M. Tech.

IN

TELECOMMUNICATION

CURRICULUM AND SYLLABI

(Applicable from 2023 admission onwards)

Department of Electronics and Communication Engineering

NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

Kozhikode - 673601, KERALA, INDIA

The Programme Educational Objectives (PEOs) of M. Tech. in Telecommunication

PEO1	Graduates apply their knowledge in mathematics, signal processing and communications for fostering skills to identify, analyze and solve engineering problems pertaining to design, development and deployment of telecommunication systems.
PEO2	Graduates demonstrate high levels of creativity, critical thinking, research aptitude and technical and communication skills for productive and successful careers in industries, R and D organizations and other allied professions.
PEO3	Graduates possess commitment to professional ethics and sensitivity to diverse societal needs in their professional careers.
PEO4	Graduates exhibit a desire for life-long learning through technical training, teaching, research and developmental activities, participation in conferences/workshops and professional societies.

Programme Outcomes (POs) & Programme Specific Outcomes (PSOs) of M. Tech. in Telecommunication

PO1	An ability to independently carry out research /investigation and development work to solve practical problems.
PO2	An ability to write and present a substantial technical report/document.
PO3	Students should be able to demonstrate a degree of mastery over the area as per the specialization of the programme. The mastery should be at a level higher than the requirements in the appropriate bachelor programme.
PSO 1	Ability to learn the latest technologies and products in the area of Communication & Networking.
PSO 2	Competence in using modern tools (software and hardware) for the design and analysis of systems based on communications technology and information networking.

CURRICULUM

The minimum number of credits to be earned by a student for the award of the degree is 75. The total credits must not exceed 77.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M. Tech. programme shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Programme Core (PC)	23
2.	Programme Electives (PE)	15
3.	Institute Elective (IE)	2
4.	Projects	35

The effort to be put in by the student is indicated in the tables below as follows:

L: Lecture (One unit is of 50 minute duration)
T: Tutorial (One unit is of 50 minute duration)
P: Practical (One unit is of one hour duration)
O: Outside the class effort / self-study (One unit is of one hour duration)

PROGRAMME STRUCTURE

Semester I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EC6301E	Mathematics for Communication Engineering	3	0	2	7	4	PC
2.	EC6302E	Communication Networks	3	0	2	7	4	PC
3.	EC6303E	Wireless Communication Techniques	3	0	2	7	4	PC
4.	EC6304E	Information Theory and Coding	3	0	0	6	3	PC
5.		Elective 1					3	PE
6.		Institute Elective					2	IE
		Total					**20**	**--**

Semester II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EC6305E	Estimation and Detection Theory	3	0	2	7	4	PC
2.	EC6306E	Communication Systems, Standards and Practice	3	0	0	6	3	PC
3.	EC6307E	Communication System Design Lab	0	0	2	1	1	PC
4.		Elective 2					3	PE
5.		Elective 3					3	PE
6.		Elective 4					3	PE
7.		Elective 5					3	PE

8.	EC6396E	Project Phase I	0	0	0	6	2	PC
		Total					**22**	**--**

Semester III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EC7397E	Project Phase II	0	0	0	9	3	PC
2.	EC7398E	Project Phase III	0	0	0	45	15	PC
		Total					**18**	**--**

Semester IV

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EC7399E	Project Phase IV	0	0	0	45	15	PC
		Total					**15**	**--**

List of Electives

Institute Elective Basket (Students need to credit Minimum 2 credits from this basket):

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	IE6001E	Entrepreneurship Development	2	0	0	4	2
2	ZZ6001E	Research Methodology	2	0	0	4	2
3	MS6174E	Technical Communication and Writing	2	1	0	4	2

Elective Basket 1 (Students need to credit Minimum 3 credits from this basket):

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	EC6321E	Digital Communication Techniques	3	0	0	6	3
2	EC6322E	Advanced Techniques in Error Control Coding	3	0	0	6	3
3	EC6323E	MIMO Communication Systems	3	0	0	6	3
4	EC6324E	Multi Carrier Systems and Applications	3	0	0	6	3
5	EC6325E	Markov modelling and Theory of Queues	3	0	0	6	3
6	EC6326E	Wireless Networking	3	0	0	6	3
7	EC6327E	Ultra-Wideband Communications	3	0	0	6	3
8	EC6328E	Nano magnetism and Spintronics	3	0	0	6	3
9	EC6329E	5G: Features, Standards and Evolution	3	0	0	6	3
10	EC6330E	Telecom network management	3	0	0	6	3
11	EC6331E	RF and Microwave Active Circuits	3	0	0	6	3
12	EC6332E	RF and Microwave Passive Circuits	3	0	0	6	3
13	EC6333E	Antenna Design	3	0	0	6	3
14	EC6334E	Adaptive Signal Processing	3	0	0	6	3

Elective Basket 2 (Students need to credit Minimum 3 credits from this basket):

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	EC6404E	Machine Learning and Pattern Recognition	3	0	2	7	4
2	EC6421E	Array Signal Processing	3	0	0	6	3
3	EC6423E	Digital Image Processing Techniques	3	0	0	6	3
4	EC6424E	Linear and Non-linear Optimization	3	0	0	6	3
5	EC6445E	Computer Vision	3	0	0	6	3
6	EC6446E	Deep Learning	3	0	0	6	3
7	EC6447E	Deep Learning in Computer Vision	3	0	0	6	3
8	EC6451E	Reinforcement Learning	3	0	0	6	3

Students can take a maximum of two elective courses, each having minimum 3 credits, can be credited from courses offered in any M. Tech. specialization by the Institute, with the consent of the Programme Coordinator and the Course Faculty.

Syllabus for M. Tech in Telecommunication

EC6301E MATHEMATICS FOR COMMUNICATION ENGINEERING

Pre-requisites: NIL

L	T	P	O	C
3	0	2	7	4

Total Sessions: 39L + 26P

Course Outcomes:

CO1: Acquire the ability to model and analyze random experiments using the concepts of probability theory.

CO2: Apply the concepts of probability, random variables/ vectors/sequences/processes to analyze statistical problems in communication engineering.

CO3: Understand the concepts of high dimensional geometry to model and analyze signals and linear systems.

CO4: Understand various matrix properties and decomposition techniques to design and optimize communication systems

Lecture Sessions:

Sample space, events, axioms of probability, conditional probability and independence of events - Random variables: distributions and their parameters - Functions of random variables - Moment generating functions - Jointly distributed random variables and their transformations, independence, conditional distribution, covariance, correlation, conditional expectation - Inequalities and bounds: Cauchy-Schwarz, Chebyshev, Markov - Convergence of a sequence of random variables - Limit theorems, central limit theorem, strong law of large numbers.

Random processes: specifications, nth order joint PDFs, ergodicity, stationarity, wide-sense stationarity, correlation properties, power spectral density - Gaussian processes - Random processes as input to LTI system.
Linear Algebra: Vector spaces, basis, dimension, linear transformation, matrix representation of linear transforms, fundamental subspaces of a matrix - Fundamental theorem of linear algebra - Inner product spaces, Gram-Schmidt algorithm, orthonormal matrices, determinants.

Norms, vector norms, the equivalence of norms, dual norms, Matrix norms, spectral radius - Eigenvalues and eigenvectors, characteristic polynomial, diagonalization, unitary matrices, Schur's triangularization theorem, Cayley-Hamilton theorem, normal matrices - Decompositions: QR, LU, and Cholesky - Hermitian matrices, positive semi-definite matrices, singular value decomposition.

Practical Sessions:

1. Generation of continuous and discrete random variables
2. Empirical computation of the distribution of conditional random variables
3. Generation of vector random variables
4. Application of the law of large numbers to Monte Carlo integration
5. Simulation of Discrete Time Markov Chain
6. Estimation of power spectral density using white noise
7. AEP and Shannon source coding theorem.
8. Generation of AWGN

References:

1. Papoulis and S. U. Pillai, *Probability, Random Variables, and Stochastic Processes*, 4th Edition, McGraw Hill 2002
2. Geoffrey Grimmett, *Probability and Random Processes*, 3rd Edition, Oxford University Press, 2001.
3. Anurag Kumar, *Discrete Event Stochastic Processes, Lecture Notes for an Engineering Curriculum*,
4. Dept. ECE, Indian Institute of Science, Bengaluru, 2012. [Online]. Available:
5. https://ece.iisc.ac.in/anurag/wp-content/uploads/2020/07/discrete-event-stochastic-processes.pdf
6. Gilbert Strang, Introduction to Linear Algebra, Wellesley-Cambridge Press, 6th Edn., 2023.
7. Kenneth Hoffman, Ray Kunze, *Linear Algebra*, 2nd edition, PHI Learning, 2014.

EC6302E COMMUNICATION NETWORKS

Pre-requisites: NIL

L	T	P	O	C
3	0	2	7	4

Total Sessions: 39L + 26P

Course Outcomes:

CO1: Describe the basic building blocks of a computer network and understand the architecture of the global Internet
CO2: Describe, analyze and compare a number of datalink, network, and transport layer protocols
CO3: Develop a strong theoretical foundation on performance analysis of various queueing models with applications to Internet
CO4: Develop the ability to explore the design and development of more resource efficient and eco-friendly networking technologies

Lecture Sessions:
Introduction : General issues in networking - Circuit switching, packet switching and virtual circuit switching - Layered architecture for Internet -Performance metrics for networks- Data link layer- Framing- Error detection - Reliable Transmission - Automatic repeat request (ARQ) schemes and performance analysis- medium access control (MAC) protocols - Direct Link Networks- -Ethernet and multiple access networks - IEEE 802.11 wireless LANs: Distributed coordination function

Internetworking: IPV4 and IPV6- Addressing in internet- Subnetting and supernetting- Routing in Internet - Routing protocols for Internet- Datagram forwarding in Internet- Address resolution protocol (ARQ)- Dynamic host configuration protocol (DHCP)- Mobile IP Transport layer protocol- TCP and UDP- End-to-end reliability in Internet- Time out computation in TCP- TCP flow control and congestion control - Random Early Detection

Performance analysis: Introduction to Queuing theory- Markov processes: Markov property - Discrete time Markov Chain- transition probabilities, irreducibility, aperiodicity, transitive, null recurrent and positive recurrent chains. Poisson process- continuous time Markov chain -Queuing models for Datagram networks- Little's theorem- M/M/1 queuing systems- M/M/m/m queuing models- M/G/1 queue- Mean value analysis- Time reversibility- Closed queuing networks- Jackson's Networks.

Practical Sessions:
1. Socket Programming for ping command
2. Socket Programming for Web Server
3. Chat Application in C Language
4. Network Sniffer to capture incoming packets
5. NS2 simulation of wireless networks

References:

1. Peterson L.L. and Davie B.S., *Computer Networks: A System Approach*, Elsevier, 6^{th} edition, 2020
2. James. F. Kurose and Keith.W. Ross, *Computer Networks, A top-down approach featuring the Internet*, Pearson Education, 8^{th} Edition, 2020
3. D. Bertsekas and R. Gallager, *Data Networks*, PHI, 2nd Edition, 2000
4. S. Keshav, *An Engineering Approach to Computer Networking*, Pearson Education, 2005
5. Anurag Kumar, *Discrete Event Stochastic Processes, Lecture Notes for an Engineering Curriculum*, Dept. ECE, Indian Institute of Science, Bengaluru, 2012. [Online]. Available: https://ece.iisc.ac.in/anurag/wp-content/uploads/2020/07/discrete-event-stochastic-processes.pdf

EC6303E WIRELESS COMMUNICATION TECHNIQUES

Pre-requisites: NIL

L	T	P	O	C
3	0	2	7	4

Total Sessions: 39L + 26P

Course Outcomes:

CO1: Classify the wireless channel of a given wireless communication system into the available analytical or empirical models

CO2: Apply appropriate techniques to mitigate the impact of channel impairments

CO3: Analyse the capacity and reliability of wireless communication systems

CO4: Design and Develop resource efficient and eco-friendly wireless technologies

Lecture Sessions:

Review of Cellular concept: TDMA, FDMA, CDMA, frequency reuse, co-channel interference, power control for reducing interference, improving capacity in cellular systems, cell splitting, sectoring, hand-off strategies, call blocking in cellular networks.

Mobile radio propagation, free space propagation model, ground reflection model, large scale path loss, small scale fading and multipath propagation - impulse response model of a multipath channel - Parameters of a mobile multipath channel: multipath delay spread, doppler spread, coherence bandwidth, coherence time, time dispersion and frequency selective fading, frequency dispersion and time selective fading, concepts of level crossing rate and average fade duration.

Time, frequency, and space diversity, concept of diversity branches and signal paths, performance gains, selective combining, maximal ratio combining, equal gain combining, Alamouti scheme, MGFs in diversity analysis.

Orthogonal frequency division multiplexing (OFDM) fundamentals, transmitter & receiver chain, concept of cyclic prefix, peak-to-average power ratio, performance study, OFDMA, SC-FDMA, case study with respect to LTE/5G.

Capacity of wireless channels: AWGN channel capacity - Capacity of fading channels: slow and fast fading channels, frequency selective fading channels - Multiuser Capacity: uplink Fading Channel, downlink Fading Channel, frequency-Selective fading Channels - Multiuser Diversity

Practical Sessions:

1. BER of BPSK/QPSK over AWGN channel
2. Simulation of wireless fading channels
3. Experiments on using diversity techniques to mitigate fading: maximal ratio combining, selective combining, and equal gain combining
4. BER performance of OFDM varying guard interval.

References:

1. Andrea Goldsmith, *Wireless Communications*, Cambridge University press, 2006.
2. David Tse and Pramod Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, South Asian Edition, 2006
3. T.S. Rappaport, *Wireless Communication*, Principles and Practice, PHI, 2002.
4. Simon Haykin and Michael Moher, *Modern Wireless Communications*, Pearson Education, 2007
5. F. Khaled, S. Kaiser, *Multi-carrier and spread spectrum systems*, John Wiley & Sons, 2003.
6. Aditya K. Jagannatham, *Principles of modern wireless communication systems*. McGraw-Hill Education, 2015.

EC6304E INFORMATION THEORY AND CODING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Analyze the fundamental limits on the error-free representation of information signals and the transmission of such signals over a noisy communication channel.

CO2: Design and analyze lossless data compression techniques with varying efficiencies as per problem requirements.

CO3: Analyze the capacity of discrete and continuous channels

CO4: Design various encoding and decoding strategies for block and convolutional codes.

Entropy - Memoryless sources- Markov sources- Entropy of a discrete random variable- Joint, conditional and relative entropy- Mutual Information and conditional mutual information- Chain relation for entropy, relative entropy, and mutual Information- Source coding problem - Kraft's inequality - Optimal codes- Huffman code - Shannon's Source Coding Theorem – Introduction to Rate distortion Theory- Rate distortion function of binary and Gaussian sources.

The capacity of discrete memoryless channels - Asymptotic Equipartition Property (AEP) - Shannon's Channel Coding Theorem and Converse - Entropy of continuous sources and channels - Differential entropy – Entropy maximization results- Waveform channels- Gaussian channels- Shannon-Hartley Theorem - Shannon limit – Modulation and coding trade-off of digital modulation schemes-power limited and bandwidth limited systems.

Channel Coding - Error detection and correction - Review of vector space - Linear block codes – Generator and parity check matrices - Distance properties - Non-systematic and systematic codes - Finite fields - Galois Field arithmetic- Extension Fields - Minimal Polynomials - Conjugates and Conjugacy classes - Cyclic codes – Construction and Decoding- BCH codes – Construction and decoding - Reed Solomon codes - Introduction to low-density parity check codes - Convolutional codes - Maximum likelihood decoding - Viterbi decoding - Hard decision and soft decision decoding - Concatenated codes - Introduction to Turbo codes.

References:

1. Thomas M. Cover and Joy A. Thomas, *Elements of Information Theory*, Wiley India Pvt Ltd, 2nd Edition 2013.
2. Shu Lin and Daniel. J. Costello Jr., *Error Control Coding: Fundamentals and applications*, 2nd Edition, Pearson Education, 2010.
3. John G. Proakis and M. Salehi, *Digital Communication*, 5th Edition, McGraw Hill Education, 2014.
4. David J. C. MacKay, *Information Theory, Inference and Learning Algorithms*, Cambridge University Press, 2005
5. R. E. Blahut, *Theory, and Practice of Error Control Codes*, Addison-Wesley, 1983.
6. MacWilliams, F. J., and N. J. A. Sloane, *The Theory of Error Correcting Codes*, Amsterdam, Netherlands: North-Holland, 1978.

EC6305E ESTIMATION AND DETECTION THEORY

Pre-requisites: Matrix Theory, Probability and Random Processes.

L	T	P	O	C
3	0	2	7	4

Total Sessions: 39L + 26P

Course Outcomes:

CO1: Acquire knowledge of the estimation and detection theory and apply in real-life applications.
CO2: Describe and validate the estimation techniques through the standard properties and bounds.
CO3: Derive, implement, and analyze various techniques for parameter estimation.
CO4: Formulate, describe, and analyze various decision techniques in noisy observations.
CO5: Implement scientific research papers on estimation/detection problems using simulation tools.

Lecture Sessions:

Fundamentals of Estimation Theory
Fundamentals of Estimation Theory: Role of Estimation in Communication Systems - Desirable Properties of Estimators - Minimum Variance Unbiased (MVU) Estimators - Finding MVU Estimators - Cramer-Rao Lower Bound - Scalar and Vector Parameter Estimation Scenarios - Transformation of Parameters - Linear Modeling - Generic Formulation and Examples

Parameter Estimation
Deterministic Parameter Estimation: Best Linear Unbiased Estimator - Maximum Likelihood Estimation (MLE) - Closed form and Numerical Determination Cases - Non-linear MLE - Least Squares Estimation (LSE) - Batch Processing, Geometric Representation of LSE, Order Recursive LSE and Sequential LSE.
Random Parameter Estimation: Philosophy of Bayesian Estimators - Multivariate Gaussian Random Variables - Jointly Gaussian Case - Bayesian Linear Model - Minimum Mean Square Error (MMSE) Estimator - Maximum a Posteriori (MAP) Estimator - Linear MMSE Estimation and Sequential Linear MMSE Estimation - Wiener and Kalman Filters.

Detection Theory
Fundamentals of Detection Theory: Hypothesis Testing - General Modeling of Binary Hypothesis Testing Problem - Bayes' Detection - MAP Detection - ML Detection - Minimum Probability of Error Criterion - Min-Max Criterion - Neyman-Pearson Criterion - Receiver Operating Characteristics Curves - Multiple Hypothesis Testing - Composite Hypothesis Testing - Detection of Signals in White Gaussian Noise (WGN): Binary Detection of Known Signals in WGN, M-ary Detection of Known Signals in WGN - Matched Filter Approach.

Practical Sessions:
1. Plot the probability density function of real WGN and various estimators.
2. Plot the CRLB for DC level estimation.
3. Implement various methods for parameter estimation and validate through CRLB.
4. Plot the receiver operating characteristic curve of Neyman-Pearson criterion.
5. Detect a known signal in WGN and correlated Gaussian noise.
6. Detect a signal with unknown amplitude in WGN.
7. Detect a sinusoidal signal with unknown amplitude/phase/frequency in WGN.

References:

1. S. M. Kay, *Fundamentals of Statistical Signal Processing, Vol. 1: Estimation Theory*, Pearson Education, 1993.
2. S. M. Kay, *Fundamentals of Statistical Signal Processing, Vol. 2: Detection Theory*, Pearson Education, 1993.
3. S. M. Kay, *Fundamentals of Statistical Signal Processing, Vol. 3: Practical Algorithm Development*, Pearson Education, 2018.
4. Jerry M. Mendel, *Lessons in Estimation Theory for Signal Processing, Communication and Control*, Prentice Hall Inc., 1995.
5. Ralph D. Hippenstiel, *Detection Theory: Applications and Digital Signal Processing*, CRC Press, 2002.

EC6306E COMMUNICATION SYSTEMS, STANDARDS AND PRACTICE

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Determine key configuration parameters of 5G system to meet given requirements.
CO2: Analyze 5G standards and design enhancements.
CO3: Determine key configuration parameters of Wi-Fi 6, and analyze modifications and enhancements of Wi-Fi 6 features.
CO4: Compare features and applications of existing and upcoming wireless technologies.

5G
Review of cellular concept - Review of basics of wireless communication - Evolution to 5G - Spectrum for 5G, frequency ranges and bands, spectrum sharing, NR-U - 5G use cases, requirements and performance metrics: IMT 2020, eMBB, URLLC, mMTC - Key 5G features - 3GPP and 5G standards - 5G architecture: 5G RAN architecture, 5GC architecture, Network slicing – Non-Public Networks – Control plane protocol stack: NAS, RRC - User plane stack: SDAP, PDCP, RLC, MAC, PHY - PHY layer: Numerology and slot structure, downlink/uplink data/control aspects, OFDM waveform, MCS options, MIMO, link budget calculation, peak throughput calculations - Initial access - Mobility - Selected topics related to URLLC, MTC, V2X, IAB, power saving features, big data collection in 5GC - Selected topics on 6G.

Wi-Fi
Evolution of Wi-Fi - Spectrum: unlicensed spectrum, bands - Wi-Fi use cases, requirements and performance metrics - Wi-Fi architectures - MAC aspects of IEEE 802.11 ax: BSS coloring, OFDMA, multi-user operation - power saving features, frame aggregation - PHY aspects of IEEE 802.11ax: MU-MIMO, Numerology, tone plan, physical layer packet formats, MCS options - Selected topics on Wi-Fi 7.

Non-cellular wireless technologies
Classifications of wireless technologies: based on coverage area, application - Vehicular ad hoc networks, wireless Sensor networks - IEEE 802.15.4 LR-WPAN: PHY, MAC - Selected topics on IEEE 802.15.1 Bluetooth, LoRa, Sigfox, IEEE 802.16 WiMAX, IEEE 802.15.4 Zigbee, IEEE 802.15.6, WirelessHART.

References:

1. Juan Montojo, Peter Gaal, Haris Zisimopoulos and Wanshi Chen, "*Fundamentals of 5G Communications: Connectivity for Enhanced Mobile Broadband and Beyond*", First Edition, McGraw Hill, 2021.
2. "3GPP TS 38.300", Version 16.12.0, 3GPP, 2023.
3. Erik Dahlman, Stefan Parkvall and Johan Skold, "*5G NR: The Next Generation Wireless Access Technology*", Second Edition, Academic Press, 2020.
4. E. Khorov, A. Kiryanov, A. Lyakhov and G. Bianchi, "*A Tutorial on IEEE 802.11ax High Efficiency WLANs*," in IEEE Communications Surveys & Tutorials, vol. 21, no. 1, pp. 197-216, 2019.

EC6307E COMMUNICATION SYSTEM DESIGN LAB

Pre-requisites: NIL

L	T	P	O	C
0	0	2	1	1

Total Practical Sessions: 26

Course Outcomes:

CO1: Demonstrate proficiency in utilizing new hardware and software tools to implement and test digital communication systems effectively.

CO2: Apply acquired skills to implement and perform a comprehensive performance analysis of digital modulation schemes over realistic channels, evaluating metrics such as bit error rate (BER), signal quality, and system capacity, showcasing an understanding of practical challenges in communication system design.

CO3: Explore and employ various techniques to enhance the performance of digital communication systems, such as error-correcting codes, equalization, and diversity techniques, demonstrating the ability to optimize system performance under different channel conditions.

CO4: Demonstrate skills for conducting oral presentations and writing good-quality technical reports.

The following list of experiments is only indicative. The experiments can be implemented using convenient hardware or software tools.

List of Experiments:

1. Performance study of MPSK modulated communication systems over wired channels
2. Analysis of improvement in BER performance with BCH channel codes using codes of different code rates over wired channels
3. Analysis of multipath effects of wireless communication channels using QAM modulated communication system
4. Design, implementation, and performance study of timing and carrier synchronization in wireless communication systems
5. Design and implementation of channel estimation techniques for wireless channels
6. Design, implementation, and performance evaluation of wireless channel equalizers (Zero forcing and MMSE)
7. Study of the performance of receiver diversity techniques in wireless communication systems
8. Study the performance of the WSN/ IoT network for remote monitoring and analysis of sensor data
9. Course project

References:

1. L.W. Couch, *Digital and Analog Communication Systems*, 7th Edition, Pearson, 2007.
2. W. Tomasi, *Electronics Communication Systems: Fundamentals Through Advanced*, 5th Edition, Pearson, 2007
3. J.G. Proakis, and M. Salehi, *Contemporary Communication Systems using MATLAB*, Bookware Companion Series, 2006
4. Any application notes related to the implementation of digital communication systems using HDL, USRP/SDR

EC6396E PROJECT PHASE I

Pre-requisites: NIL

L	T	P	O	C
0	0	0	6	2

Course Outcomes:

CO1: Survey the literature on new research areas and compile findings on a particular topic

CO2: Organize and illustrate technical documentation with scientific rigor and adequate literal standards on the chosen topic strictly abiding by professional ethics while reporting results and stating claims

CO3: Develop aptitude for research and independent learning.

CO4**:** Demonstrate communication skills in conveying the collected data through technical reports and oral presentations using modern presentation tools.

The objective of this phase of the project is to impart training to the students in collecting materials on a specific topic in the broad domain of Engineering/Science from books, journals and other sources, compressing and organizing them in a logical sequence, and presenting the matter effectively both orally and in written format. The topic should not be a replica of what is contained in the syllabi of various courses of the M. Tech programme. The topic chosen by the student shall be approved by the project guide(s) and the evaluation committee. Based on the collected information and acquired knowledge, the student is expected to identify unresolved problems in the domain of the selected topic.

EC7397E PROJECT PHASE II

Pre-requisites: NIL

L	T	P	O	C
0	0	0	9	3

Course Outcomes:

CO1: Develop aptitude for research and independent learning

CO2: Demonstrate the ability to select unresolved problems in the domain of the selected project topic and explore suitable solutions

CO3: Gain the expertise to use new tools and techniques for the design and development.

CO4**:** Demonstrate communication skills in conveying the technical documentation via oral presentations using modern presentation tools.

The work carried out in EC7397E Project Phase II is a continuation of EC6396E Project Phase I and to be continued in EC7398E and/or EC7399E. In these project phases, students get an opportunity to apply and extend knowledge acquired in the first and second semesters of their M. Tech. programme. The work will be carried out individually. The objective of the Project Phase II is to identify unresolved problems in the domain of the selected topic (if not done at the end of the second semester) and explore possible solutions. The proposed solution(s) shall be compared with the ones which are available in the literature or in practice using suitable methods along with a feasibility study. The work can be analytical, simulation, hardware design or a combination of these in the emerging areas of Telecommunication under the supervision of a faculty from the ECE Department.

The performance of the students will be evaluated in the beginning of the third semester by an evaluation committee. By the time of this evaluation, students are expected to have a clear idea of the work to be done, and have learnt the analytical / software / hardware tools. Presenting preliminary designs and results are highly desirable. The students are also expected to submit an interim technical report including the project work carried out in this phase and the work plan for the forthcoming semester(s).

EC7398E PROJECT PHASE III

Pre-requisites: NIL

L	T	P	O	C
0	0	0	45	15

Course Outcomes:

CO1: Develop aptitude for research and independent learning
CO2: Acquire the knowledge and awareness to carry out cost-effective and environment friendly designs.
CO3: Gain the expertise to use new tools and techniques for the design and development.
CO4**:** Develop the ability to write good technical report, to make oral presentation of the work, and to publish the work in reputed conferences/journals.

The work carried out in EC7398E Project Phase III is a continuation of EC7397E Project Phase II and shall be continued in EC7399E or it can be an internship work carried out in an industry. In both cases, the work will be carried out individually. The objective of the Project Phase III is to design/develop the solution proposed in the Project Phase II using one or more of the following approaches: (i) Analytical models (ii) Computer simulations (iii) Hardware implementation. The project work of a student during the third semester is evaluated by a committee in two phases. The first evaluation shall be conducted in the middle of the semester. This should be followed by the end semester evaluation.

If a student plans for an internship in the fourth semester or exploring a different project topic in the fourth semester after doing the Project Phase III in the institute, the student should complete the work planned in the beginning of the third semester, attaining all the objectives and shall prepare a project report of the complete work starting from Project phase I to Project Phase III. If a student plans to continue the same work in the Project phase IV, a detailed project report should be submitted at the end of the Project Phase IV. In case of an internship, the work will be decided jointly by the guides of the student both in the institute and the internship organization. A detailed internship report shall be prepared and submitted by the student.

EC7399E PROJECT PHASE IV

Pre-requisites: NIL

L	T	P	O	C
0	0	0	45	15

Course Outcomes:

CO1: Develop aptitude for research and independent learning

CO2: Acquire the knowledge and awareness to carry out cost-effective and environment friendly designs.

CO3: Gain the expertise to use new tools and techniques for the design and development.

CO4**:** Develop the ability to write good technical report, to make oral presentation of the work, and to publish the work in reputed conferences/journals.

The work carried out in EC7399E Project Phase IV is a continuation of EC7398E Project Phase III or it can be an internship work carried out in an industry. The students are expected to communicate their innovative ideas and results to reputed conferences and/or journals. The work carried out by the students in Project Phase IV will be evaluated in two phases. The first evaluation shall be conducted towards the end of the semester by an internal committee. This should be followed by a second evaluation by the committee including an external examiner.

IE6001E ENTREPRENEURSHIP DEVELOPMENT

Pre-requisites: NIL

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes:

CO1: Describe the various strategies and techniques used in business planning and scaling ventures.
CO2: Apply critical thinking and analytical skills to assess the feasibility and viability of business ideas.
CO3: Evaluate and select appropriate business models, financial strategies, marketing approaches, and operational plans for startup ventures.
CO4: Assess the performance and effectiveness of entrepreneurial strategies and actions through the use of relevant metrics and indicators.

Entrepreneurial Mindset and Opportunity Identification
Introduction to Entrepreneurship Development - Evolution of entrepreneurship, Entrepreneurial mindset, Economic development, Opportunity Recognition and Evaluation - Market gaps - Market potential, Feasibility analysis - Innovation and Creativity in Entrepreneurship - Innovation and entrepreneurship, Creativity techniques, Intellectual property management.

Business Planning and Execution
Business Model Development and Validation - Effective business models, Value proposition testing, Lean startup methodologies - Financial Management and Funding Strategies - Marketing and Sales Strategies - Market analysis, Marketing strategies, Sales techniques - Operations and Resource Management - Operational planning and management, Supply chain and logistics, Stream wise Case studies.

Growth and Scaling Strategies
Growth Strategies and Expansion - Sustainable growth strategies, Market expansion, Franchising and partnerships - Managing Entrepreneurial Risks and Challenges - Risk identification and mitigation, Crisis management, Ethical considerations - Leadership and Team Development - Stream wise Case studies

References:

1. Kaplan, J. M., Warren, A. C., & Murthy V. (Indian Adoption) *Patterns of entrepreneurship management*. John Wiley & Sons, 2022.
2. Kuratko, D. F. *Entrepreneurship: Theory, process, and practice*. Cengage learning, 2016.
3. Barringer, B. R. *Entrepreneurship: Successfully launching new ventures*. Pearson Education India, 2015
4. Rajiv Shah, Zhijie Gao, Harini Mittal, *Innovation, Entrepreneurship, and the Economy in the US, China, and India*, Academic Press, 2014
5. Dr. K. Sundar, Entrepreneurship Development, Second Edition Vijaya Nichkol Imprints, Chennai, 2022
6. E. Gordon,Dr. K. Natarajan,*Entrepreneurship Development*, Sixth Editions Himalya Publishers,Delhi, 2017
7. Debasish Biswas, Chanchal Dey,*Entrepreneurship Development in India*, Taylor & Francis, 2021

ZZ6001E RESEARCH METHODOLOGY

Pre-requisites: NIL

L	T	P	O	C
2	0	0	4	2

Total Lecture sessions: 26

Course Outcomes

CO1: Explain the basic concepts and types of research
CO2: Develop research design and techniques of data analysis
CO3: Develop critical thinking skills and enhanced writing skills
CO4: Apply qualitative and quantitative methods for data analysis and presentation
CO5: Implement healthy research practice, research ethics, and responsible scientific conduct

Exploring Research Inquisitiveness
Philosophy of Scientific Research, Role of Research Guide, Planning the Research Project, Research Process, Research Problem Identification and Formulation, Variables, Framework development, Research Design, Types of Research, Sampling, Measurement, Validity and Reliability, Survey, Designing Experiments, Research Proposal, Research Communication, Research Publication, Structuring a research paper, structuring thesis/ dissertation,

Research Plan and Path
Developing a Research Plan: Reviewing the literature- Referencing – Information sources – Information retrieval – Role of libraries in information retrieval – Tools for identifying literatures – Reading and understanding a research article – Critical thinking and logical reasoning; Framing the research hypotheses, Converting research Question into a Model; Data collection- Types of data-Dataset creation- Primary and Secondary data- Scales of measurement- Sources and collection of data- Processing and analysis of data-Understanding Data-statistical analysis, displaying of data-Data visualization-Data interpretation; Research design- Qualitative and Quantitative Research- Designing of experiments- Validation of experiments- Inferential statistics and result interpretation

Scientific Conduct and Ethical Practice
Plagiarism– Ethics of Research- Scientific Misconduct- Forms of Scientific Misconduct. Plagiarism, Unscientific practices in thesis work-Conduct in the workplace and interaction with peers – Intellectual property: IPR and patent registration, copyrights; Current trends – Usage and ethics of AI tools in scientific research.

References:

1. Leedy, P D, “*Practical Research: Planning and Design”,* USA: Pearson, Twelfth ed., 2018.
2. Krishnaswamy, K. N., Sivakumar, A. I., and Mathirajan, M., “*Management Research Methodology”*, Pearson Education, 2006.
3. Tony Greenfield and Sue Greener., Research Methods for Postgraduates, USA: John Wiley & Sons Ltd., Third ed., 2016.
4. John W. Creswell and J. David Creswell, "*Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*", USA: Sage Publications, Sixth ed., 2022

MS6174E TECHNICAL COMMUNICATION AND WRITING

Pre-requisites: NIL

L	T	P	O	C
2	1	0	4	2

Total Lecture Sessions: 26

Course Outcomes:

CO1: Apply effective communication strategies for different professional and industry needs.

CO2: Collaborate on various writing projects for academic and technical purposes.

CO3: Combine attributes of critical thinking for improving technical documentation.

CO4: Adapt technical writing styles to different platforms.

Technical Communication

Process(es) and Types of Speaking and Writing for Professional Purposes - Technical Writing: Introduction, Definition, Scope and Characteristics - Audience Analysis - Conciseness and Coherences - Critical Thinking - Accuracy and Reliability - Ethical Consideration in Writing - Presentation Skills - Professional Grooming - Poster Presentations

Grammar, Punctuation and Stylistics

Constituent Structure of Sentences - Functional Roles of Elements in a Sentence - Thematic Structures and Interpretations - Clarity - Verb Tense and Mood - Active and Passive Structures - Reporting Verbs and Reported Tense - Formatting of Technical Documents - Incorporating Visuals Elements - Proofreading

Technical Documentation

Types of Technical Documents: Reports, Proposals, Cover Letters - Manuals and Instructions - Online Documentation - Product Documentation - Collaborative Writing: Tools and Software - Version Control Document Management - Self Editing, Peer Review and Feedback Processes

References:

1. Foley, M., & Hall, D. (2018). *Longman advanced learner's grammar, a self*-*study reference & practice book with answers*. Pearson Education Limited.
2. Gerson, S. J., & Gerson, S. M. (2009). *Technical writing: Process and product*. Pearson.
3. Kirkwood, H. M. A., & M., M. C. M. I. (2013). *Hallidays introduction to functional grammar* (4th ed.). Hodder Education.
4. Markel, M. (2012). *Technical Communication* (10th ed.). Palgrave Macmillan.
5. Tuhovsky, I. (2019). *Communication skills training: A practical guide to improving your social intelligence, presentation, Persuasion and public speaking skills.* Rupa Publications India.
6. Williams, R. (2014). *The Non-designer's Design Boo*k. Peachpit Press.

EC6321E DIGITAL COMMUNICATION TECHNIQUES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Demonstrate the limitations of communication systems for effectively utilizing the fundamental resources namely bandwidth and power.
CO2: Analyze systematically the flow and processing of information from the source to various blocks at the transmitter side and understand the inverse operations at the receiver.
CO3: Design and analyze various processing units of a digital communication system such as line coding and pulse shaping, various modulation techniques, equalization, synchronization and detection.
CO4: Develop a framework for the performance evaluation of various modulation schemes in AWGN channels using the concepts of signal space and derive expressions for the probability of error.

Modulations, Demodulations, and Error Performance
Memoryless Digital Modulations: Pulse amplitude modulation - Carrier-Phase modulation - Quadrature amplitude modulation - Orthogonal multidimensional signals - Signal space representation - Connecting linear vector space to physical waveforms - Scalar and vector communication over memoryless channels - Optimum receiver in additive white Gaussian noise (AWGN) channels: Cross correlation receiver and Matched filter receiver - Error probabilities - Optimum receiver for colored Gaussian noise channels - Optimum Receiver for Signals with random phase in AWGN Channels - Optimum receiver for binary signals - Optimum receiver for M-ary orthogonal signals - Probability of error for envelope detection of M-ary orthogonal signals.

Carrier and Symbol Synchronization
Carrier recovery and symbol synchronization in signal demodulation - Carrier phase estimation - Effect of additive noise on the phase estimate - Maximum likelihood phase estimation - Symbol timing estimation - Maximum likelihood timing estimation - Receiver structure with phase and timing recovery - Joint estimation of carrier phase and symbol timing - Frequency offset estimation and tracking.

Communication over Band-Limited Channels
Communication Over Band Limited Channels: Optimum pulse shaping - Nyquist's criterion for zero ISI, Partial response signaling - Precoding for detection of partial response signals - Equalization Techniques: Zero forcing linear equalization, Decision feedback equalization, and Adaptive equalization.

References:

1. John G. Proakis and Masoud Salehi, *Digital Communications*, McGraw Hill, 5th Edition, 2008.
2. John G. Proakis, Masoud Salehi, and Gerhard Bauch, *Contemporary Communication Systems using MATLAB*, Cengage Learning, 3rd Edition, 2013.
3. Bernard Sklar, Fredric Harris, *Digital Communications: Fundamentals and Applications*, Pearson, 3rd Edition, 2021.
4. John R. Barry, Edward A. Lee, and David G. Messerschmitt, *Digital Communication*, Springer, 3rd Edition 2004.
5. Marvin. K. Simon, Sami. M. Hinedi, and William. C. Lindsey, *Digital Communication Techniques: Signal Design and Detection*, Prentice Hall,1999.
6. Scott L. Miller and Donald Childers, *Probability and Random Processes with Applications to Signal Processing and Communications*, Academic Press, 2nd Edition, 2012.

EC6322E ADVANCED TECHNIQUES IN ERROR CONTROL CODING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply various decoding algorithms, including Maximum Likelihood decoding, Viterbi algorithm, belief propagation decoding, and iterative decoding, for error correction in different channel codes.

CO2: Analyze the properties and bounds of linear block codes demonstrating evaluation skills in assessing code parameters and limitations.

CO3: Evaluate the performance and characteristics of capacity-achieving codes.

CO4: Design and construct coding schemes utilizing convolutional codes, including punctured codes, recursive systematic convolutional coders, and concatenated codes, showcasing synthesis skills in constructing complex coding systems.

Review of linear block codes - Bounds on code parameters - Hamming bound - Singleton bound - Plotkin bound – Structure of Finite Fields – Roots of polynomials – Splitting field – Generalized Reed Solomon codes – Decoding of RS codes – Berlekamp-Massey algorithm – Maximum Distance Separable codes – Reed-Muller codes

Capacity achieving codes- Low-density parity-check codes- Regular and Irregular codes - Quasi-Cyclic LDPC codes- Encoding methods –- Tanner graphs- Decoding through message passing - Belief propagation decoding – Density evolution - Thresholds – EXIT charts – Capacity achieving degree distribution- LDPC Code ensemble - Polar codes – Philosophy of Polar codes- Polarization of binary erasure channels - Encoding operation – Recursive construction of Polar codes - decoding algorithms – Successive cancellation decoding

Convolutional Codes - Generator matrix - State, tree, and trellis diagram- Transfer function – Maximum Likelihood decoding - Hard versus Soft decision decoding - Soft output Viterbi algorithm – Sequential decoding - Punctured Convolutional Codes and Rate-Compatible Schemes - Recursive Systematic Convolutional Coders – Turbo codes – Construction of Turbo codes – Interleavers – Turbo decoding - Extrinsic information – Iterative decoding of Turbo codes – The BCJR algorithm - Concatenated codes

References:

1.1 Ron M. Roth, *Introduction to Coding Theory*, Cambridge University Press, 2006.

2.Thomas Joseph Richardson and Rüdiger Leo Urbanke, *Modern Coding Theory*, Cambridge University Press, 2008.

3.Jorge Castiñeira Moreira and Patrick Guy Farrell, *Essentials of Error-Control Coding*, John Wiley & Sons, Ltd, 2006.

4.Orhan Gazi, Polar codes: *A non-trivial approach to channel coding*, Springer Topics in Signal Processing, Springer Nature Singapore Pte Ltd. 2019.

5.MacWilliams, F. J., and N. J. A. Sloane, *The Theory of Error Correcting Codes*, Amsterdam

EC6323E MIMO COMMUNICATION SYSTEMS

Pre-requisites: EC6303D Wireless Communication Techniques

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Design precoders for MIMO communication systems.
CO2: Design MIMO communication transceivers with and without channel state information.
CO3: Design space time codes for MIMO systems.
CO4: Analyze and design optimum Communication systems for given channel conditions.

Review of performance of SISO fading channels and channel models - - MIMO channel models, Classical i.i.d. and extended channels, Frequency selective and correlated channel models, Capacity of MIMO Channels with and without channel state information - Ergodic and outage capacity - Capacity bounds and Influence of channel properties on the capacity - Capacity of correlated channels with KPF channel model.

Sources and types of diversity - Analysis under Rayleigh fading - Diversity and channel knowledge - Alamouti space time code - MIMO spatial multiplexing - Space time receivers –Matched filter bound - ML, ZF, MMSE and BLAST receivers- Sphere decoding, - Diversity multiplexing trade-off (DMT).

Space time block codes- real and complex orthogonal designs - Code design criteria for quasi-static channels (Rank, determinant and Euclidean distance) - Orthogonal designs, Generalized orthogonal designs, Quasi-orthogonal designs and Performance analysis - Space Time Trellis Codes - Representation of STTC - shift register -generator matrix, state-transition diagram- trellis diagram - Code construction - Delay diversity as a special case of STTC and Performance analysis.

References:

1. Paulraj, R. Nabar and D. Gore, *Introduction to Space-Time Wireless Communications*, Cambridge University Press 2003
2. Hamid Jafarkhani, *Space-Time Coding: Theory and Practice*, Cambridge University Press 2005
3. E.G. Larsson and P. Stoica, *Space-Time Block Coding for Wireless Communications*, Cambridge University Press 2008
4. EzioBiglieri , Robert Calderbank et al *MIMO Wireless Communication,s* Cambridge University Press 2007
5. David Tse and Pramod Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, South Asian Edition, 2006

EC6324E MULTI CARRIER SYSTEMS AND APPLICATIONS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Distinguish various terminologies related to multi carrier communications and gain exposure to the various existing and upcoming technologies and systems.

CO2: Develop the ability to find technical solutions for engineering design that involves multi carrier signal processing

CO3: Demonstrate proficiency in utilizing appropriate wireless modules available in the market to solve communication challenges

Fundamentals: Digital communication systems – Wireless channels: multi-path fading characteristics, basic channel models – Principles of multi-carrier systems: orthogonal frequency division multiplexing (OFDM), multi carrier spread spectrum systems, hybrid multiple access schemes, performance study of each schemes under ideal scenarios.

Design and implementation aspects of OFDM systems: pulse shaping, synchronization, equalization, coding, adaptive techniques, practical implementation challenges - Orthogonal frequency division multiple access (OFDMA) systems: concept, basic resource allocation techniques – Basics of multiple-input-multiple-output (MIMO) - OFDM architecture.

Applications of multi carrier systems in wireless technologies: wireless local area networks (WLAN), 4G & 5G cellular systems – Drawbacks of OFDM/OFDMA systems - Future scope for multi-carrier systems: basics of non-orthogonal multiple access (NOMA), Filter Bank Multi Carrier (FBMC), generalized frequency division multiplexing (GFDM), Orthogonal Time Frequency Space (OTFS).

References:

1. F. Khaled, S. Kaiser, *Multi-carrier and spread spectrum systems*, John Wiley & Sons, 2003.
2. H. Shinsuke, R. Prasad, *Multicarrier techniques for 4G mobile communications*. Artech House, 2003.
3. E. Dahlman, S. Parkvall, J. Skold. 4G, *LTE-advanced Pro and the Road to 5G*. Academic Press, 2016.
4. Any appropriate application notes or technical documents related to NOMA, FBMC, GFDM, and OTFS

EC6325E MARKOV MODELING AND THEORY OF QUEUES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Demonstrate knowledge in the domain of discrete event stochastic processes such as renewal and regenerative processes, Markov processes and Semi-Markov processes.
CO2: Understand the theory of discrete and continuous time Markov chains and their characterization
CO3: Analyze and design various queuing models for applications in telecommunications and networking
CO4: Demonstrate the ability to build simulation models for queuing systems, conduct performance evaluation and present the results in the form of technical reports and oral presentations

Stochastic Processes: Renewal Processes - Reward and Cost Models, The renewal equation - Renewal Theorems-Poisson Process; Point Processes; Regenerative Processes.

Discrete-Time Markov Chain - Transition Probabilities, Communication Classes, Irreducible Chains; positive recurrence and invariant probability vector, Continuous Time Markov Chain - Pure-Jump Continuous-Time Chains, Regular Chains, Birth and Death Process, Markov renewal sequences -Semi-Markov Processes.

Single Class and Multi-class Queuing Networks: Simple Markovian queues; M/G/1 queue; G/G/1 queue; Open queuing networks; Closed queuing networks; Mean value analysis; Multi-class traffic model; Service time distributions; BCMP networks; Priority systems.

References:

1. Anurag Kumar, *Discrete Event Stochastic Processes, Lecture Notes for an Engineering Curriculum*, Department of Electrical Communication Engineering. Indian Institute of Science, Bengaluru, 2012
2. D. Bertsekas and R, Gallager, *Data Networks*, PHI, 2nd Edition, 2000
3. Sheldon M. Ross, *Introduction to Probability Models*, Academic Press, 9th edition, 2007

EC6326E WIRELESS NETWORKING

Pre-requisites: EC6302E Communication Networks, EC6303E Wireless Communication Techniques

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39L

Course Outcomes:

CO1: Design security algorithm and protocols for networks
CO2: Analyze the 802.11 MAC protocol to find throughput and latency
CO3: Analyze various enhancements done to TCP and IP to improve performance of wireless networks
CO4: Analyze and design data gathering, MAC protocols and localization algorithms used in wireless sensor networks

Spatial Point Processes and their Applications - Point Processes in 1D and 2D - Formulation of Point Processes - Example: Binomial Process - Foundations - One-dimensional Poisson Process - Spatial Poisson Process - Distributional Characterisation - Characterisations of a Point Process Distribution - - Transforming a Point Process - Marked Point Processes - Distances in Point Processes - Estimation from Data

Wireless Local Area Networks – IEEE 802.11 Standards – Multiple Access in IEEE 802.11 – Performance Modeling and Throughput - Stochastic Model for a Wide Area TCP Connection. Mobile Network Layer – Mobile IP – Goals, assumptions and requirements – Entities and Terminology – IP packet delivery – Agent discovery – Registration – Tunneling and encapsulation – Optimizations – Reverse Tunneling – IPv6 – IP micro-mobility support. Mobile Transport Layer - Traditional TCP - Congestion control - Slow start - Fast retransmit/fast recovery - Implications of mobility - Classical TCP improvements - Indirect TCP - Snooping TCP - Mobile TCP - Fast retransmit/fast recovery - Transmission/time-out freezing - Selective retransmission - Transaction-oriented TCP – Cellular Wireless Network – Networking aspects of 4G LTE and 5G.

Introduction to the time synchronization problem - Protocols based on sender/receiver synchronization - Protocols based on receiver/receiver synchronization. Localization and positioning - Properties - Possible approaches - Mathematical basics for the trilateration problem - Single-hop localization - Positioning in multihop environments - Impact of anchor placement - Topology control - Motivation and basic ideas - Controlling topology in flat networks – Power control - Hierarchical networks by dominating sets - Hierarchical networks by clustering - Combining hierarchical topologies and power control - Adaptive node activity

References

1. Peterson L.L. and Davie B.S., *Computer Networks: A System Approach*, Elsevier, 6th Edition, 2020
2. Kumar, Anurag, D. Manjunath, and Joy Kuri, *Communication Networking: An Analytical Approach* Elsevier, 2004
3. Beard, Cory and Stallings, William , *Wireless Communication Networks and Systems*, Pearson, 2015
4. Dahlman, Erik and Parkvall, Stefan and Skold, Johan, *4G, LTE-advanced Pro and the Road to 5G*, Academic Press, 2016
5. Schiller and Jochen H., *Mobile Communication*, .2nd Ed, Pearson education, 2004
6. Karl, Holger, and Andreas Willig, *Protocols and Architectures for Wireless Sensor Networks*, John Wiley and Sons, 2007
7. Baddeley, Adrian, Imre Bárány, and Rolf Schneider, *Spatial point processes and their applications. Stochastic Geometry*, Lectures given at the CIME Summer School held in Martina Franca, Italy, September 13–18, 2004 (2007): 1-75

EC6327E ULTRA WIDEBAND COMMUNICATIONS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Identify the benefits and challenges involved in ultra wideband (UWB) communications.
CO2: Analyze the effects of multipath propagation and multiple access interference in UWB.
CO3: Compare different UWB pulse design techniques.
CO4: Identify the characteristics and benefits of software defined radio (SDR).

Introduction to UWB concepts; advantages and challenges of UWB - UWB Channel Estimation and Synchronization: Channel Estimation at SubNyquist Sampling Rate, Performance Evaluation, Estimating UWB Channels with Frequency-dependent distortion, Channel Estimation from Multiple Bands, Low complexity Rapid Acquisition in UWB Localizers - Ultra Wideband Geolocation: Signal Model, Position Techniques, Sources of Error in Time-based Positioning, Ranging and Positioning, Location-Aware Applications.

UWB Modulation Options: UWB Signaling Techniques, Data Mapping, Spectral Characteristics, Data Mapping and Transceiver Complexity, Modulation Performances in Practical Conditions - Ultra Wideband Pulse Shaper Design: Transmit Spectrum and Pulse Shaper, FIR Digital Pulse Design, Optimal UWB Single Pulse Design, Optimal UWB Orthogonal Pulse Design, Design Example and Comparisons, Antenna Issues: Design Considerations, Antenna and Pulse versus BER Performance, Ultra Wideband Receiver Architectures: System Model, UWB Receiver Related Issues, TH-IR-UWB Receiver Options.

UWB Channel Modeling: Principles and Background, Channel Sounding Techniques, UWB Statistical-Based Channel Modeling, Impact of UWB Channel on System Design - MIMO and UWB: Potential Benefits of MIMO and UWB, Literature on UWB Multi Antenna techniques, Spatial channel measurements and Modeling, Spatial Multiplexing, Spatial Diversity, Beamforming - Software Defined Radio (SDR), Characteristics and benefits of SDR, design principles, enhanced flexibility with software radios, receiver design challenges.

References:

1. H, Arslan, Zhi Ning Chen, Maria-Gabriella Di Benedetto, *Ultra WIdeband Wireless Communication*, Wiley, 2005.
2. W. P. Siriwongpairat, K. J. Ray Liu, *Ultra-Wideband Communications Systems: Multiband OFDM Approach*, Wiley-IEEE Press, 2008.
3. H. Nikookar, Ramjee Prasad, *Introduction to Ultra Wideband for Wireless Communications*, Springer, 2010.
4. S. Haykin and M. Moher, Modern *Wireless Communication*, Pearson Education, 2005.
5. Jeffrey H. Reed, *Software Radio: A Modern Approach to Radio Engineering*, Prentice Hall, May 2002
6. Faranak Nekoogar, *Ultra-Wideband Communications: Fundamentals and Applications*, Prentice Hall, 2005.
7. C. Oestges and B. Clerckx, *MMIO Wireless Communications*, 1st Ed, 2007.
8. Paul Burns, *Software Defined Radio for 3G*, Artech House Inc., 2003.

EC6328E NANOMAGNETISM AND SPINTRONICS

Prerequisites: Engineering Electromagnetics

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Develope knowledge about magnetism for modeling spin wave devices
CO2: Design and implement spin wave devices for RF generations
CO3: Design and implement spintronic devices for building memory devices for RF generations
CO4: Design and implement spin torque magnonic devices for building memory devices, RF generations, and logic devices

Ground for nanomagnetism
Magnetic fields, Magnetization and magnetic moment, magnetic materials, The various types of magnetic energy, Handling dipolar interactions, The Bloch domain wall, Magnetometry and magnetic imaging techniques, Magnetic ordering in low dimensions, Magnetic anisotropy in low dimensions, Domains and domain walls in thin films, Domains and domain walls in nanostructures, multiferroics

Precessional dynamics of magnetization
Macrospins: The case of uniform magnetization, Magnetization reversal in nanostructures, Ferromagnetic resonance and Landau-Lifshitz-Gilbert equation, Spin waves, Precessional switching of macrospins driven by magnetic field, Precessional motion of domain walls and vortices driven by a magnetic field, Magnonics, Spin wave-based RF filters, multiplexers and amplifier, Spin wave antenna, Micromagnetic simulation and applications

Spintronic Memory Technology-MRAM devices
Introduction to spin, concept of spinors and vectors, connection with light polarization, overview of spintronic devices Magnetoresistance phenomena, modelling spin valve and MTJ devices, spin injection and spin transistor Spin transfer torque, emerging and exploratory spintronic devices, Spin torque nano-oscillators, Spintronic device modeling, Device applications: Memory, sensors, microwave oscillators and detectors, Micromagnetic simulation of spin torque devices,Spintronic based RF components, Spin torque magnonic devices

References:

1. Gurevich and Melkov, *Magnetization Oscillations and Waves,* CRC Press
2. Anil Prabhakar, and Daniel D. Stancil. *Spin waves: Theory and Applications*,Springer US, 2009.
3. Shinjo, Teruya, ed. *Nanomagnetism and Spintronics*. Elsevier Science & Technology, 2013.
4. Dieny (ed.), *Introduction to Magnetic Random-access Memory*, Wiley-IEEE Press,2017
5. M.D. Coey, *Magnetism and Magnetic Materials*, Cambridge: Cambridge University Press, 2012
6. Recent research papers and review articles on topics of current interest

EC6329E 5G: FEATURES, STANDARDS AND EVOLUTION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Compare cellular technologies, identify aspects behind evolution and related migration challenges.
CO2: Analyze 5G features by identifying and studying related clauses in 3GPP standards.
CO3: Configure key parameters of 5G system to meet given requirements.
CO4: Analyze and design 5G enhancements and potential 6G features.

4G and 5G Overview

4G overview - Evolution to from 1G technologies to 5G - Migration challenges from 4G to 5G - Spectrum for 5G, frequency ranges and bands, spectrum sharing, NR-U - 5G use cases, requirements and performance metrics: IMT 2020, eMBB, URLLC, mMTC - Key 5G features.

Architecture and protocol stacks

3GPP and 5G standards - 5G architecture: 5G RAN architecture, 5GC architecture – Network slicing – QoS – Policy control – 5G security – Interworking with EPC and non-3GPP technologies – EPC to 5GC migration – Non-Public Networks – Data collection in 5GC – Control plane protocol stack: NAS, RRC - User plane stack: SDAP, PDCP, RLC, MAC, PHY - Initial access – Random Access – Paging –Mobility.

5G PHY

Numerology – symbol, slot and frame structure – Bandwidth and sampling rate– Downlink control aspects: control region, search space, DCI formats – Downlink data aspects: modulation and coding, resource allocation in time and frequency, HARQ operation, Reference Signals, MIMO, beam management – Uplink control aspects: UCI types, PUCCH formats – Uplink data aspects: modulation and coding options, HARQ, Reference signals, MIMO, Power control, beam management – OFDM waveform – MIMO – Link budget calculations – Peak throughput calculations

5G features and towards 6G

Selected topics related to 5G Advanced, mmWave, massive MIMO, URLLC, MTC, D2D, V2X, NTN and power saving features of 5G - Selected topics on potential 6G features.

References:

1. Juan Montojo, Peter Gaal, Haris Zisimopoulos and Wanshi Chen, *Fundamentals of 5G Communications: Connectivity for Enhanced Mobile Broadband and Beyond*, First Edition, McGraw Hill, 2021.
2. *3GPP TS 38.300*, Version 16.12.0, 3GPP, 2023.
3. Stefan Rommer, Peter Hedman, Magnus Olsson, Lars Frid, Shabnam Sultana and Catherine Mulligan, *5G Core Networks: Powering Digitalization*, First edition, Academic Press, 2019.
4. Erik Dahlman, Stefan Parkvall and Johan Skold, *5G NR: The Next Generation Wireless Access Technology*, Second Edition, Academic Press, 2020.
5. Stefania Sesia, Issam Toufik, Matthew Baker, *LTE – The UMTS Long Term Evolution: From Theory to Practice*, Second Edition, Wiley, 2011.

EC6330E TELECOM NETWORK MANAGEMENT

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Acquire the knowledge on top-down design, implementation, performance evaluation of telecommunication networks.
CO2: Understand the importance of network management in telecommunication networks.
CO3: Gain knowledge on state-of-the-art network management techniques.
CO4: Develop the skills to improve the capabilities of state-of-the-art network management techniques.

Network Architectures: Requirement based top-down network design, end-to-end services, service level agreements, performance evaluation techniques - Analytic modelling and topological design of communication networks: centralized polling networks, packet switched networks, T1 networks, concentrator location problems - Reliability theory and its application in network planning and network reliability analysis.

Design and implementation of networks: performance metrics, analysis tools, quality of service - Planning and managing networking elements: hardware, software, protocols, applications - Information modelling for Network Management.

Network management protocols - Management information bases and management platforms - Telecommunication Management Networks: examples, case studies in Internet and Mobile Networks

References:

1. M. Subramanian, *Network Management Principles and Practice*, 2nd Edition, Pearson, 2010
2. A. Leinwand, K. F. Conroy, *Network Management: A Practical Perspective*, Addison-Wesley, 1996
3. J. Laiho, A. Wacker and T. Novosad, *Radio Network Planning and Optimization for UMTS*, John Wiley & Sons, 2006
4. H. Hanrahan, *Network Convergence: Services, Applications, Transport, and Operations Support*. John Wiley & Sons, 2007
5. S., Aidarous, P. Thomas, *Telecommunications Network Management Technologies and Implementations*, Wiley-IEEE Press, 1998

EC6332E RF AND MICROWAVE PASSIVE CIRCUITS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Basic concepts of microwave circuits network with S-parameters.
CO2: Develop the basic concepts of matching a load to a given system load.
CO3: Design microwave planar microstrip line filters.
CO4: To equip students with practical skills in the design, simulation, and measurement of RF and microwave passive circuits.

Review of basic microwave theory: Transmission lines-concepts of characteristics impedance, reflection coefficient, standing and propagating waves, equivalent circuit. Discontinuities and Bends: Introduction, open-circuit end correction, corners, symmetrical step, T-junction, series gaps, and Bends in microstrip line, Network analysis: Z, ABCD, Y, T, S-parameters.

Smith chart, Impedance matching technique, Implementation using simulators. Loads & Termination, Behaviour of passive lumped components at microwave frequencies (resistor, capacitors and inductor) Planar transmission lines and Different types of transmission lines- CPW, SIW, suspended line, Resonators, Filter design by the Insertion Loss method, Filter transformations, Filter implementation, Stepped-Impedance Low-Pass filters, coupled line filters, Filters using coupled resonators.

Multi-port Network: Introduction; Even-and odd-mode analysis; Power divider and combiner; Branch- line couple, Branch-line coupler with multiple sections; Introduction to Hybrid-ring couplers, qualitative description and complete analysis of hybrid-ring couplers, Rate race coupler, Lange Coupler, Balun.

References:

1. Pozar, D.M., *Microwave Engineering*, 4th Ed., John Wiley & Sons. 2012.
2. Franco di Paolo, *Networks and Devices using Planar Transmission Lines*, CRC Press, 2018.
3. Roberto Sorrentino and Giovanni Bianchi, *Mirowave and RF Engineering* John Wiley & Sons, 2010.
4. Ludwig, R. and Bogdanov, G., *RF Circuit Design: Theory and Applications*, 2nd Ed, Pearson Education, 2011.
5. Collin, R.E., *Foundations for Microwave Engineering*, 2nd Ed., Wiley - India, 2007.
6. Fooks, E.H. and Zakarevicius, R. A., *Microwave Engineering Using Microstrip Circuits*, Prentice Hall, 1990

EC6331E RF AND MICROWAVE ACTIVE CIRCUITS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: To familiarize students with the theoretical principles underlying the analysis and design of active circuits
CO2: Develop the basic concepts of biasing and matching the active device at input and out port.
CO3: Develop the basic skills to design and development of power amplifier
CO4: Develop the basic skills to design and development of mixer using diode and FETs

Active RF components: RF diodes- Schottky, PIN, Varactor, Gunn diode, applications of diode. BJTs, RF FETs, HEMTs, HBT, device model, device characterization, Noise Figure, gain comparison, Intermodulation distortion, third –order intercept point, dynamic range, Smith Chart, interconnecting networks, network properties and application Scattering Parameters.

Matching and biasing network: Impedance matching using discrete components, Microstrip line matching, amplifiers classes of operation and biasing network, RF transistor amplifiers design: characteristics of amplifier, amplifier power relations, stability considerations, constant gain, noise figure circle Constant VSWR circles, broadband, high-power and multistage amplifiers.

Mixer characteristics, Image frequency, conversion loss, noise figure, Diode mixer: small signal diode characteristics, single ended mixer, large signal model, switching model, FETs mixer: single ended FET mixer balance mixer, Other FET mixer, Image reject mixer.

References:

1. D. M. Pozar, *Microwave and RF Design of Wireless Systems*, John Wiley & Sons, 2001
2. C. Bowick, *RF circuit design*, 2nd Edition, Newnes, 2007.
3. R. C. Li, *RF Circuit Design*, 2nd Edition, John Wiley & Sons, 2012.
4. G. Gonzalez, *Microwave Transistor Amplifiers: Analysis and Design*, 2nd Edition, Prentice Hall, 1996.
5. T. H. Lee, *Planar Microwave Engineering: A Practical Guide to Theory, Measurement, and Circuits*, Cambridge University Press, 2004.
6. R. Ludwig, G. Bogdanov, *RF Circuit Design- Theory and Applications*, 2nd Edition, Pearson. 2017.

EC6333E ANTENNA DESIGN

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: To develop a comprehensive understanding of electromagnetic wave radiation, reception, and fundamental parameters of antenna.
CO2: Develop a skill for analysis the radiation from different types of antennas.
CO3: To enable students to design and evaluate antennas and array.
CO4: Develop the ability to measure the antenna parameters and characterises.
CO5: Develop the basic skills to design and simulate of antennas in the electromagnetic simulation tool.

Fundamental Concepts: Co-ordinate system, Radiation pattern, near- and far-field regions, reciprocity, directivity and gain, effective aperture, polarization, input impedance, efficiency, Friis transmission equation, radiation integrals and auxiliary potential functions; Radiation from Wires and Loops: Infinitesimal dipole, finite-length dipole, linear elements near conductors, dipoles for mobile communication, small circular loop.

Aperture Antennas: Huygens' principle, radiation from rectangular and circular apertures, design considerations, horn antenna, Babinet's principle, Fourier transform method in aperture antenna theory, horn antenna; Microstrip Antennas: Basic characteristics, feeding methods, Transmission line model cavity model, design of rectangular and circular patch antennas, Conformal antenna, Fractal structure antenna, A case study on Broadband antenna.

Antenna Arrays: Analysis of uniformly spaced arrays with uniform and non-uniform excitation amplitudes, extension to planar arrays, synthesis of antenna arrays using Schelkunoff polynomial method, Fourier transform method, and Woodward-Lawson method. Antenna measurement: amplitude and phase measurement, gain measurement (using two and three antennas), and polarization measurement, typical sources of error in antenna measurement, and test ranges. Simulation of antennas (dipole antenna, horn antenna, patch antenna and etc.) in Electromagnetics simulation tool.

References:

1. Jordan, E.C. and Balmain, K.G., *Electromagnetic Waves and Radiating Systems*, 2nd Ed., Pearson Education, 2015.
2. Constantine A. Balanis,, *Antenna Theory: Analysis and Design*", 4th Ed., John Wiley & Sons, 2016.
3. Garg, R., Bhartia, P., Bahl, I. and Ittipiboon, A., *Microstrip Antenna Design Handbook*, Artech House, 2001.
4. Elliot, R.S., *Antenna Theory and Design*, Student Edition, Wiley-India, 2006.
5. Stutzman, W.L. and Thiele, H.A., *Antenna Theory and Design*, 3rd Ed., John Wiley & Sons, 2012.
6. John D Kraus, Ronald J Marhefka, Ahmad S Khan, *Antennas and Wave Propagation*, 5h Ed., McGraw Hill Education, 2017. Course Outcomes:

EC6334E ADAPTIVE SIGNAL PROCESSING

Pre-requisites: Random Process and Linear Algebra

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Understand the need of adaptive filtering and theory of adaptation in various real-life applications.
CO2: Design Wiener filters and evaluate their performance.
CO3: Design and implement the LMS, RLS, and Kalman filters and apply in the communications and signal processing field.
CO4: Compute and analyze the performance metrics of different adaptive algorithms.
CO5: Demonstrate the advantages and disadvantages of different adaptive algorithms.

Adaptive Filter and Theory of Adaptation
Adaptive Filtering: Need for adaptive filtering - FIR adaptive filters - Performance function - Gradient and Minimum mean square error - Linear optimum filtering (Wiener filter) - Prediction filters - Geometrical significance of eigenvalues and eigenvectors.
Theory of Adaptation: Searching the performance surface - Newton's method - Steepest descent method - Convergence analysis - Learning curve - Excess mean square error.

Adaptive Algorithms and Applications
Adaptive Algorithms: Least Mean Square (LMS) - Sign LMS - Normalized LMS - Block LMS - Recursive least squares (RLS) algorithm for adaptive filtering of stationary process - Comparison of LMS and RLS algorithms - RLS for quasi-stationary signals - Exponentially weighted RLS - Sliding window RLS - Applications - Adaptive beamforming - Echo cancellation - Channel Equalization.

Kalman Filter and Applications
Kalman Filtering: Statistical filtering for non-stationary signals - Kalman filtering - Principles - Initialization and tracking - Scalar and vector Kalman filter - Applications in signal processing - Time varying channel estimation - Radar tracking.

References:

1. Bernard Widrow and Samuel D Stearns, *Adaptive Signal Processing*, Pearson, 2002.
2. Simon Haykin, *Adaptive Filter Theory*, 5th Edition, Pearson, 2014.
3. Behrouz Farhang-Boroujeny, *Adaptive Filters: Theory and Applications*, 2nd Edition, Wiley, 2013.
4. Ali H. Sayed, *Fundamentals of Adaptive Filtering*, Wiley-IEEE Press, 2003.
5. Dimitris G. Manolakis, Vinay K. Ingle, Stephen M. Kogon, *Statistical and Adaptive Signal Processing: Spectral Estimation, Signal Modeling, Adaptive Filtering, and Array Processing*, Artech House, 2005.
6. Michael G. Larimore, C. Richard Johnson, *Theory and Design of Adaptive Filters*, Pearson, 2001.

EC6404E: MACHINE LEARNING AND PATTERN RECOGNITION

Pre-requisites: NIL

L	T	P	O	C
3	0	2	7	4

Total Sessions: 39L+ 26P

Course Outcomes:

CO1: Apply knowledge of linear systems, probability theory, statistics and optimization theory for data representation and classification.
CO2: Analyze basic mathematical and statistical techniques in machine learning.
CO3: Design machine learning algorithms to classify real world data.
CO4: Evaluate systems to make sound decisions on real world problems.
CO5: Develop skill for continuous learning and conduct independent research in the area of machine learning and pattern recognition.

Lecture Sessions:
Introduction to features, feature vectors and classification, Bayes theorem, Bayes decision theory, minimum-error-rate classification, Discriminant functions, Decision surfaces, Normal density and discriminant functions.
Estimation of unknown probability density function: parameter estimation methods, Maximum-Likelihood Estimation-Gaussian case, Maximum a Posteriori estimation– Bayesian estimation: Gaussian case –Nonparametric density estimation – Parzen-window method, EM algorithm.

Perceptron, learning algorithm, X-OR problem, multi-layer perceptrons, error surfaces, convex and nonconvex problems, Backpropagation algorithm, stochastic gradient descent, LMS, loss and activation functions, Radial basis function networks.
Features, dimensionality reduction, K-L Transform, Fisher linear discriminants, Haar transform, Boosting: combining classifiers, boosted cascades, Viola-Jones algorithm.

Databases, training, validation and testing: k-fold validation, iterations, data balance, accuracy, precision, Receiver Operating Characteristics (ROC), performance measures.
Markov chain models, Viterbi algorithm, Hidden Markov Models, Training markov models using neural networks.

Unsupervised learning and clustering: Criterion functions for clustering – Algorithms for clustering: K-Means, Hierarchical, Self-Organizing Maps, DBSCAN. Cluster validation.
Factor Analysis, Decision trees, Classification and Regression Trees (CART).

Practical Sessions:
Suggested List of Experiments
1. Simulating central limit theorem, estimation of probability density function using parametric and non-parametric methods.
2. Classification using Bayes discriminant function.
3. Dimensionality reduction using FLD and PCA
4. Simulation of an X-OR problem and its classification using an MLP.
5. Implementation of the back-propagation algorithm. Classification of a 4 dimensional 3-class problem using FLD and MLP.
6. Implementation of an ROC and result analysis from ROC.
7. Implementation of Viterbi algorithm
8. End semester mini project.

References:

1. C.M. Bishop, *Pattern Recognition and Machine Learning*, Springer, 2006.
2. R.O. Duda, P.E. Hart and D.G. Stork, *Pattern Classification*, 3rd Edn., John Wiley, 2001.
3. S. Theodoridis and K. Koutroumbas, *Pattern Recognition*, 4th Edn., Academic Press, 2009.

EC6421E ARRAY SIGNAL PROCESSING

Pre-requisites: Linear Algebra

L	T	P	O	C
3	0	0	6	3

Total Sessions: 39L

Course Outcomes:

CO1 : Obtain basic understanding of spatial signals and its analysis.
CO2 : Familiarize with the basic knowledge of the sensor arrays.
CO3 : Perform the spatial frequency analysis of array signals.
CO4 : Implement various methods of beamforming and direction of arrival estimation.

Spatial Signals and Sensor Arrays
Spatial Signals: Signals in space and time - Spatial frequency - Direction vs. frequency - Wave fields – Far field and Near field signals.
Sensor Arrays: Spatial sampling - Uniform linear arrays - Planar arrays - Random arrays - Array steering vector - Virtual array of MIMO configuration - Broadband arrays.

Spatial Frequency and Beamforming
Aliasing in spatial frequency domain - Spatial frequency transform and Spatial spectrum - Spatial Domain Filtering - Beamforming: Data-independent, Statistically optimum, and Adaptive beamforming techniques - Spatially white signal.

Direction of Arrival Estimation
Non parametric methods: Beam forming and Capon methods - Resolution of Beamforming method – Signal Subspace methods: Subspace fitting, ESPRIT and Toeplitz approximation – Noise Subspace methods: Pisarenko, MUSIC and Minimum Norm - Spatial Smoothing.
Target Tracking: Kalman Filter, and Interacting multiple model filter

References:

1. Harry L. Van Trees, *Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory*, Wiley, 2002.
2. Don H. Johnson and Dan E. Dudgeon, *Array Signal Processing: Concepts and Techniques*, Prentice-Hall, 1993.
3. Prabhakar S. Naidu., *Sensor array signal processing*, CRC Press, 2001.
4. Dimitris G. Manolakis, Vinay K. Ingle, and Stephen M. Kogon, *Statistical and Adaptive Signal Processing: Spectral Estimation, Signal Modeling, Adaptive Filtering, and Array Processing*, Artech House, 2005.
5. Vijay K. Madisetti, *The Digital Signal Processing Handbook: Wireless, Networking, Radar, Sensor Array Processing, and Nonlinear Signal Processing*, CRC Press, 2nd Edition, 2010.

EC6423E: DIGITAL IMAGE PROCESSING TECHNIQUES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Demonstrate the methods of image acquisition, representation and manipulation to design and develop algorithms for solving image processing problems related to various applications like medicine, industry, communications etc.

CO2: Analyze various image processing algorithms for preprocessing, restoration, compression and segmentation using various spatial and frequency domain methods.

CO3: Identify and solve complex real world problems in image processing using modern signal processing tools, active cooperative learning and be able to demonstrate them effectively.

CO4: Analyze linear systems involving random processes.

CO5: Acquire skills to conduct independent study and analysis of image processing problems and techniques that would engage in lifelong learning

Image representation: Gray scale and colour Images, image sampling and quantization, colour spaces. Connectivity and relations between pixels – Simple manipulations of pixels: arithmetic, logical and geometric operations – Various techniques for image enhancement and restoration - filters in spatial and frequency domains, histogram-based processing, homomorphic filtering, Image Registration – Examples and case studies

Morphological Image Processing: The structuring element, Basic operations on sets, Erosion, Dilation, Opening and Closing, Hit-or-Miss Transform, Basic Morphological Algorithms and applications.
Image segmentation: Edge detection, line detection, curve detection, Edge linking and boundary extraction, boundary representation, region representation and segmentation - Thresholding, Otsu's Method, Variable and multi variable thresholding, Similarity based Segmentation - Segmentation Using Morphological Watersheds, Use of Motion in Segmentation – Image representation and object recognition: Descriptors for boundaries and regions, global descriptors – Pattern recognition as applied to images

Fundamental concepts of image compression: Compression models, Information theoretic perspective, Fundamental coding theorem – Lossless Compression: Huffman Coding, Arithmetic coding, Bit plane coding, Run length coding – Lossy compression: Quantization – Scalar and Vector, Transform coding – Image compression standards, Introduction to Sub band coding – Basic concepts of video compression, Introduction to video compression standards

References:

1. R. C. Gonzalez, R. E. Woods, *Digital Image Processing,* Pearson Education. 3rd Edn.,2016
2. Jain A.K., *Fundamentals of Digital Image Processing,* 7th Edn., Prentice-Hall, 2002.
3. Jae S. Lim, *Two Dimensional Signal and Image Processing,* Prentice-Hall, Inc., 1990.
4. Pratt W.K., *Digital Image Processing,* John Wiley, 4th Edn., 2007.
5. K. R. Castleman, *Digital image processing,* Prentice Hall, 1996.

EC6424E: LINEAR & NONLINEAR OPTIMIZATION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Mathematical background: sequences and subsequences, mapping and functions, continuous functions infimum and supremum of functions minima and maxima of functions, differentiable functions – Vectors and vector spaces, matrices, linear transformation, quadratic forms, gradient and Hessian-Linear equations, solution of a set of linear equations, basic solution and degeneracy, convex sets and convex cones, convex hulls, extreme point, convex and concave functions, differentiable convex functions

Linear Programming: introduction, optimization model, formulation and applications – Classical optimization techniques: single and multi variable problems, types of constraints, graphical method –
Linear optimization algorithms: simplex method, basic solution and extreme point, degeneracy, primal simplex method, dual linear programs, primal, dual, and duality theory, dual simplex method, primal dual algorithm – Post optimization problems: sensitivity analysis and parametric programming.

Nonlinear Programming: minimization and maximization of convex functions, local & global optimum, convergence – Unconstrained optimization: one dimensional minimization, elimination methods: Fibonacci & Golden section search, gradient methods – Constrained optimization: Lagrangian method, Kuhn-Tucker optimality conditions, convex programming problems, Augmented Lagrangian method (ALM) Applications of optimization theory in signal processing: signal processing via convex optimization, applications in weight design, linearizing pre-equalization, robust Kalman filtering, online array weight design, basis pursuit denoising (BPDN), compressive sensing and orthogonal matching pursuit (OMP).

References:

1. David G Luenberger, *Linear and Non Linear Programming,* Addison-Wesley, 2nd Edn., 2001.
2. S.S. Rao, *Engineering Optimization.; Theory and Practice,* John Wiley, 4th Edn., 2013.
3. S.M. Sinha, *Mathematical programming: Theory and Methods,* Elsevier, 2006.
4. Hillier and Lieberman, *Introduction to Operations Research,*" McGraw-Hill, 8th Edn., 2005.
5. Kalyanmoy Deb, *Optimization for Engineering: Design Algorithms and Examples,* 2nd Edn., Prentice Hall, 1998.
6. Igor Griva, ArielaSofer, Stephen G. Nash: *Linear and Nonlinear Optimization*, 2nd Edn., SIAM, 2009.

EC6445E: COMPUTER VISION

Pre-requisites: Basic Skill in Matrix Theory

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply knowledge of linear systems, probability theory, statistics and optimization theory for computer vision applications.
CO2: Design computer vision algorithms on real world data.
CO3: Evaluate computer vision systems to make sound decisions on real world problems.
CO4: Develop skill to conduct independent research in the area of computer vision.

Digital Image Formation and low-level processing: Overview and State-of-the-art, Fundamentals of Image Formation, Transformation: Orthogonal, Euclidean, Affine, Projective, etc, Fourier Transform, Convolution and Filtering, Image Enhancement, Restoration, Histogram Processing – Depth estimation and Multi-camera views: Perspective, Binocular Stereopsis: Camera and Epipolar Geometry – Homography, Rectification, DLT, RANSAC, 3-D reconstruction framework; Auto-calibration. apparel.

Feature Extraction: Edges - Canny, LOG, DOG – Line detectors (Hough Transform), Corners - Harris and Hessian Affine, Orientation Histogram, SIFT, SURF, HOG, GLOH, Scale-Space Analysis- Image Pyramids and Gaussian derivative filters, Gabor Filters and DWT. Image Segmentation: Region Growing, Edge Based approaches to segmentation, Graph-Cut, MeanShift, MRFs, Texture Segmentation – Object detection.

Motion Analysis: Background Subtraction and Modeling, Optical Flow, KLT, Spatio-Temporal Analysis, Dynamic Stereo – Motion parameter estimation – Object Recognition: Hough transforms and other simple object recognition methods, Shape correspondence and shape matching, Shape priors for recognition.
Deep Neural Networks in Computer Vision.

References:

1. Richard Szeliski, *Computer Vision: Algorithms and Applications,* 2nd Edn., Springer-Verlag London Ltd., 2022.
2. Richard Hartley and Andrew Zisserman, *Multiple View Geometry in Computer Vision,* 2nd Edn., Cambridge University Press, 2004.
3. K. Fukunaga, *Introduction to Statistical Pattern Recognition,* 2nd Edn., Academic Press, Morgan Kaufmann, 2014.
4. R.C. Gonzalez and R.E. Woods, *Digital Image Processing,* 3rd Edn., Prentice Hall, 2007.

EC6446E: DEEP LEARNING

Pre-requisites: Basic Skill in Matrix Theory

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply knowledge of linear systems, probability theory, statistics and optimization theory for deep learning applications.

CO2: Design deep learning algorithms on real world data.

CO3: Evaluate deep learning models to make sound decisions on real world problems.

CO4: Develop skill to conduct independent research in the area of neural networks and deep learning.

.

Review of Linear Models: Linear Regression, Linear Classifiers, Training a Linear Model, Perceptron Learning Rule, Activation Functions, Loss Functions.
Optimization: Formulation of Objective Function, Convex Functions, Local Minima, Global Minima, Visualizing Gradient Descent, Stochastic Gradient Descent (SGD), Problems and Workarounds in SGD.
Multilayer Perceptron (MLP): Feedforward Neural Networks, Bias Vector, Weight Matrix, Activation Vector, Types of Activation Functions, Feature Learning, Deep and Shallow Networks.
Back Propagation: Multivariate Chain Rule, Representation using Computational Graph, Backpropagation Algorithm, Backpropagation on Multilayer Network.

Convolutional Neural Networks (CNN): Foundations on 2D Convolution, Convolutional Layers - Sparse Connectivity and Weight Sharing, CNN Architecture, Applications of CNN: Classification, Object Recognition.
Generalization of Trained Model, Reasoning about Generalization, Bias and Variance, Remedies for Overfitting.

Recurrent Neural Networks (RNN): Sequence to Sequence Prediction, Concept of RNN, Self-loops, Backpropagation through Time, Applications of RNN, Exploding/Vanishing Gradients, Remedies, Adjusting Derivatives for Descent: Momentum-Based Learning, AdaGrad, RMSProp, Adam. LSTM Networks.
Residual Networks: Residual Blocks, Deep Residual Networks (ResNets), Residual Learning, Examples.

Attention and Transformer Networks: RNN Encoder-Decoder Model, Learning to Align and Translate, Attention Networks, Transformers: Encoder-Decoder Stacks, Scaled Dot-product Attention, Self Attention, Multi-Head Attention, Transformer Architecture, Vision Transformer, Applications.

Generative Modeling: Generative Adversarial Networks (GAN), CycleGAN, Reversible Models: Reversible Blocks, Deep Reversible Architectures.

References:

1. Bengio, Yoshua, Ian Goodfellow, Aaron Courville, *Deep learning*, Vol. 1. Cambridge, MA, USA: MI press, 2017.
2. Nielsen, Michael A., *Neural networks and Deep Learning*, Vol. 25. San Francisco, CA, USA: Determination press, 2015.
3. Aggarwal, Charu C., *Neural Networks and Deep Learning*, Springer 10.978 ,2020.
4. Lyla B. Das, Sudhish N. George, Anup Aprem *Artificial Intelligence and Machine Learning: Theory and Practice*, IK International Publishing House, 2022.

EC6447E: DEEP LEARNING IN COMPUTER VISION

Pre-requisites: Basic Skill in Matrix Theory

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply knowledge of linear systems, probability theory, statistics and optimization theory for deep learning applications.

CO2: Design computer vision algorithms on real world data

CO3: Evaluate computer vision systems to make sound decisions on real world problems.

CO4: Develop skill to conduct independent research in the area of computer vision

.

Computer Vision Overview, Historical context, Applications. Image Classification with Linear Classifiers, Data-driven Approach, k-Nearest Neighbour, Linear Classifiers, Algebraic/Visual/Geometric viewpoints, SVM, Softmax loss – Regularization and Optimization: Regularization, Stochastic Gradient Descent, Momentum, AdaGrad, ADAM, Learning Rate Schedules – Neural Networks: Multi-layer Perceptron, Backpropagation.

Image Classification with Convolutional Neural Networks (CNN): History, Higher-level Representations, Image Features, Convolution and Pooling, CNN Architectures: Batch Normalization, Transfer Learning, AlexNet, VGG, GoogLeNet, ResNet.
Training Neural Networks: Activation Functions, Data Processing, Weight Initialization, Hyperparameter tuning, Data augmentation. Visualizing and Understanding, Feature Visualization and Inversion, Adversarial Examples. DeepDream, Style Transfer, Object Detection and Image Segmentation, Single-stage Detectors, Two-stage Detectors, Semantic/Instance/Panoptic Segmentation, Recurrent Neural Networks: RNN, LSTM, GRU, Language Modeling, Image Captioning, Sequence-to-sequence Prediction, Encoder–Decoder Architecture – Attention and Transformers: Self-Attention, Transformers, Vision Transformers.

Generative Models - Supervised vs. Unsupervised Learning, Pixel RNN, Pixel CNN, Variational Autoencoders, Generative Adversarial Networks, Self-supervised Learning - Pretext tasks, Contrastive Learning, Multisensory Supervision, Low-Level Vision - Optical Flow, Depth Estimation, Stereo Vision.

References:

1. Bengio, Yoshua, Ian Goodfellow, Aaron Courville., Deep learning, Vol. 1. Cambridge, MA, USA: MI press, 2017.
2. Nielsen, Michael A., *Neural networks and Deep Learning*, Vol. 25. San Francisco, CA, USA: Determination press, 2015.
3. Aggarwal, Charu C., *Neural Networks and Deep Learning*, Springer 10.978, 2020.
4. Szeliski R., *Computer Vision: Algorithms and Applications*, Springer Nature, 2022 Jan 3.
5. Lyla B. Das, Sudhish N. George, Anup Aprem, *Artificial Intelligence and Machine Learning: Theory and Practice*, IK International Publishing House, 2022.

EC6451E: REINFORCEMENT LEARNING

Pre-requisites: Familiarity with machine learning and training neural networks with modern libraries and Background in Linear Algebra, Probability and Statistics, Computer Programming (Python)

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Model real-world sequential decision-making problems using Markov decision process and knowledge of associated solution methodologies.

CO2: Analyze classical model-free reinforcement learning algorithms and state-of-art deep reinforcement learning algorithms.

CO3: Solve sequential decision-making problems with hidden dynamics using exact and reinforcement learning techniques.

CO4: Demonstrate the potential of reinforcement learning in real-world problems through a course project.

Review of probability and statistics: Random variable, Expectation, Conditional Probability, Conditional Expectation, Markov Property, and Markov Chains.
Markov Reward Process: Definition, Finite and Infinite horizon reward process, Value function and Bellman equation.
Markov Decision Process (MDP): Definition, Finite and Infinite horizon MDP, Bellman dynamic programming equations for MDP. Numerical solution methods: Value iteration, Policy iteration (Generalized policy iteration), Linear programming.

Reinforcement learning: model free and model-based methods.
Monte Carlo and Temporal Difference Learning methods: Estimation of value function using Monte Carlo: first-visit and every-visit – Q-learning and Q-learning with exploration – Temporal difference methods: TD (0) and TD (λ) – Policy iteration using TD learning – Double Learning – Deep reinforcement methodologies: Deep Q-learning (DQN), Double DQN, and Duelling DQN.
Policy Gradient reinforcement learning methods: Policy gradient, Policy gradient theorem (finite and infinite horizon), REINFORCE, REINFORCE with baseline – Actor-Critic algorithm. Advantage Actor-Critic (A2C) and Asynchronous A2C (A3C) – Exploration in policy gradient.
Recent advances in policy gradient reinforcement learning: Trust region policy gradient algorithms and its variants such as Natural Policy Gradient, Trust Region Policy Optimization, Proximal Policy Optimization, Deterministic Policy Gradient and Deep Deterministic Policy Gradient, Soft-Q learning and Soft actor-critic.

Partially Observed Markov Decision Process (POMDP): Definition, Belief and Belief state formulation of POMDP, Belief computation using Hidden Markov Model (HMM) – Bellman dynamic programming for Finite and Infinite horizon POMDP – Exact algorithms for POMDP, Reinforcement learning in POMDP: Policy gradient and Deep Recurrent Q-learning networks (DQRN).
Other topics in reinforcement learning: Multi-agent learning, Meta-learning, Ethics in reinforcement learning, Application of reinforcement learning to real-world problems.

References:

1. Lyla B. Das, Sudhish N. George, Anup Aprem, *Artificial Intelligence and Machine Learning: Theory and Practice*, IK International Publishing House, 2022.
2. R. Sutton and A. Barto, *Reinforcement Learning: An Introduction,* 2nd Edn., MIT Press, 2018.
3. C. Szepesvari. Morgan and Claypool Publishers, *Algorithms for Reinforcement Learning,* 2010.
4. M. Wiering and M. van Otterlo, *Reinforcement Learning: State-of-the-Art,* Springer, 2012.