

SRM VALLIAMMAI ENGINEERING COLLEGE

(An Autonomous Institution)

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

QUESTION BANK



VI SEMESTER

PEC603 – ADVANCED WIRELESS COMMUNICATION TECHNIQUES

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PEC603 – ADVANCED WIRELESS COMMUNICATION TECHNIQUES

UNIT I - WIRELESS CHANNEL MODELS

Channel classification- channel models – COST -231 Hata model, NLOS Multipath Fading Models: Rayleigh, Rician, Nakagami, 5G Channel model requirements and Measurements, propagation scenarios, METIS channel models, Map-based model, stochastic model.

PART A

Q.No	Questions	CO	BT Level	Competence
1.	Define wireless channel classification and list any two types.	CO1	BTL1	Remember
2.	What is a propagation channel model in wireless communication?	CO1	BTL1	Remember
3.	State the significance of large scale and small scale fading in channel classification.	CO1	BTL2	Understand
4.	Write the general expression for path loss and mention the influence of distance.	CO1	BTL1	Remember
5.	What is the COST-231 Hata model and where is it used?	CO1	BTL2	Understand
6.	List the main parameters considered in the COST-231 Hata model.	CO1	BTL1	Remember
7.	Differentiate LOS and NLOS channels in wireless communication.	CO1	BTL2	Understand
8.	Define multipath fading and mention its basic cause.	CO1	BTL1	Remember
9.	State the key assumption behind Rayleigh fading.	CO1	BTL1	Remember
10.	What is Rician fading and what does the K-factor represent qualitatively?	CO1	BTL2	Understand
11.	Mention one situation where Rician fading is more appropriate than Rayleigh fading.	CO1	BTL2	Understand
12.	What characterizes the Nakagami fading model at a basic level?	CO1	BTL1	Remember
13.	State any two advantages of Nakagami model for wireless channel characterization.	CO1	BTL2	Understand
14.	What is meant by 5G channel model requirements in terms of frequency and bandwidth?	CO1	BTL2	Understand
15.	List any two key features expected from 5G channel models.	CO1	BTL1	Remember

16.	Define channel measurement in the context of 5G channel modeling.	CO1	BTL1	Remember
17.	What is meant by a propagation scenario in wireless channel modeling?	CO1	BTL2	Understand
18.	Give two examples of typical propagation scenarios considered for 5G channels.	CO1	BTL1	Remember
19.	What is the basic idea of the METIS channel models?	CO1	BTL2	Understand
20.	Distinguish between map-based and stochastic channel models in one sentence each.	CO1	BTL2	Understand
21.	What is a map-based channel model?	CO1	BTL1	Remember
22.	What is a stochastic channel model in wireless communications?	CO1	BTL1	Remember
23.	State any two limitations of purely stochastic channel models conceptually.	CO1	BTL2	Understand
24.	Why is it necessary to have different channel models for different environments?	CO1	BTL2	Understand

PART B

1.	a) Classify wireless channels and describe any three types with suitable examples.	(8)	CO1	BTL3	Apply
	b) For an urban macrocell scenario, justify the selection of an appropriate large-scale and small-scale channel model.				
2.	Using the COST-231 Hata model, show how path loss varies with base station height and frequency for a typical urban macrocell and comment on the trends.	(16)	CO1	BTL3	Apply
3.	For a given NLOS scenario, analyze qualitatively how Rayleigh, Rician, and Nakagami fading models differ in representing the received signal envelope.	(16)	CO1	BTL4	Analyze
4.	Consider a 5G mm Wave link in an urban street canyon. Develop an appropriate combination of map-based and stochastic channel models and justify your choice.	(16)	CO1	BTL4	Analyze

5.	a) Explain Rayleigh, Rician, and Nakagami fading models and highlight their key assumptions.	(8)	CO1	BTL4	Analyze
	b) Analyze which model is more suitable for (i) indoor hotspot, (ii) vehicular urban street, with reasons.				
6.	Apply the concept of propagation scenarios to design channel models for indoor office, urban microcell, and rural fixed wireless access cases.	(16)	CO1	BTL3	Apply
7.	Evaluate the key 5G channel model requirements and propose how METIS-style models address wideband, massive MIMO, and high-mobility conditions.	(16)	CO1	BTL4	Analyze
8.	Design a simple link scenario and choose appropriate large-scale and small-scale fading models; justify your modeling assumptions.	(16)	CO1	BTL3	Apply
9.	Analyze the impact of mobility (pedestrian vs vehicular) on small-scale fading characteristics for typical cellular links.	(16)	CO1	BTL4	Analyze
10.	Apply Nakagami fading with different shape factors to represent various propagation conditions and comment on model flexibility.	(16)	CO1	BTL3	Apply
11.	Analyze how LOS probability and blockage statistics influence the choice of 5G channel models in dense urban environments.	(16)	CO1	BTL4	Analyze
12.	Propose a measurement campaign outline for extracting channel parameters in a new 5G deployment scenario and discuss its importance.	(16)	CO1	BTL3	Apply
13.	Examine how frequency band (sub-6 GHz vs mmWave) affects path loss, shadowing, and multipath behavior in wireless channels.	(16)	CO1	BTL4	Analyze
14.	Apply COST-231 Hata and a simple free-space model to the same link and compare their suitability for macrocell design.	(16)	CO1	BTL3	Apply

15.	Analyze how environment (urban, suburban, rural) modifies the parameters in empirical path loss models and interpret the implications.	(16)	CO1	BTL4	Analyze
16.	Design a conceptual map-based channel model for a campus deployment and explain how building layout affects multipath.	(16)	CO1	BTL3	Apply
17.	a) Describe the main features of map-based and stochastic channel models.	(8)	CO1	BTL4	Analyze
	b) Analyze the suitability of hybrid (map-based + stochastic) modeling for 5G urban microcell deployments.				

UNIT II - CAPACITY OF WIRELESS CHANNELS

Capacity in AWGN, capacity of flat fading channel, capacity of frequency selective fading channels. Capacity of MISO, SIMO systems.

PART A

Q.No	Questions	CO	BT Level	Competence
1.	Define channel capacity for a communication channel.	CO2	BTL1	Remember
2.	What is AWGN channel and what does "additive" represent in it?	CO2	BTL1	Remember
3.	State the parameters on which AWGN channel capacity depends.	CO2	BTL2	Understand
4.	Distinguish between bandwidth-limited and power-limited regimes in AWGN channels.	CO2	BTL2	Understand
5.	Define flat fading channel in terms of coherence bandwidth.	CO2	BTL1	Remember
6.	What is the basic difference between flat fading and frequency selective fading?	CO2	BTL2	Understand
7.	Explain, in one or two sentences, how flat fading affects all frequency components of a signal.	CO2	BTL2	Understand
8.	What is a frequency selective fading channel?	CO2	BTL1	Remember
9.	List two effects of frequency selective fading on a transmitted signal.	CO2	BTL2	Understand

10.	Define ergodic capacity in fading channels conceptually.	CO2	BTL1	Remember
11.	What is outage capacity in the context of wireless channels?	CO2	BTL1	Remember
12.	Explain why channel state information (CSI) impacts capacity in fading channels.	CO2	BTL2	Understand
13.	What do MISO and SIMO systems stand for?	CO2	BTL1	Remember
14.	Briefly state how multiple transmit antennas can influence capacity (MISO).	CO2	BTL2	Understand
15.	Briefly state how multiple receive antennas can influence capacity (SIMO).	CO2	BTL2	Understand
16.	Define diversity order qualitatively in a capacity context.	CO2	BTL1	Remember
17.	What is the role of spatial multiplexing in increasing capacity (conceptual)?	CO2	BTL2	Understand
18.	List any two assumptions used in basic MIMO capacity analysis.	CO2	BTL1	Remember
19.	What is the effect of correlation between antenna elements on capacity conceptually?	CO2	BTL2	Understand
20.	Define SNR and indicate its role in determining channel capacity.	CO2	BTL1	Remember
21.	What is meant by water-filling idea in frequency selective channels ?	CO2	BTL2	Understand
22.	State any one practical limitation in achieving theoretical capacity in wireless channels.	CO2	BTL2	Understand
23.	Why is capacity of a frequency selective channel generally higher than a flat fading channel for same bandwidth?	CO2	BTL2	Understand
24.	How does time variation of the channel influence the notion of average capacity?	CO2	BTL2	Understand

PART B

1.	Apply the AWGN capacity expression to compute and interpret capacity for different SNR and bandwidth values relevant to 4G/5G systems.	(16)	CO2	BTL3	Apply
2.	a) Explain ergodic capacity and outage capacity for a flat fading channel with neat sketches.	(8)	CO2	BTL3	Apply
	b) Compare the impact of CSI at the transmitter on ergodic and outage capacity with suitable arguments.				

3.	Compare the capacities of flat fading and frequency selective fading channels for the same average SNR and bandwidth, highlighting the role of water-filling.	(16)	CO2	BTL4	Analyze
4.	For a SIMO system with two and four receive antennas, apply the capacity expressions and discuss how diversity order influences achievable rates.	(16)	CO2	BTL3	Apply
5.	Analyze the effect of antenna correlation in a MISO system on channel capacity and discuss practical ways to reduce spatial correlation.	(16)	CO2	BTL4	Analyze
6.	Design a simple link budget and capacity estimation for a cellular downlink using MISO transmission with beamforming at the base station.	(16)	CO2	BTL3	Apply
7.	Evaluate the trade-off between bandwidth expansion and power increase when targeting a specified capacity in an AWGN and in a fading channel.	(16)	CO2	BTL4	Analyze
8.	Apply capacity concepts to compare performance of narrowband vs wideband systems at the same transmit power constraint.	(16)	CO2	BTL3	Apply
9.	Analyze how imperfect CSI at the receiver affects capacity in fading channels and discuss possible compensation techniques.	(16)	CO2	BTL4	Analyze
10.	a) Explain the basic idea of water-filling power allocation in frequency selective channels.	(8)	CO2	BTL4	Analyze
	b) Analyze qualitatively the capacity gain obtained by water-filling over equal power allocation.				
11.	Compare MISO and SIMO capacities under the same total number of antennas and SNR, and analyze which configuration is preferable in practice.	(16)	CO2	BTL4	Analyze
12.	Apply Shannon capacity concepts to justify the need for high-order MIMO in 5G systems.	(16)	CO2	BTL3	Apply
13.	Analyze the effect of peak power constraints vs average power constraints on theoretical capacity results.	(16)	CO2	BTL4	Analyze

14.	Design a simple MISO link with transmit beamforming and discuss how beam steering improves effective SNR and capacity.	(16)	CO2	BTL3	Apply
15.	Analyze why practical systems rarely achieve Shannon capacity and discuss key limiting factors (coding, channel estimation, hardware).	(16)	CO2	BTL4	Analyze
16.	Apply capacity expressions to compare uplink and downlink performance in a cellular system with different power budgets.	(16)	CO2	BTL3	Apply
17.	Critically analyze the role of multi-antenna diversity vs spatial multiplexing in maximizing capacity under realistic constraints.	(16)	CO2	BTL4	Analyze

UNIT III - DIVERSITY

Realization of independent fading paths, Receiver Diversity: Selection combining, Threshold Combining, Maximum-ratio Combining, Equal gain Combining. Transmitter Diversity: CSI known at transmitter, CSI unknown at the transmitter.

PART A

Q.No	Questions	CO	BT Level	Competence
1.	Define diversity in wireless communications.	CO3	BTL1	Remember
2.	What is meant by independent fading paths?	CO3	BTL1	Remember
3.	List any two methods to realize independent fading paths.	CO3	BTL2	Understand
4.	What is spatial diversity and how is it realized at the receiver?	CO3	BTL2	Understand
5.	Define selection combining (SC) in receiver diversity.	CO3	BTL1	Remember
6.	Mention one advantage and one limitation of selection combining.	CO3	BTL2	Understand
7.	What is threshold combining in diversity reception?	CO3	BTL1	Remember
8.	Explain the basic idea behind threshold combining in one or two sentences.	CO3	BTL2	Understand

9.	Define maximum ratio combining (MRC).	CO3	BTL1	Remember
10.	Why is MRC often considered the optimal linear diversity combining scheme?	CO3	BTL2	Understand
11.	What is equal gain combining (EGC)?	CO3	BTL1	Remember
12.	Compare MRC and EGC in terms of required channel information.	CO3	BTL2	Understand
13.	Distinguish between receiver diversity and transmitter diversity.	CO3	BTL2	Understand
14.	What is meant by CSI known at transmitter?	CO3	BTL1	Remember
15.	What is meant by CSI unknown at transmitter?	CO3	BTL1	Remember
16.	How does knowledge of CSI at transmitter help in improving performance?	CO3	BTL2	Understand
17.	Define time diversity with a simple example.	CO3	BTL1	Remember
18.	Define frequency diversity with a basic explanation.	CO3	BTL1	Remember
19.	What is polarization diversity?	CO3	BTL1	Remember
20.	State any two benefits of using diversity techniques in wireless systems.	CO3	BTL2	Understand
21.	What is diversity order and what does it indicate qualitatively?	CO3	BTL1	Remember
22.	Explain the impact of increasing diversity order on error performance conceptually.	CO3	BTL2	Understand
23.	Why is diversity particularly useful in multipath fading environments?	CO3	BTL2	Understand
24.	Mention one practical limitation of implementing high-order diversity.	CO3	BTL2	Understand

PART B

1.	a) Explain selection combining (SC), equal gain combining (EGC), and maximum ratio combining (MRC) with conceptual diagrams.	(8)	CO3	BTL3	Apply
	b) Describe the relative performance and complexity of SC, EGC, and MRC in Rayleigh fading channels.				
2.	a) Define diversity order and combining gain, and explain their significance in link design.	(8)	CO3	BTL4	Analyze
	b) Analyze how increasing diversity order impacts BER, complexity, and hardware requirements.				
3.	For a given mobile channel with deep fades, propose suitable combinations of time, frequency, and spatial diversity and justify your design.	(16)	CO3	BTL3	Apply
4.	Compare receiver diversity and transmitter diversity schemes when CSI is known or unknown at the transmitter, focusing on implementation and performance.	(16)	CO3	BTL4	Analyze
5.	Design a simple diversity system using polarization diversity and explain how it mitigates fading in a base station receiver.	(16)	CO3	BTL3	Apply
6.	Analyze threshold combining performance relative to selection combining and MRC in terms of complexity and error performance in fading channels.	(16)	CO3	BTL4	Analyze
7.	Apply the concepts of combining gain and diversity gain to explain why diversity is preferred over mere power increase in fading channels.	(16)	CO3	BTL3	Apply
8.	Analyze how Doppler spread and coherence time influence the effectiveness of time diversity techniques such as interleaving.	(16)	CO3	BTL4	Analyze
9.	Apply frequency diversity via multicarrier or spread spectrum to mitigate frequency selective fading and explain the benefits.	(16)	CO3	BTL3	Apply

10.	Compare the relative advantages of spatial, frequency, and time diversity for different wireless applications.	(16)	CO3	BTL4	Analyze
11.	Design a simple receiver architecture that combines spatial and polarization diversity and explain its operation.	(16)	CO3	BTL3	Apply
12.	Analyze the practical constraints that limit the number of diversity branches in handheld devices.	(16)	CO3	BTL4	Analyze
13.	Apply MRC conceptually to a SIMO system in an OFDM receiver and explain how it improves performance on each subcarrier.	(16)	CO3	BTL3	Apply
14.	Analyze performance degradation when the assumption of independent fading branches is violated due to correlation.	(16)	CO3	BTL4	Analyze
15.	Propose a diversity scheme suitable for high-speed train communication and justify the chosen types of diversity.	(16)	CO3	BTL3	Apply
16.	Analyze how diversity techniques complement error control coding in combating fading and noise.	(16)	CO3	BTL4	Analyze
17.	Apply diversity principles to suggest improvements in a given fading-prone wireless link case study.	(16)	CO3	BTL3	Apply

UNIT IV – MULTI USER MIMO COMMUNICATIONS

Advances in MIMO wireless communications: Spatial modulation, MIMO based cooperative communication and cognitive radio, multiuser MIMO, cognitive-femtocells and large MIMO systems for 5G wireless.

PART A

Q.No	Questions	CO	BT Level	Competence
1.	Define MIMO and mention what "multi user MIMO" implies.	CO4	BTL1	Remember
2.	What is spatial modulation (SM) in MIMO systems?	CO4	BTL1	Remember
3.	State one key idea of spatial modulation in terms of antenna index.	CO4	BTL2	Understand
4.	Give any two advantages of spatial modulation.	CO4	BTL2	Understand
5.	What is cooperative communication in wireless networks?	CO4	BTL1	Remember

6.	Mention the basic role of relay nodes in cooperative communication.	CO4	BTL2	Understand
7.	Define cognitive radio in simple terms.	CO4	BTL1	Remember
8.	What is the main objective of cognitive radio in spectrum usage?	CO4	BTL2	Understand
9.	Explain the term "primary user" and "secondary user" in cognitive radio context.	CO4	BTL1	Remember
10.	What is meant by MIMO based cooperative communication?	CO4	BTL2	Understand
11.	Define multiuser MIMO system.	CO4	BTL1	Remember
12.	Why is interference management important in multiuser MIMO?	CO4	BTL2	Understand
13.	State one benefit of serving multiple users simultaneously with MIMO.	CO4	BTL2	Understand
14.	What are cognitive femtocells in cellular networks?	CO4	BTL1	Remember
15.	Mention one advantage of using cognitive femtocells in 5G systems.	CO4	BTL2	Understand
16.	What is meant by "large MIMO" or "massive MIMO" system?	CO4	BTL1	Remember
17.	Give any two motivations for large MIMO systems in 5G wireless.	CO4	BTL2	Understand
18.	Define beamforming in the context of MIMO systems.	CO4	BTL1	Remember
19.	What is spatial multiplexing gain in MIMO?	CO4	BTL1	Remember
20.	State one challenge in implementing multiuser MIMO in practice.	CO4	BTL2	Understand
21.	How does channel estimation affect multiuser MIMO performance?	CO4	BTL2	Understand
22.	Why are multiuser MIMO techniques important for 5G networks?	CO4	BTL2	Understand
23.	Define user scheduling in a multiuser MIMO system.	CO4	BTL1	Remember
24.	What is interference alignment at a conceptual level?	CO4	BTL2	Understand

PART B

1.	Apply the concept of spatial modulation to design a simple MIMO scheme with four transmit antennas and explain how information is mapped to antenna indices and symbols.	(16)	CO4	BTL3	Apply
2.	Analyze the advantages and limitations of spatial modulation compared to conventional spatial multiplexing in terms of spectral efficiency and receiver complexity.	(16)	CO4	BTL4	Analyze
3.	For a cooperative communication system with one source, one relay, and one destination, propose a MIMO-based cooperative strategy and justify its benefits.	(16)	CO4	BTL3	Apply
4.	Examine how cognitive radio and cognitive femtocells improve spectrum utilization in 5G, and analyze the interference management challenges they introduce.	(16)	CO4	BTL4	Analyze
5.	Design a basic multiuser MIMO downlink scenario and discuss user scheduling and precoding concepts.	(16)	CO4	BTL3	Apply
6.	a) Describe the basic idea of massive MIMO and its deployment in 5G systems.	(8)	CO4	BTL3	Apply
	b) Explain in detail the key implementation issues such as channel estimation, pilot contamination, and hardware constraints.				
7.	Apply beamforming principles to a multiuser MIMO system and explain how spatial beams can be used to separate users and control interference.	(16)	CO4	BTL3	Apply
8.	Analyze how channel state information quality affects multiuser MIMO precoding and overall system performance.	(16)	CO4	BTL4	Analyze
9.	Apply cooperative communication ideas to design a simple relay-aided MIMO link for coverage extension in a cellular network.	(16)	CO4	BTL3	Apply
10.	Compare centralized and distributed MIMO/cooperative schemes in terms of complexity and backhaul requirements.	(16)	CO4	BTL4	Analyze
11.	Design a cognitive radio-based multiuser MIMO system for secondary users sharing spectrum with a primary cellular	(16)	CO4	BTL3	Apply

	system and explain protection mechanisms.				
12.	Analyze the challenges of implementing multiuser MIMO in dense small-cell and femtocell deployments.	(16)	CO4	BTL4	Analyze
13.	Apply spatial multiplexing and diversity modes in a multiuser scenario and explain how mode switching can be done based on channel conditions.	(16)	CO4	BTL3	Apply
14.	Analyze inter-user interference in multiuser MIMO and discuss possible interference alignment or cancellation strategies conceptually.	(16)	CO4	BTL4	Analyze
15.	Design a simple scheduler that selects users for MU-MIMO transmission based on channel orthogonality and explain its operation.	(16)	CO4	BTL3	Apply
16.	Analyze fairness vs throughput trade-offs in multiuser MIMO scheduling.	(16)	CO4	BTL4	Analyze
17.	Apply the concepts of large MIMO and cognitive femtocells to propose a high-capacity, interference-aware 5G architecture.	(16)	CO4	BTL3	Apply

UNIT V - MIMO TECHNOLOGY

Introduction to MUD, Linear decorrelator, MMSE MUD, Adaptive MUD, MIMO-MUD WCDMA/UMTS-3GPP-LTE.

PART A

Q.No	Questions	CO	BT Level	Competence
1.	Define multiuser detection (MUD).	CO5	BTL1	Remember
2.	Why is MUD required in multiuser communication systems?	CO5	BTL2	Understand
3.	What is a linear decorrelator detector conceptually?	CO5	BTL1	Remember
4.	How does a decorrelator attempt to suppress multiuser interference?	CO5	BTL2	Understand
5.	Define MMSE MUD in simple terms.	CO5	BTL1	Remember
6.	State one difference between decorrelator-based MUD and MMSE MUD.	CO5	BTL2	Understand

7.	What is adaptive MUD?	CO5	BTL1	Remember
8.	Mention one reason for using adaptive algorithms in MUD.	CO5	BTL2	Understand
9.	What does MIMO-MUD refer to?	CO5	BTL1	Remember
10.	State any one advantage of combining MIMO with MUD.	CO5	BTL2	Understand
11.	Expand WCDMA and indicate its basic multiple access technique.	CO6	BTL1	Remember
12.	What is the main spreading concept in WCDMA?	CO6	BTL2	Understand
13.	Expand UMTS and mention its generation in cellular standards.	CO6	BTL1	Remember
14.	Briefly indicate the role of MIMO in UMTS evolution.	CO6	BTL2	Understand
15.	What is 3GPP and why is it important for mobile communication standards?	CO6	BTL1	Remember
16.	State one MIMO-related feature introduced in 3GPP LTE.	CO6	BTL2	Understand
17.	Expand LTE and mention its cellular generation.	CO6	BTL1	Remember
18.	Conceptually, how does LTE benefit from MIMO techniques?	CO6	BTL2	Understand
19.	Define uplink and downlink in cellular systems.	CO6	BTL1	Remember
20.	State one basic difference between uplink and downlink MUD requirements.	CO5	BTL2	Understand
21.	What is interference cancellation in the context of MUD?	CO5	BTL1	Remember
22.	Mention one limitation of practical multiuser detection schemes.	CO5	BTL2	Understand
23.	Define SIC (successive interference cancellation).	CO5	BTL1	Remember
24.	How do standardization bodies (like 3GPP) influence practical MIMO-MUD designs?	CO6	BTL2	Understand
25.	State any one future trend in advanced MIMO or MUD for beyond-5G systems in one or two lines.	CO6	BTL2	Understand
PART B				

1.	Apply the principles of linear decorrelator and MMSE multiuser detectors to a CDMA uplink and qualitatively compare their interference suppression capability.	(16)	CO5	BTL3	Apply
2.	a) Describe successive interference cancellation (SIC)-based multiuser detection with a neat conceptual diagram.	(8)	CO5	BTL3	Apply
	b) Explain the advantages and drawbacks of SIC and PIC in heavily loaded CDMA/WCDMA systems.				
3.	For a WCDMA/UMTS uplink, propose a MIMO-MUD receiver structure and explain how it improves performance over a single-user matched filter.	(16)	CO5	BTL3	Apply
4.	Examine how adaptive algorithms can be used to realize adaptive MUD in time-varying channels, discussing convergence and tracking issues conceptually.	(16)	CO5	BTL4	Analyze
5.	Apply interference cancellation and MUD concepts to design a receiver for a heavily loaded CDMA system and justify your design choices.	(16)	CO5	BTL3	Apply
6.	Analyze complexity–performance trade-offs among matched filter, decorrelator, MMSE, and SIC-based multiuser detectors.	(16)	CO5	BTL4	Analyze
7.	Apply MIMO-MUD ideas to an uplink OFDM-based multiuser system and describe how spatial and multiuser detection gains combine.	(16)	CO5	BTL3	Apply
8.	Analyze how MUD performance is impacted by power control errors and near–far effects in CDMA or WCDMA systems.	(16)	CO5	BTL4	Analyze
9.	Apply the concept of MIMO in LTE downlink to describe how different transmission modes (spatial multiplexing, transmit diversity) are used for various channel conditions.	(16)	CO6	BTL3	Apply
10.	Analyze the evolution from WCDMA/UMTS to LTE in terms of multiple access, MIMO support, and resulting improvements in spectral efficiency.	(16)	CO6	BTL4	Analyze
11.	Apply knowledge of 3GPP standards to outline key MIMO features in LTE and LTE-Advanced for downlink and uplink.	(16)	CO6	BTL3	Apply

12.	Analyze how 3GPP standardization decisions shape practical MIMO and MUD implementations in commercial systems.	(16)	CO6	BTL4	Analyze
13.	For an advanced wireless system such as 5G NR, design a high-level MIMO and MUD strategy for a dense urban scenario and justify your choices.	(16)	CO6	BTL4	Analyze
14.	Apply concepts of massive MIMO and hybrid beamforming to propose an architecture for mm Wave 5G base stations.	(16)	CO6	BTL3	Apply
15.	Analyze challenges in implementing real-time MUD and MIMO processing on hardware platforms with limited resources.	(16)	CO6	BTL4	Analyze
16.	Apply system-level thinking to suggest how MUD and MIMO jointly enhance capacity and reliability in a heterogeneous network.	(16)	CO6	BTL3	Apply
17.	a) Explain how MIMO and MUD concepts are used together in an OFDM-based uplink system.	(8)	CO6	BTL4	Analyze
	b) Analyze the main challenges in implementing real-time MIMO-MUD processing in practical 5G hardware.				