PDCCH, as these formats are optimized for specific use cases and transmission modes.
- **DCI formats 2 and 2A** provide Downlink scheduling information for Closed Loop and Open Loop Spatial Multiplexing, respectively. In this case, DCI contains information about the modulation and coding scheme and the redundancy version for each of the two codewords.
- **DCI formats 3 and 3A** carry Transmit Power Control (TPC) commands for the uplink.

Table 7.10 Fields of DCI Format 0

Information Type	Number of Bits	Purpose
Flag for format 0/1A differentiation	1	Indicates format 0 or format 1A
Hopping flag	1	Indicates whether PUSCH frequency hopping is performed
Resource block assignment and hopping resource allocation	$\lceil \log_2(N_{RB}^{DL}(N_{RB}^{DL}+1)/2) \rceil$	Indicates assigned resource blocks
Modulation and coding scheme and redundancy version	5	For determining the modulation order, redundancy version and the transport block size
New data indicator	1	Indicates whether the packet is a new transmission or a retransmission
TPC command for scheduled PUSCH	2	Transport Power Control (TPC) command for adapting the transmit power on the PUSCH
Cyclic shift for demodulation reference signal	3	Indicates the cyclic shift for the demodulation reference signal for PUSCH
UL index	2	Indicates the scheduling grant and only applies to TDD operation with uplink-downlink configuration 0
Downlink Assignment Index (DAI)	2	For ACK/NAK reporting and only applies to TDD operating with uplink-downlink configurations 1-6
CQI request	1	Requests an aperiodic CQI from the UE

Table 7.11 Fields of DCI Format 1

Information Type	Number of Bits	Purpose
Resource allocation header	1	Indicates whether it is of resource allocation type 0 or 1
Resource block assignment	Depends on resource allocation type	Indicates assigned resource blocks
Modulation and coding scheme	5	For determining the modulation order and the transport block size
H-ARQ process number	3 (TDD), 4 (FDD)	Indicates the H-ARQ process
New data indicator	1	Indicates whether the packet is a new transmission or a retransmission
Redundancy version	2	Identifies the redundancy version used for coding the packet
TPC command for PUCCH	2	TPC command for adapting the transmit power on the PUCCH
Downlink Assignment Index (DAI)	2	For ACK/NAK reporting and only applies to TDD operation

- To receive the PDSCH, the UE shall monitor a set of PDCCH candidates for Control Information. Upon detecting a PDCCH with DCI format 1, 1A, 1B, 1C, 1D, 2, or 2A intended for itself, the UE then decodes the corresponding PDSCH in the same frame.
- To transmit the PUSCH, the UE shall first detect a PDCCH with format 0 intended for itself.

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2. Channel Encoding and Modulation

a) Downlink Control Information (DCI)

- The DCI is mapped to the PDCCH Physical Channel, and multiple PDCCHs can be transmitted in a subframe. A 16-bit CRC is attached to the Control Information symbols. The CRC parity bits are then scrambled according to the following rules:

- If UE transmit antenna selection is not configured or applicable, the CRC parity bits are scrambled with one Radio Network Temporary Identifier (RNTI), which is the UE identity. Then the UE is able to detect its own DCI.

- If UE transmit antenna selection is configured and applicable, the CRC parity bits of PDCCH with DCI format 0 are scrambled with the corresponding RNTI and the antenna selection mask shown in table 7.12 which informs the UE about the selected antenna port.

Table 7.12 UE Transmit Antenna Selection Mask

UE Transmit Antenna Selection	Antenna Selection Mask
UE port 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
UE port 1	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1

- The Tail-Biting Convolutional code with rate 1/3 is used as the channel coding scheme, while QPSK is the modulation scheme.

- After channel coding, cell-specific scrambling is applied, and the PDCCH shall be transmitted on the same set of antenna ports as the PBCH.

- The PDCCH is located in the first n OFDM symbols of each subframe, $1 \leq n \leq 4$.

- For frame structure type 2, PDCCH can also be mapped onto the first two OFDM symbols of the DwPTS field, while the third OFDM symbol is for the primary synchronization signal.

- Before being mapped to Resource Elements, the PDCCH complex-valued symbols are first organized into quadruplets, which are then permuted according to the sub- block Interleaver for rate matching.

- Each PDCCH is transmitted using one or more Control Channel Elements (CCEs), where each CCE corresponds to nine sets of four Physical Resource Elements known as Resource Element Groups (REGs).

- Four QPSK symbols are mapped to each REG.

Table 7.14 PDCCH Formats

PDCCH Format	# CCEs (n)	# REGs	# PDCCH Bits
0	1	9	72
1	2	18	144
2	4	36	288
3	8	72	576

b) Control Format Indicator (CFI)

- The CFI indicates how many OFDM symbols the DCI spans in the subframe. Such an indicator is needed because the load on PDCCH varies, depending on the number of Resource Blocks and the signalling format conveyed on PDCCH.

- The PDCCH loads are different for DCI format 0 and format 1, as indicated by tables 7.10 and 7.11

- The CFI takes values CFI = 1, 2, or 3.

- $N_{RB}^{DL} > 10$ the DCI spans 1, 2, or 3 OFDM symbols, given by the value of the CFI.

- $N_{RB}^{DL} < 10$ the DCI spans 2, 3, or 4 OFDM symbols, given by CFI+1.

- The CFI uses a Block Code predefined based on (3, 2) simplex coding with repetition of coding rate 1/16, listed in table 7.15.

- The CFI is mapped to the PCFICH Physical Channel carried on specific Resource Elements in the first OFDM symbol of the subframe. The PCFICH is transmitted when the number of OFDM symbols for PDCCH is greater than zero. In addition, the PCFICH shall be transmitted on the same set of antenna ports as the PBCH.

Table 7.15 CFI Codeword

CFI	CFI Codeword $b_0, b_1, \ldots, b_{31}$
1	0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1
2	1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0
3	1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1
4 (Reserved)	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

c) H-ARQ Indicator (HI)

- The Control Information HI is for H-ARQ acknowledgement in response to Uplink transmission.

- It has two values: HI = 1 for a positive acknowledgment (ACK) and HI = 0 for a negative acknowledgment (NAK).

- A repetition code with rate 1/3 is applied, which has two codewords (000) and (111).

- HI is mapped onto the PHICH physical channel.

- Multiple PHICHs mapped to the same set of Resource Elements constitute a PHICH group, where PHICHs within the same group are separated through different Orthogonal sequences with a spreading factor of four.

- A PHICH is identified by the index pair (ngroup, nseq), where ngroup is the PHICH group number and nseq is the Orthogonal sequence index within the group.

- The numbers of PHICH groups are different for frame structure type 1 and type 2.

Broadcast Channels

-They carry system information such as downlink system bandwidth, antenna configuration, and reference signal power.
- The UEs can get the necessary system information after the cell search (or synchronization) procedure
- Due to the large size of the system information field, it is divided into two portions:
i)Master Information Block (MIB) transmitted on the PBCH:- It contains basic system parameters necessary to demodulate the PDSCH (with remaining SIB)
-Transmission of the PBCH is characterized by a fixed pre-determined transport format and resource allocation (no higher layer control)
ii)System Information Blocks (SIB) transmitted on the PDSCH:- contains the remaining SIB
-Error detection is provided through a 16-bit CRC, and then the CRC parity bits are scrambled according to the eNode-B transmit antenna configuration, shown in table 7.16
-The tail-biting convolutional coding with rate 1/3 is used
-The modulation scheme is QPSK, no H-ARQ is supported
-MIMO modes, PBCH supports are single-antenna transmission and OL transmit diversity, dynamic adaptation modulation and coding is not possible due to the lack of channel quality feedback
-The Transmission Time Interval (TTI) for the PBCH is 40ms
-The PBCH occupies the most narrow bandwidth supported by LTE (1.4MHz) and is located in the subframe guaranteed to be used in the downlink
-This allows the UE to detect and decode the PBCH without any prior knowledge of the system bandwidth and the duplex mode.

-Once the PBCH is detected and the MIB is decoded the UE can extract the system bandwidth and the duplex mode

Multicast Channels

Multimedia Broadcast and Multicast Services (MBMS), introduced in LTE supports multicast/broadcast services, it sends the same content information to all the UEs (broadcast) or to a given set of UEs (multicast) and is used for delivering services such as mobile TV

- Multicell transmission is preferred as large gains can be achieved through soft combining of transmissions from multiple base stations.
- This can cause interference between signals from different base stations in UTRA, but LTE provides enhanced support to MBMS transmission, called the Enhanced-MBMS (E-MBMS) and is achieved through single frequency network

-The extended CP ensures that the signals from different base stations still fall within the CP at the receiver, which avoid ISI

-In such Multicast/Broadcast Single Frequency Networks (MBSFN), the same information is broadcast on the same radio resources from multiple synchronized neighboring base stations to multiple UEs

-The E-MBMS transmission occurs on the MCH transport channel, with 7.5kHz subcarrier spacing and extended CP, this is of two types:

i)Single-cell transmission (non-MBSFN operation): The MBMS service (MTCH and MCCH)is transmitted on MCH, and combining of MBMS transmission from multiple cells is not supported

ii)Multi-cell transmission (MBSFN operation): The MBMS service (MTCH and MCCH)is transmitted synchronously on the MCH, and combining is supported with the SFN operation

Downlink Physical Signals

Processing and resource mapping of downlink physical signals including downlink reference signals and synchronization signals.

1) Downlink Reference Signals

It consists of known reference symbols, intended for channel estimation at the UE to perform coherent demodulation.

- To facilitate channel estimation scattered reference signals are inserted in the resource grid at pre-determined intervals

-There are three different types of reference signals: i) Cell-specific reference signals ii) MBSFN reference signals iii) UE-specific reference signals

i) Cell-Specific Reference Signals

-Cell-specific reference signals are transmitted in all downlink subframes in a cell supporting non-MBSFN transmission

-In case of subframes used for MBSFN transmission, only the first two OFDM symbols can be used for cell-specific reference symbols
-The cell specific reference signals are defined separately for antenna ports 0,1,2, and 3 (only for normal subcarrier spacing of $\Delta f = 15$kHz) as shown in fig7.12
- For the antenna port $p \in \{0,1\}$ the reference symbols are inserted within the first and the third last OFDM symbols in each slot
- For the antenna port $p \in \{2,3\}$ the reference symbols are inserted only in the second OFDM symbol.
- Hence the ports 0 and 1 have two times the reference symbols as in ports 2 and 3
-This causes an imbalance in the quality of the channel estimates and impacts the benefits of using four antennas
- In the frequency domain the reference symbols are transmitted every six subcarriers, that is with a spacing of five subcarriers between neighboring reference symbols
-The resource element (k,l) occupied by reference symbol on any one antenna port in a slot is not used for transmission on any other antenna port in the same slot and is set as zero, hence the reference signals are orthogonal to each other
-An example of resource mapping for cell-specific reference signals is shown in fig 7.12, where R_p denotes a resource element used for transmission of reference signal on antenna port p. There are four reference symbols per resource block for $p \in \{0,1\}$ and two reference symbols per block for $p \in \{2,3\}$.

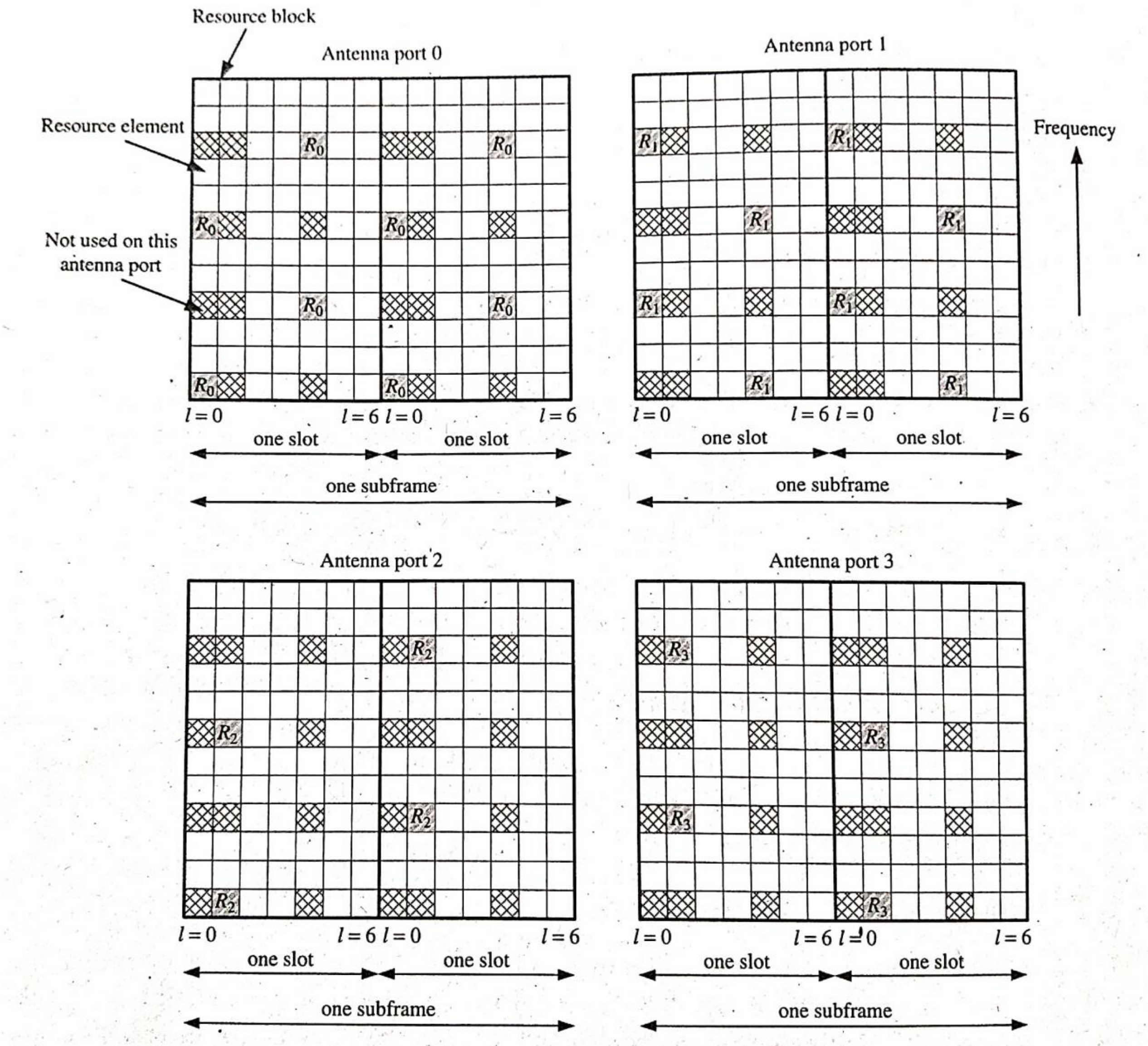

Figure 7.12 An example of mapping of downlink cell-specific reference signals, with four antenna ports and the normal CP. R_p denotes the resource element used for reference signal transmission on antenna port p.

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ii) MBSFN Specific Reference Signals

MBSFN reference signals are only transmitted in subframes allocated for MBSFN transmission, which is only defined for extended CP and transmitted on antenna port 4

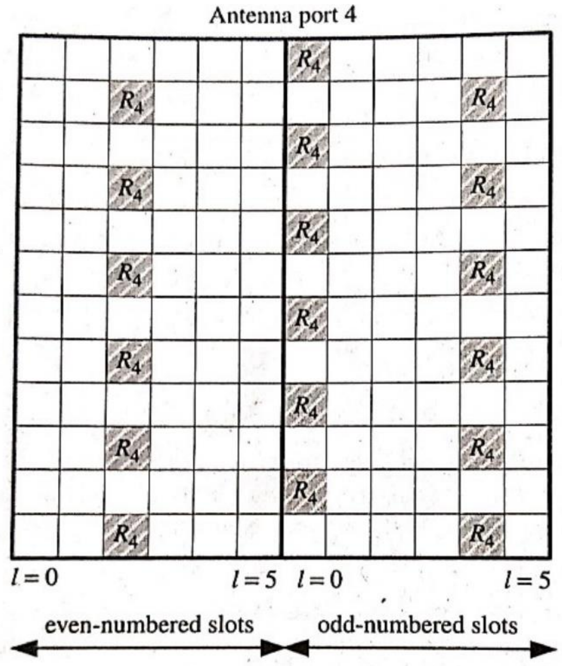

Figure 7.13 An example of mapping of MBSFN reference signals, with the extended CP and $\Delta f=$ 15kHz.

-In time domain, for even-numbered slots, the reference symbols are inserted in the third and second OFDM symbol for $\Delta f = 15$kHz and $\Delta f = 7.5$kHz respectively

- For odd-numbered slots, they are inserted in the first and fifth OFDM slots for $\Delta f = 15$kHz and first and third for $\Delta f = 7.5$kHz

-In the frequency domain they are transmitted every two subcarriers for $\Delta f = 15$kHz and four subcarriers for $\Delta f = 7.5$kHz

-Based on these rules an example of resource mapping of MBSFN reference signals are shown in the fig 7.3

ii) UE-Specific Reference Signals

UE-specific reference signals support single-antenna port transmission with beamforming for the PDSCH and are transmitted on antenna port 5

-They are transmitted only on the resource blocks upon which the corresponding PDSCH is mapped, they are not transmitted in resource elements in which one of the other physical signals or physical channels is transmitted.

-For even-numbered slots, the reference symbols are inserted in the fourth and the seventh OFDM symbols; for odd-numbered slots, they inserted in the third and sixth OFDM symbols; with a frequency shit of two subcarriers between neighboring symbols.

- An example with normal CP is shown in fig 7.14

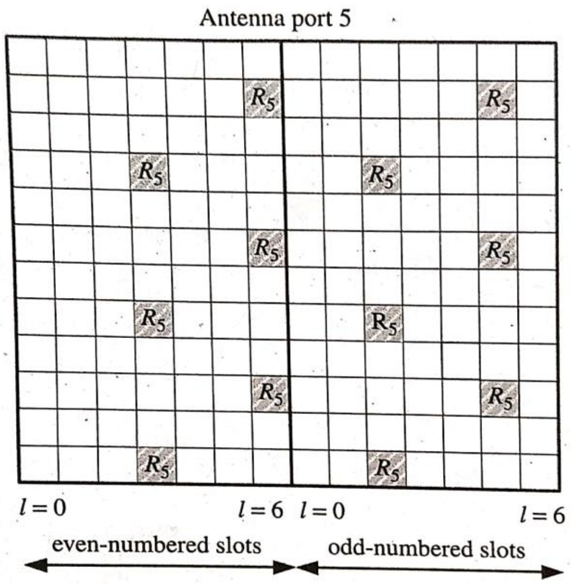

Figure 7.14 An example of mapping of UE-specific signals, with the normal CP.

Synchronization Signals

The downlink synchronization signals are sent to facilitate the cell search procedure, during which the time and frequency synchronization between UE, and the eNode-B is achieved and the cell ID is obtained.

- A physical-layer cell ID is uniquely defined as:

$$N_{ID}^{cell} = 3N_{ID}^{(1)} + 3N_{ID}^{(2)}$$

where $N_{ID}^{(1)} = 0,1,\ldots\ldots,167$ represents the physical-layer cell-ID group and $N_{ID}^{(2)} = 0,1,2$ represents the physical-layer ID within the cell-ID

-The synchronization signals are classified as primary and secondary synchronization signals

Primary synchronization signals identify the symbol timing and the cell ID index $N_{ID}^{(1)}$

Secondary synchronization signals identify the frame timing and cell ID group index $N_{ID}^{(2)}$

-They are designed to produce cell search results fast and with low complexity

-For frame structure type 1 the primary and secondary synchronization signals are mapped to the last and the second last OFDM symbols in slot 0 and 10.

- For frame structure type 2 the primary synchronization signal is mapped to the third OFDM symbol in slot 2 and 12 and secondary synchronization signal is mapped to the last OFDM symbols in slot 1 and 11

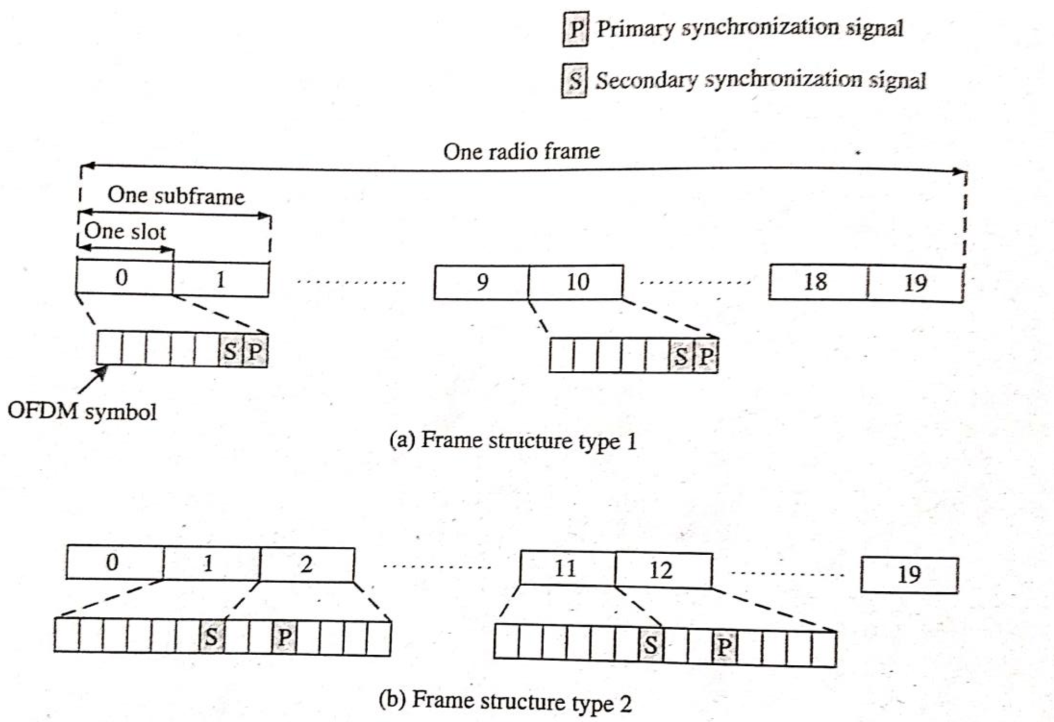

Figure 7.15 The mapping of primary and secondary synchronization signals to OFDM symbols for frame structure type 1 and type 2, with the normal CP. 'P' and 'S' denote primary and secondary synchronization signals, respectively.

H-ARQ in the Downlink

In LTE due to channel fading and ISI, it is impossible to guarantee error-free transmission. Hence an elegant approach to solve this is H-ARQ protocol, which combines FEC and retransmission within a single framework.
-Both Type I Chase Combining (CC) H-ARQ and Type II Incremental Redundancy (IR) H-ARQ schemes have been defined
-**At the receiver:** turbo decoding is applied to received code block, if no error detected, then an ACK signal is sent back to the transmitter through PUCCH (physical uplink control channel) and the decode block is sent to the upper layer
-if error is detected then an NAK is fed back and the code block is stored in the buffer
-the retransmitted code block which is detected by DCI is combined with the previously received version
-**At the transmitter:** for each retransmission the same turbo-encoded data is transmitted with different puncturing, so that each has a different redundancy version
-Puncturing is performed during rate matching, rate matcher can produce four different redundancy

versions of the original code block

- The H-ARQ transmission are indexed with the redundancy version rv_{idx}, which indicates a new transmission ($rv_{idx} = 0$) or the $rv_{idx} - th$ retransmission ($rv_{idx} = 1,2, or\ 3$)
-the time interval between successive H-ARQ transmissions is typically 8ms in LTE, this is large and leads to inefficiency
-To mitigate this an *N-channel Stop-and-Wait* protocol is used for downlink H-ARQ operation, it consists of N parallel H-ARQ processes
-The fig 7.16 shows a 10ms frame with TTI index 1 transmitting the H-ARQ process 1, TTI index 2 transmitting the H-ARQ process 2, and so on.
- The H-ARQ ACK/NAK for H-ARQ process 1 is received in TTI index 5
-then at TTI index 9 the H-ARQ process 1 is transmitted again (new transmission if an ACK received retransmission if NAK is received

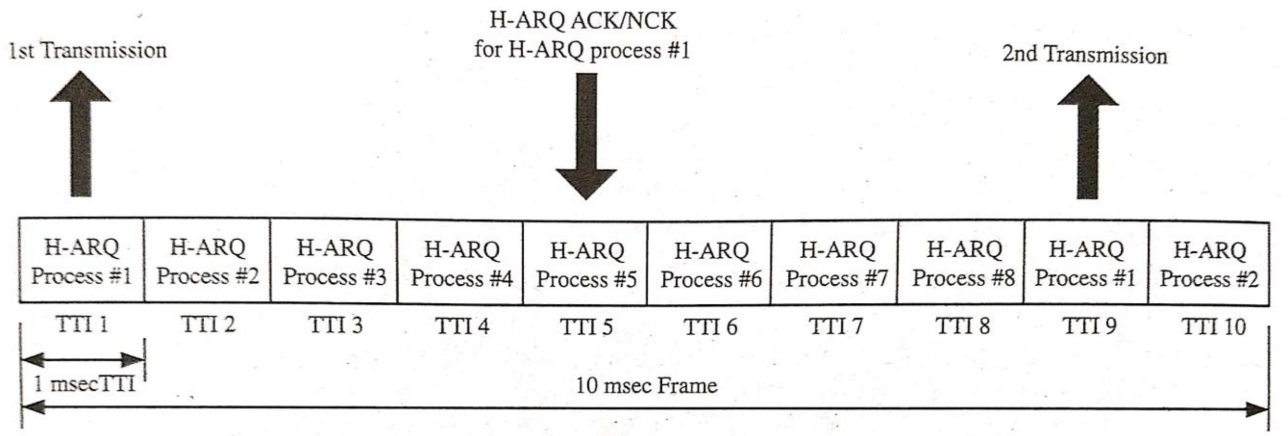

Figure 7.16 An example of a 10-msec frame with eight H-ARQ processes. The H-ARQ process 1 is transmitted in the first TTI, for which the H-ARQ ACK/NAK is received in the 5-th TTI, and then the H-ARQ process 1 is transmitted again in the 9-th TTI.

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