Annexure AP29-3

Indian Institute of Technology Jodhpur

M. Tech. and M. Tech.-Ph. D. (Dual Degree) In Intelligent Communication Systems Curriculum Structure for AY 2022-23 Onwards

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M. Tech. and M. Tech.-Ph. D. (Dual Degree)
In
Intelligent Communication Systems
Curriculum Structure

1. Introduction

During the past few years, there has been an exponential growth in the usage of communication technologies. The fast development of economy and society requires modern and high-performance communications systems that can cater for massive deployment of connected devices, while still offering acceptable levels of energy consumption, equipment cost and network deployment and operation cost. Emerging communication systems need to support a wide variety of applications and services requiring increased spectral efficiency, higher data rates, low latency and high reliability and security. Communications and Signal processing is one of the key technologies to meet the growing connectivity requirements for new use cases (e.g. for ultra-low latency or high reliability cases) and new applications for the industry, opening up new techno-financial development path also for operators.

The development of communications technology has vastly relied on theories and models, from information theory to channel modelling and detection/estimation theory. The traditional approaches are showing serious limitations, especially in view of the increased complexity of communication networks and the diversified services that the mobile networks are expected to offer with the introduction of network virtualization, implementation of 5G/ IoT, immersive multimedia with varied Quality of Experience etc. The advent of 5G conceptualization and modelling of 6G are introducing new challenges and possibilities for mobile and other high-speed communications service providers. Integration of artificial intelligence/machine learning techniques into networks is one way the industry is addressing these complexities. Advances in artificial intelligence, particularly taking advantage of rapidly increasing network and user behaviour data, indicates a new technological frontier of communications and networking, not only in new methodology in systems and network design, but also in new network architecture accommodating machine learning for broader and efficient services through network deployments. The cloud computing paradigms are further evolving with the introduction of fog computing and edge computing, therefore changing the nature of edge devices as a combination of communication devices and computing devices, and this continues in a heterogeneous manner hardware, software and protocols used in multiple participating networks.

Further, current and future industry trends indicate increased involvement of visual computing and multimedia processing for various automation processes, healthcare, transportation and entertainment.

The M. Tech. and M. Tech.-Ph. D. Dual Degree programme in **Intelligent Communication Systems** prepares students for an advanced engineering career by in-depth understanding of modern communication networks on all layers of the system and their associated signal processing methods. The program provides students an opportunity to learn the specialization in depth by updating and renewing their technical knowledge in a rapidly changing telecommunication industry.

2. Objectives of the program

The program aims at imparting critical awareness and in-depth knowledge of the new trends, approaches, methods, systems, standards, as well as communication network architectures, and protocols immersive multimedia and application of joint computing-communication-control framework to address communication network management issues. The program prepares the students for a variety of career paths including:

1. An industrial path to take up the role of a technical leader or a manager through strong fundamentals and applied technology concepts
2. An academic path to conduct cutting-edge research in the next-generation telecommunication networks and information processing systems and eventually pursue a research or academic profession.

3. Expected Graduate Attributes

Graduates of the PG program in **Intelligent Communication Systems** are expected to have the following attributes:

- Strong fundamentals in communications and signal processing methods and its applications to next generation communication and multimedia systems.

- Understanding of cutting-edge technologies including massive MIMO, massive machine type communications, immersive multimedia, AR/VR, software defined networking for future generations of wireless communication and networking for devices that not only communicate but also engage in computing (e.g. edge device intelligence).

- Understanding of evolving standards, their adoption by industry, and in particular how standards evolve using several building blocks of modern communication systems. Such knowledge is essential for developing products based on interoperable standards.

- Analytical, modeling, computational and experimental skills required to design and implement next-generation communication systems for various applications that require different Quality of Service /Quality of Experience for the end users.

- Preparedness to develop several/critical components of the entire value chain, e.g. modem chipsets, network software, AR/VR user experiences, information centric networks etc.

- Ability to do critical and creative thinking, and to conduct independent and original research and scholarship.

- Ability to apply existing skills and knowledge to identify and formulate new problems, produce new ideas, approaches or actions.

- Ability to teach and express ideas in both written and oral formats.

4. Learning Outcomes

The graduates of the program will be able:

- To characterize and evaluate the performance of communication systems.

- To develop understanding of cutting-edge technologies on future generations of wireless communication and networking through the core courses.

- To develop understanding of standards development and research necessary for building next generation standards for interoperable device/network requirements, including candidate technologies selection criteria/mechanisms/harmonization, appreciation of evolutionary versus revolutionary approaches on new technology standards.

- To develop unique skill sets, through specifically designed bouquet courses, to analyze multi-user networks and understanding of techniques used in systems such as interference management, spectral efficiency improvements, energy efficient communications, information centric networks, evolving multimedia content & communications.

- To implement end-to-end communication systems based on evolving standards, with focus on various MIMO technologies, multicarrier communication, low latency designs, energy efficiency, network function virtualization, network slicing etc.

- To develop systems that can quantify perceptual effects of multimedia signal capture and processing on end user experience.

- To master a specific set of methods, appropriate to their dissertation, with the depth needed to produce methodologically rigorous research.

- To carry out research work demonstrating scientific problem solving and generate IPR.

5. Program Structure

Overall Structure (M. Tech. Degree Requirements for Intelligent Communication Systems)

Category	M. Tech. Compulsory (MC) (Core+ Stream Core)	M. Tech. Elective (ME)	M. Tech. Open (MO)	M. Tech. Project (MP)	Non-graded (NG)	Total Graded + Non-graded
Credits	20 (6+14)	16	6	16	4	**62**

6. List of Compulsory Core Courses:

S. No.	Course Name	L-T-P	Credits
1	Wireless Communications (EEL7020)	3-0-0	3
2	Modern Communication Networks	3-0-0	3

7. List of Stream Core Courses (Students need to choose one of the following streams):

S. No.	Course Name	L-T-P	Credits
Wireless Systems (14 credits)			
1	Cellular Communication Networks	3-0-0	3
2	Machine Learning for Communications (EEL7480)	3-0-0	3
3	Embedded System Design (EEL7150)	3-0-0	3
4	Digital Communications: Hands On	1-0-2	2
5	Introduction to Wireless Standards	3-0-0	3
Communication Networks (14 credits)			
1	Design and analysis of Communication Networks (EEL7760)	3-0-2	4
2	Information-Centric Networks	3-0-2	4
3	Data Communication and Networking (EEL7200)	2-0-2	3
4	Introduction to Wireless Standards	3-0-0	3
Multimedia Communications (14 credits)			
1	Introduction to Immersive Multimedia	3-0-0	3
2	Data Compression (EEL7560)	3-0-0	3
3	Mulsemedia Techniques and Systems	3-0-0	3
4	Multimodal Interface Lab	0-0-4	2
5	Introduction to Multimedia Standards	3-0-0	3

8. List of Programme Elective Courses:

Course Name	Course Name
Cellular Communication Networks	Computational Imaging
Machine Learning for Communications	Speech and Audio Processing
Embedded System Design	Machine Learning for Communication Lab
Digital Communications: Hands On	Queuing Theory
Introduction to Wireless Standards	Wavelets
Design and analysis of Communication Networks	MIMO Wireless Communications
Information Centric Networks	RF system design for Communications
Intelligent Radio Networks	Optimal Filtering

Data Communication and Networking	VLSI broadband communication circuit
Introduction to Immersive Multimedia	Embedded System Design Lab
Data Compression	Radar Engineering
Mulsemedia Techniques and Systems	UAV assisted Wireless Networks
Multimodal Interface Lab	Optical Signal Processing
Introduction to Multimedia Standards	Computation Oriented Communications
Coding Theory	Delay Tolerant Networks
Antenna Engineering	Hardware Aware Communications
Network Information Theory	Optical Networks
Statistical Decision Theory	3D Shape Analysis
Multi-rate Digital Signal Processing	Visual Perception
Digital Image Processing and Applications	Real Time Communications
Digital Video Processing	Optical Communication Systems
Radio Frequency Integrated Circuit Design	Optical Communication Systems Lab
Adaptive Signal Processing	Tactile Internet
Advanced Digital Signal Processing	Selected Topics in Communication I
Optical Fiber Communications	Selected Topics in Communication II
Image sensor Design and Application	Selected Topics in Communication III
Applied Optimization for Wireless Communication	Selected Topics in Signal Processing I
Physical Layer Security	Selected Topics in Signal Processing II
Compressive Sensing	Selected Topics in Signal Processing III
Free Space Optical Communications	Millimeter Wave Technology
GNSS Signal Processing	Digital Image and Video Processing Lab
Backhaul Networks for Wireless Systems	Radio Frequency Integrated Circuit Design Lab

Courses from Other Departments:

Course Name	**Course Name**
Optimization for Data Science	Vehicular Ad Hoc Networks
Bio-Image Computing	Introduction to Haptics
Neuromorphic computing and design	Mobile and Pervasive Computing
Graph Theory and Applications	Introduction to Wireless Ad hoc Networks
Matrix Computations	Cognitive Internet of Vehicles
Machine Learning	Computer Vision
Deep Learning	5G Mobile Networks
Security and Its Applications	Edge and Fog Computing
Visual Computing Lab	Quantum Communication

Semester Wise Plan:

	Courses	L-T-P	GC		Courses	L-T-P	GC
	Bridge course on Introduction to Programming						
	I Semester				II Semester		
MC	Wireless Communications	3-0-0	3	ME	Program Electives		6
MC	Modern Communication Networks	3-0-0	3	MC	**Stream Core** **Wireless Systems** *Machine Learning for Communications* *Embedded System Design* **Communication Networks** *Information-Centric Networks* *Data Communication and Networking* **Multimedia Communications** *Data Compression* *Mulsemedia Techniques and Systems*	 3-0-0 3-0-0 3-0-2 2-0-2 3-0-0 3-0-0	6/7
MC	**Stream Core** **Wireless Systems** *Cellular Communication Networks* **Communication Networks** *Design and Analysis of Communication Networks* **Multimedia Communications** *Introduction to Immersive Multimedia*	 3-0-0 3-0-2 3-0-0	3/4				
ME	Program Electives		6	MO	Open Elective		3
NG	Technical Communication	1-0-0	1	NG	Innovation and IP Management	1-0-0	1
	Total (Graded + Non-graded)		16/17		Total (Graded + Non-graded)		16/17
	III Semester				IV Semester		
MP	Project I	0-0-6	6	MP	Project II	0-0-10	10
MC	**Stream Core** **Wireless Systems** *Digital Communications: Hands On* *Introduction to Wireless Standards* **Communication Networks** *Introduction to Wireless Standards* **Multimedia Communications** *Multimodal Interface Lab* *Introduction to Multimedia Standards*	 1-0-2 3-0-0 3-0-0 0-0-4 3-0-0	5/3	MO	Open Elective		3
ME	Program Electives		4	NG	Ethics and Professional Life	1-0-0	1
NG	Systems Engineering and Project Management	1-0-0	1				
	Total (Graded + Non-graded)		16/14		Total (Graded + Non-graded)		14

9. Topic clouds and Mapping of Topic clouds with proposed compulsory courses

Topics	Compulsory Courses
QoS parameters for communication, Digital modulation techniques, Channel models - AWGN channel, Frequency selective Channels, Multipath Fading channels, Signal Detection, Error performance, Channel Coding Techniques, channel capacity, Diversity techniques, Capacity of Fading channels, MIMO systems	Wireless Communications
Communication layers' architecture, Congestion control and routing protocols, multiple access techniques, Software Defined Networking (SDN), SDN architectural planes, SDN platforms and APIs, Network Function Virtualization (NFV) Architecture, Virtual Network Function, Programmable networks, NFV containers and orchestration, Network slicing (NS) using SDN and NFV, Information Centric Networks (ICN), Network Slicing in Information Centric Networks	Modern Communication Networks
Multi-user communications- MAC, Broadcast, K-User Interference channel (M2M communications), Interference Management Techniques- Interference avoidance, Interference alignment, interference cancellation- NOMA, interference coordination - network MIMO, Multicarrier modulation	Cellular Communication Networks (Stream Core Course)
Machine learning for channel estimation and prediction, automatic modulation classification, channel encoding and decoding	Machine Learning for Communications (Stream Core Course)
Architecture of ARM Cortex M3 and Cortex A series, memory management, programming of embedded processors, hardware-software codesign, scheduling algorithms	Embedded Systems Design (Stream Core Course)
Introduction to programmable hardware, Software Architecture, USRP hardware, signal processing chain, channel modeling, estimation and equalization, fading and diversity, carrier and symbol synchronization, multicarrier modulation, CDMA	Digital Communications: Hands On (Stream Core Course)
Evolution of standards, Standardization forums, mobile cellular standards (3GPP, 5G and beyond), emerging 6G standards, WLAN standards, Standards for Body Area Networks, Personal Area Networks, AI	Introduction to Wireless Standards (Stream Core Course)
Probabilistic models for communication systems, Modelling and Analysis of Communication Networks (mobility models, channel models, topology models, queueing models), Simulation of Communication Networks (discrete event based, Monte-Carlo, rate-based)	Design and analysis of Communication Networks (Stream Core Course)
Introduction to information centric networks (ICN), Data-centric networks vs. Host-centric networks, Architectures of content distribution networks (CDNs), Characteristics of CDNs, ICN architectures, Content naming strategies, Routing of content in ICNs, ICN caching strategies, Security aspects of ICN	Information Centric Networks (Stream Core Course)

Overview of the communication layers' architecture, Network Deployment and Management, MAC Layer Analysis, Network Layer Analysis, Transport Layer, Discussion on Recent Advancements	Data Communication and Networking (Stream Core Course)
Redundancies in image and video: statistical, perceptual, spatial and temporal, Lossless compression, Lossy and perceptual compression, Error resilience, Perceptual audio coding	Data Compression (Stream Core Course)
Sensory enhanced virtual experience, Components of mulsemedia centric VR experience, immersive visual, haptic and audio signals, Use-cases in AR/VR and technology enhanced learning	Mulsemedia Techniques and Systems (Stream Core Course)
Evolution of multimedia standards, H.265 (HEVC), MPEG-I (Coded Representation of Immersive Media), H.266 (VVC), MPEG PCC, MPEG 21	Introduction to Multimedia Standards (Stream Core Course)
Immersive and interactive multimedia, concepts of QoE, QoS to QoE mapping, applications (and use-cases): AR/VR, holography, 360 degree audiovisual content, OTT and high quality broadcast, KPI driven systems for enhanced experiences	Introduction to Immersive Multimedia (Stream Core Course)
Introduction to principles of Multimodal Interfaces, Basic haptic rendering and perception experiments using haptic interfaces, AR and VR models, EEG, Eye Tracker, Gesture (Kinect), Audio Assistance	Multimodal Interface Lab (Stream Core Course)

10. Detailed Program Compulsory Course Contents

Title	**Modern Communication Networks**	Number	**EEL7XXX**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech. and Ph. D.	Type	Compulsory
Prerequisite	Fundamentals of Data Communications		

Objectives

The instructor will:

1. Provide knowledge of layered communication architecture, fundamentals of software defined networking, network function virtualization aspects, network slicing in cloud, edge, 5G networks, IoT, etc.

Learning Outcomes

The students are expected to have the ability to:

1. Thorough understanding of fundamental concepts of Network Virtualization and Softwarization
2. Plan, design, and develop next generation networks using softwarization techniques considering varied QoS requirements for different use-cases

Contents

Fundamentals of Communication Networks: (5 Lectures)
Brief discussion on OSI Layered Architecture (2 Lectures)
Transport, Network, and Data Link Layer Technologies (3 Lectures)

Software Defined Networking: (11 Lectures)
Introduction and motivation to network softwarization (2 Lectures)
SDN planes (Data, Control, and Management planes) (5 Lectures)
SDN platforms and APIs (4 Lectures)

Network Function Virtualization: (11 Lectures)
NFV Architecture, Virtual Network Function (3 Lectures)
Programmable networks, NFV management, Orchestration, Virtual Machines and Containers (8 Lectures)

Network Slicing: (10 Lectures)
Network Slicing with SDN and NVF, Edge and Cloud computing as Network Slicing enablers (5 Lectures)
Use-cases of Network Slicing using NFV and SDN in cloud and edge computing (3 Lectures)
Network Slicing in Information Centric Networks, Hardwarization and softwarization trade-offs (2 Lectures)

Perspective in Cellular Networks: (5 Lectures)
SDN and NFV in cellular networks (5G and B5G) – 5 Lectures

Indicative Assignments:

- Introduction to networking network monitoring tools and simulation tools
- Experiments on Software Defined Networking, Network Function Virtualization, and Network Slicing techniques using SDRs, Openflow, Netconf, Orchestration

Textbook

1. Goransson, P., Black, C. and Culver, T. (2016), *Software Defined Networks: A Comprehensive Approach*, 2nd Edition, Morgan Kaufmann.
2. Gray, K. and Nadeau, T. D. (2016), *Network Function Virtualization*, 1st Edition, Springer.
3. Kazmi, S. M. A., Tran, N. H. and Hong, C. S. (2019), *Network Slicing for 5G and Beyond Networks*, 1st Edition, Springer.

Self Learning Material

1. Relevant research papers will be provided.

Title	**Wireless Communications**	Number	**EEL7020**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech., Ph.D.	Type	Compulsory
Prerequisite	Fundamentals of Communications		

Objectives

The instructor will:

1. Provide students an understanding of the concepts related to communication over wireless fading channel.
2. Expose students to concepts and techniques for exploiting fading and application of these concepts in multiuser communication systems context.

Learning Outcomes

The students are expected to have the ability to:

1. Understand concepts related to deep fade, diversity techniques and channel capacity for point-to-point wireless communications systems.
2. Analyze multi-user networks and understanding of techniques like opportunistic communication, multiuser diversity, superposition coding and successive interference cancellation.

Contents

Wireless Channels [10 Lectures]:

Review of signal detection over AWGN channels and M-ary Modulation (5L)

Modelling of wireless channels; space, time and frequency channel coherence; input/output channel models for single and multi-antenna systems (5L)

Diversity Techniques [12 Lectures]:

Digital modulation and its performance in fading (4L)

Deep fade and diversity (3L)

Realizing diversity: time diversity, frequency diversity, antenna diversity (5L)

Wireless Channel Capacity [10 Lectures]:

Capacity of the Gaussian channels (2L)

Outage limited and ergodic capacity of fading channels (4L)

Water filling algorithm and opportunistic communication (4L)

Multiuser system design [10 Lectures]:

Multiple access and random access techniques (5L)

Multiuser channel capacity and multiuser diversity (5L)

Indicative Assignments:

MATLAB simulation of diversity techniques, capacity (waterfilling and channel inversion), MRC, selection combining, multiuser channel capacity (rate splitting, power splitting) with reference to 4G, 5G specifications, WLAN standards

Textbook

1. Tse, D. and Viswanath, P., (2005), *Fundamentals of wireless communication*, Cambridge University Press.
2. Goldsmith, A., (2005), *Wireless Communications*, Cambridge University Press.
3. Simon, M. K. and Alouini, M. S., (2004), *Digital communication over fading channels*, John Wiley and Sons.

Self Learning Material

Zheng, L., Principles of Wireless Communications, MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electricalengineering-and-computer-science/6-452-principles-of-wireless-communications-spring-2006/index.htm

Preparatory Course Material

Jagannatham, A. K., Principles of Communication II, NPTEL Course Material, Department of Electrical

Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104098/

11. Detailed Stream Core Course Contents

Wireless Systems Stream

Title	**Cellular Communication Networks**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech. and Ph. D.	Type	Stream Core Course
Prerequisite	Foundations of wireless communication systems		

Objectives

The Instructor will:

1. Provide an understanding of fundamental issues related to frequency planning, resource allocation and interference management techniques in cellular communication networks.
2. Introduce concepts and techniques used in existing and emerging cellular communication systems.

Learning Outcomes

The students are expected to have the ability to:

1. Analyze and design operational cellular communications networks.
2. Compare and contrast the strengths and weaknesses of various cellular communication networks.

Contents

Introduction of cellular systems[9 Lectures]:
Channel models and impairments (5L)
Quality of service requirements, coverage planning (4L)

Interference management techniques[12 Lectures]:
Interference avoidance and interference cancellation(5L)
Interference alignment (4L)
Interference coordination – network MIMO (3L)

User and Resource Management [9 Lectures]:
Association and handover management (4L)
Transmit power control (5L)

Multicarrier Systems and Orthogonal Frequency Division Multiplexing [12 Lectures]:
Multicarrier systems and orthogonal frequency division multiplexing (OFDM) (3L)
OFDM system design, Orthogonality issues (3L)
OFDM impairments and their effects in the system, Future of OFDM based waveforms (3L)
Orthogonal frequency division multiple access (3L)

Textbook

1. Miao, G., Zander, J., Sung, K., & Ben Slimane, S., (2016), Fundamentals of Mobile Data Networks, Cambridge University Press
2. Rappaport, T. S., (2010), Wireless Communications – Principles and Practice, Pearson
3. Bolcskei, H., Gesbert, D., Papadis, C. B., and Veen, A. V., (2006), Space-time Wireless Systems, Cambridge Press.

Self Learning Material

1. Koilpillai, D., *Introduction to Wireless and Cellular Communications,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/106/106/106106167/
2. ETSI 5G Technologies https://www.etsi.org/technologies/5g

Title	**Machine Learning for Communications**	Number	**EEL7480**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., Ph.D.	Type	Stream Core Course
Prerequisite	Fundamentals of Machine Learning, Data and Computer Communications		

Objectives

The Instructor will:

1. Introduce the area of machine learning in the context of communications

Learning Outcomes

The students are expected to have the ability to:

1. Apply machine learning techniques to various signal processing requirements for communications including channel estimation, automatic modulation classification and iterative channel decoding.

Contents

Channel estimation and prediction [14 Lectures]:

Adaptive transmission systems, The Impact of Outdated CSI, Classical Channel Prediction, Neural Network Based Prediction Schemes (5L)
Flat fading SISO Prediction, Channel-Gain Prediction with Real-Valued and Complex-Valued RNN, Channel Envelope Prediction, Frequency-Selective SISO Prediction (5L)
Performance and Complexity, Computational Complexity (4L)

Automatic Modulation Classification [10 Lectures]:

Signal Models for modulation classification (2L)
Likelihood based classifiers (2L)
Distribution Test-based classifiers (2L)
Modulation classification Features (2L)
Machine Learning models for Modulation classification (2L)

Channel Encoding and Decoding [18 Lectures]:

Overview of Channel coding and Deep Learning (3L)
DNN for Channel coding and to Decoding Directly (5L)
DNNs for joint equalization and Channel Decoding, CNNs for Decoding (5L)
Decoding by Eliminating Correlated Channel Noise, BP-CNN Decoding (5L)

Textbook

1. Zhechen Zhu and Ashoke K. Nandi, (2015), Automatic Modulation Classification: Principles, Algorithms and Applications, Wiley
2. Luo, F. L., (2020), *Machine Learning for Future Wireless Communications*, Wiley
3. He, R., and Ding Z., (2019), *Application of Machine Learning in Wireless Communications*, The Institution of Engineering and Technology, IET

Self Learning Material

1. Machine Learning For Communications Emerging Technologies Initiative, IEEE https://mlc.committees.comsoc.org/research-library/

Preparatory Course Material

1. Jagannatham, A. K., Principles of Communication II, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104098/

Title	**Embedded System Design**	Number	**EEL7150**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech., Ph.D.	Type	Stream Core Course
Prerequisite	Basics of Microprocessors		

Objectives

The Instructor will:

1. introduce concepts of different architectures and programming languages of embedded processors.
2. introduce design of embedded systems.

Learning Outcomes

The students are expected to have the ability to:

1. program and to design embedded system using 32-bit embedded processors based on system specifications.
2. use different IDE and debugging tools.

Contents

Review of Embedded Computing; embedded system design process; CPS and embedded Computing (3 Hours)

Architecture of ARM Cortex M3 and Cortex A series processors; Memory system mechanism; Cache; Memory management units and address translation; Performance assessment of embedded processor; Introduction to Embedded Multicore Architecture (16 Hours)

Programming of Embedded processors using assembly and C; models for program --data flow graphs; Assembly language programming of ARM Cortex M3; Hardware software co-design; (13 Hours)

Processes and real time operating systems; Multi-rate system; real time scheduling algorithms e.g. RMA,EDF and their variants; Energy efficient scheduling algorithms; Examples of design of embedded systems. (8 Hours)

Textbook

1. Josheph Yiu, (2013), The definitive Guide to ARM Cortex M3 and M4 Processors, 3rd Edition, Elsevier.
2. Marilyn Wolf, (2014), High Performance embedded Computing: Applications in Cyber Physical Systems and Mobile Computing, 2nd Edition, Elsevier.

Self Learning Material

1. Prof. Santanu Chaudhury, *Introduction to Embedded Computing*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/108102045/#

Preparatory Course Material

1. Marilyn Wolf, *Computers as Components: Principles of Embedded Computing System Design*, Third Edition, Elsevier 2012.

Title	**Digital Communications: Hands-on**	Number	EEP7XX0
Department	Electrical Engineering	L-T-P [C]	1–0–2 [2]
Offered for	B.Tech., and M. Tech.	Type	Stream Core Course
Prerequisite	Fundamentals of Digital Communication Systems		

Objectives

The Instructor will:

1. provide students with hands-on exposure towards the design and implementation of digital communication systems using software defined radio technology.

Learning Outcomes

The students are expected to have the ability to:

1. design communications systems by assessing the design trade-offs and real-world communication requirements
2. Utilize fundamental communication techniques such as CDMA and multicarrier modulation like OFDM for the current and future wireless networks relevant to industry needs.

Contents

Lecture:

Introduction to programmable hardware, Software Architecture, USRP hardware, signal processing chain, channel modeling, estimation and equalization, fading and diversity, carrier and symbol synchronization, multicarrier modulation, CDMA

Laboratory:

Lab 1: Setting up the programmable hardware to transmit and receive signals

Lab 2: Estimating signal power, noise power, the power spectrum, and the bandwidth of Signals

Lab 3: Sampling, aliasing, interpolation, resampling, upsampling, and downsampling

Lab 4: Dealing with narrowband channel impairments: synchronization and channel estimation

Lab 5: Implementation of a transmitter and receiver using programmable hardware

Lab 6-7: Receiver Structure & Waveform Synthesis of a Transmitter and a Receiver

Lab 8-9: Implementation of multicarrier modulation like OFDM and synchronization using programmable hardware

Lab 10: Implementation of CDMA

Lab 11-14: Term project

Textbook

1. Pu, D. and Wyglinski, A. M. (2013), *Digital Communication System Engineering with Software-Defined Radio*, 1st Edition, Artech House

Self Learning Material

1. Wyglinski, A. M., *Software Defined Radio Systems and Analysis,* Online Course Material, Department of Electrical and Computer Engineering, Worcester Polytechnic Institute, https://www.youtube.com/playlist?list=PLBfTSoOqoRnOTBTLahXBlxaDUNWdZ3FdS

Title	**Introduction to Wireless Standards**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech., and Ph.D.	Type	Stream Core Course
Prerequisite	Concepts of Wireless Communications and Networks		

Objectives

The Instructor will:

1. Provide knowledge of wireless standard development approaches, with cases studies of few emerging standards
2. Make students familiar with how to incorporate research results into standards
3. Present technology choices and selection criteria for different use cases

Learning Outcomes

The students are expected to have the ability to:

1. Understand building blocks of wireless standards including layered approaches
2. Interpret standards for product development including test & evaluation for compliance
3. Capability to be able to contribute to standards

Contents

Introduction to Wireless Standards: (6 Lectures)
Evolution, support to legacy systems, standalone/non-standalone deployments scenarios, different standardization forums, IPR regulations in the standards context, Government and industry roles

Case Study 1: Mobile Cellular Standards: (11 Lectures)
Aspects related to (for relevant standards) Radio Interface, Resource control and signalling aspects from UE (User Equipment) and Network side. Leverage knowledge from wireless communications, modern communication networks to create standards, technology selection criteria for 3GPP, various groups including RAN, SA, and CT Evolution of standards from legacy (3G/4G) to 5G (6 lectures) and ongoing efforts for “5G and Beyond” (5 lectures).

Case Study 2: Emerging 6G standards (8 Lectures)
3GPP, ITU, Next G Alliance, TSDSI India context. Emerging Use cases and technology considerations to support them. Physical Radio Interface, Medium Access Control, Security and signalling aspects from UE (User Equipment) – (5 lectures)
Network side (Software defined networking, Open RAN, Virtualization, Management layers). How to use standards for product development and product testing for compliant interoperable products (3 lectures)

Case Study 3: Wireless Local Area Networks (10 Lectures)
Capabilities, Data rates, Modes of operation. PHY and MAC layer considerations, user experience, Leverage knowledge from wireless communications, modern communication networks to illustrate how to create standards, technology selection criteria to fulfil market expectations from new standards
IEEE802.11 family of standard evolution including 60GHz support
- IEEE802.11 b/g/n/ac (5 Lectures)
- IEEE802.11 ax/ad/… (5 Lectures)

Newer paradigms: (7 Lectures)
Standards for Body Area Networks, Personal Area Networks, AI,

References

1. www.3gpp.org
2. IEEE SA - The IEEE Standards Association - Home
3. IEEE SA - IEEE 802.11-2016
4. Next G Alliance
5. ITU Publications : Standardization (ITU-T)
6. India's Telecom SDO (tsdsi.in)

Self Learning Material

Relevant research papers and standard contribution papers will be provided.

Title	**Design and Analysis of Communication Networks**	Number	**EEL7760**
Department	Electrical Engineering	L-T-P [C]	3–0–2 [4]
Offered for	B.Tech., M. Tech., and Ph.D.	Type	Stream Core Course
Prerequisite	Fundamentals of Data and Computer Communications, Signals and Systems		

Objectives

The Instructor will:

1. Provide in-depth understanding of communication network analysis, modeling and simulation techniques.

Learning Outcomes

The students are expected to have the ability to:

1. Analyse and evaluate communication networks using analytical and simulation-based methods including traffic models, graph models and mobility models.
2. Design and program software components for network simulations and analysis.

Contents

Probabilistic models for communication systems [10 Lectures]:

Linear System with Random process Input (4L)
LTI System with WSS Process Input, point-to-point communications link (2L)
multi-point links, random and multiple access techniques (4L)

Modelling and Analysis of Communication Networks [16 Lectures]:

Random number generation, mobility models (3L)
Channel models, topology models, graph theory and algorithms (5L)
Queuing models, queuing networks (5L)
Network calculus (3L)

Simulation of Communication Networks [16 Lectures]:

Discrete event-based simulation (3L)
Monte-carlo simulation(4L)
Rate-based simulation (3L)
Analysis of simulation results, statistical analysis (4L)
Visualization of results (2L)

Lab Experiments will be conducted on traffic modeling, link-level, system-level, packet level simulation, SW/HW in the loop.

Textbooks

1. Srikant, R. and Ying, L., (2014), Communication Networks: An Optimization, Control and Stochastic Networks Perspective , Cambridge University Press.
2. Kumar, A., Manjunath, D. and Kuri, J., (2004), Communication Networking: An Analytical Approach, Morgan Kaufman Series in Networking, (an imprint of Elsevier Science)
3. Bonald, T. and Feuillet, M., (2011), Network Performance Analysis, Wiley.

Reference Book

1. Law, A. M., (2015), Simulation Modeling and Analysis, Fifth Edition, McGraw-Hill.

Self Learning Material

1. Scalable Wireless Ad-hoc Network Simulator, http://jist.ece.cornell.edu/index.html

Preparatory Material

1. Modiano, E., *Data Communication Networks,* MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-263j-data-communication-networks-fall-2002/index.htm

Title	**Information Centric Networks**	Number	**EEL7XXX**
Department	Electrical Engineering	L-T-P [C]	3–0–2 [4]
Offered for	B. Tech., M. Tech., and Ph.D.	Type	Stream Core Course
Prerequisite	Fundamentals of Communication Networks		

Objectives

The instructor will:

1. Provide knowledge on the next generation information centric networking (ICN) technologies such as ICN architectures, content distribution networks, routing in the CDNs, caching, and security aspects.

Learning Outcomes

The students are expected to have the following:

1. Thorough understanding of fundamental architectural components of information centric networks
2. Capability to design the next generation information-centric networks

Contents

Introduction to Information/Content Centric Networks: (4 Lectures)
*Funda*mentals of TCP/IP Architecture, Limitations of host-centric networks,
Motivation for data-centric networks with example use-cases
Introduction to information centric networking approach

Content Distribution Networks: (5 Lectures)
CDN Architecture and design challenges
Characteristics of CDN: Name based routing, Publish/subscribe paradigm
Differences between ICN, CCN, and CDN

ICN Architectures: (10 Lectures)
TRIAD, DONA, Named-data architectures (4 Lectures)
Content-centric, PURSUIT, Network Information (NetInf) architectures (4 Lectures)
Introduction to SDN in ICN (2 Lectures)

Content Naming and Routing of Named Content: (11 Lectures)
Naming approaches (DONA, NDN, Hierarchical, Secure naming) (4 Lectures)
Content routing (NDN forwarding, OSPFN, Recent developments as way forward) (5 Lectures)
ICN in 5G and benefits for cellular operators (2 Lectures)

Caching in ICN: (6 Lectures)
In-network caching, Edge caching, SDN caching, Performance metrics (4 Lectures)
Practical applications of ICN such as Youtube, Netflix, etc. (2 Lectures)

Security and Privacy in ICN: (6 Lectures)
Security Challenges, Privacy Challenges, Security and Privacy handling mechanisms

Lab components (14 Sessions)
Implementation of ICN architectures using ns3 and other popular open-source platforms
Implementation of routing protocols and caching techniques
Demonstration of SDN in ICN networks
Applications of ICN in vehicular networks, IoT, etc.

Textbook

1. Gabriel M., Pedro B., (2013), *Information-Centric Networks: A New Paradigm for the Internet*, 1st Edition, Wiley
2. S. H. Ahmed, S. H. Bouk, and D. Kim, (2016), *Content-Centric Networks: An Overview, Applications and Research Challenges*, 1st Edition, Springer

Online Course Material

1. B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher and B. Ohlman, "A survey of information-centric networking," in *IEEE Communications Magazine,* vol. 50, no. 7, pp. 26-36, July 2012, doi: 10.1109/MCOM.2012.6231276.

2. Ali Ghodsi et. al., "Information-centric networking: seeing the forest for the trees," in *Proceedings of the 10th ACM Workshop on Hot Topics in Networks*, pp. 1-6, November, 2011, doi: 10.1145/2070562.2070563
3. Q. Y. Zhang, X. W. Wang, M. Huang, K. Q. Li and S. K. Das, "Software Defined Networking Meets Information Centric Networking: A Survey," in *IEEE Access*, vol. 6, pp. 39547-39563, 2018, doi: 10.1109/ACCESS.2018.2855135.

Title	**Data Communication and Networking**	Number	**EEL7200**
Department	Electrical Engineering	L-T-P [C]	2–0–2 [3]
Offered for	B. Tech., M. Tech. and Ph. D.	Type	Stream Core Course
Prerequisite	Fundamentals of Wireless Communications, Probability Theory and Random Process		

Objectives

The Instructor will expose the students to distinguished features of Wireless Networks.

Learning Outcomes

The students are expected to have the ability to:

1. Design and optimize wireless network architectures.
2. Develop end-to-end IoT applications utilizing suitable data communication and networking technologies.

Contents

Fundamentals (4 Lectures):
Overview of the communication layers' architecture (1 L)
QoS parameters, Data communication technologies: QoS perspective and layer-wise technologies (3 L)
Network Deployment and Management (3 Lectures):
Network Topologies (1 Lecture)
Node/network localization and deployment map generations (2 Lectures)
MAC Layer Analysis (7 Lectures):
Markov process, Single and Multi-Server Queues (M/M/1, M/M/c) with finite and infinite queue sizes (3 Lectures)
Contention and contention-free channel access mechanisms (2 Lectures)
Performance modeling and analysis of CSMA/CA with finite packet queues (2 Lectures)
Network Layer Analysis (8 Lectures):
Design constraints, Bounded latency networks (2 Lectures)
Routing algorithms - Analysis and optimization (3 Lectures)
Self-organizing Networks (1 Lecture)
Motivation for cross-layer protocol design (2 Lectures)
Transport Layer (2 Lectures):
TCP, UDP, Congestion Control
Discussion on Recent Advancements (4 Lectures)
Introduction to NFV, Network slicing (2 Lectures)
Energy efficient protocols and energy harvesting techniques (2 Lectures)

Lab Component (14 sessions):
Introduction to existing simulation tools, and hands on-session for Simulation Tool
NS3 simulations for MAC layer and Network layer performance analysis for WPANs
Analytical and Simulation co-validation for MAC and Network protocols
End-to-End IoT Application Development (Multi-node multi-parameter sensing system development, Edge processing, RF communication, Cloud integration, Data analytics and alerts)

Indicative Assignments and Self-Study Components:
Assignments on MAC layer analysis, network layer analysis, and transport layer using tools such as Wireshark, NS3 will be provided. Self-study topics include deeper analytical analysis of MAC layer, network layer, and transport layer protocols will be suggested.

Textbook

1. Dargie, W., and Poellabauer, C., (2010), *Fundamentals of Wireless Sensor Networks: Theory and Practice*, Wiley
2. Stallings, W., (2007), *Data and Computer Communications*, 8th Edition, Pearson

3. Bertsekas, D. P. and Gallager, R. G., (1992), *Data Networks*, 2nd Edition, Prentice Hall
4. Stallings, W., *High-speed Networks and Internets: Performance and Quality of Service*, 2nd Edition, Prentice Hall

Reference Book

1. Ian F. Akyildiz and Mehmet Can Vuran, (2010), Wireless Sensor Networks, A John Wiley and Sons Ltd. Publication.

Multimedia Communications Stream

Title	**Introduction to Immersive Multimedia**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech., and Ph.D.	Type	Stream Core Course
Prerequisite	Signals and Systems		

Objectives

The Instructor will:

1. introduce foundations of signal and point cloud representation
2. expose student to concepts of QoE

Learning Outcomes

The students are expected to have the ability to:

1. meaningfully exploit the concept of point clouds to develop applications in the broad area of immersive and user-centric multimedia communication

Contents

Transform based signal representation:
fixed and adaptive basis functions, spectral analysis, time-frequency representation (6 lectures)
Point cloud based signal representation and use-cases:
from 1D signals to 3D point clouds, concept of a 3D point cloud (4 lectures)
Depth images, meshes and volumetric grids (7 lectures)
Use-cases of point cloud: Augmented and Virtual Reality, Holography (5 lectures)
Audio point clouds, Scene based Spatial audio (5 lectures)
Point cloud video streaming:
Introduction to compression of static and dynamic point clouds, Tiling and FoV based dynamic point cloud streaming (6 lectures)
Case studies: Eg. MPEG-DASH based point cloud video streaming (3 lectures)
Quality of Experience (QoE):
concepts and mapping between QoS and QoE, point cloud quality assessment, KPI driven experience (6 lectures)

Textbook

1. Gross, M., & Pfister, H. (Eds.). (2011). *Point-based graphics*. The Morgan Kaufmann Series in Computer Graphics.

Self Learning Material

1. Katsaggelos, A.K., *Fundamentals of Image and Video Processing*, Coursera, Northwestern University, https://www.coursera.org/learn/digital

Preparatory Course Material

1. Jagannatham, A. K., *Principles of Signals and Systems*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104100/

Title	**Data Compression**	Number	**EEL7560**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M.Tech., and Ph.D	Type	Stream Core Course
Prerequisite	Elementary knowledge of Information Theory		

Objectives

The Instructor will:

1. Introduce basic principles of data compression methods

Learning Outcomes

The students are expected to have the ability to:

1. Implement some of the existing compression methods
2. Contribute in developing application-specific such methods

Contents

Redundancies in image and video: statistical, perceptual, spatial and temporal (3 lectures)
Lossless compression: Run length coding, statistical methods such Huffman and Arithmetic coding, Lempel and ziv method, differential pulse code modulation (DPCM) (5 lectures)
Lossy and perceptual compression:
Transform based signal representation, notion of fixed and adaptive basis functions (4 lectures)
Energy compaction through change of basis, frequency domain transforms DCT and Wavelets, comparison with data adaptive transforms (eg. KLT), quantization (9 lectures)
Temporal redundancy removal: intra and inter frames, concept of motion vectors and motion estimation, motion compensated temporal prediction (6 lectures)
Error resilience:
Basic techniques such as localization, data partitioning, redundant coding and concealment driven methods (4 lectures)
Perceptual error resilience: use of human perceptual cues, foveated just noticeable difference (FJND), unequal packet loss based on saliency (4 lectures)
Perceptual audio coding:
A-Law and mu-Law companding, time-frequency analysis, psychoacoustic principles like hearing thresholds, critical band frequency analysis, temporal masking (7 lectures)

Textbook

1. Khalid, S., (2017), *Introduction to Data Compression*, Elsevier
2. Solomon, D., (2007), *Data Compression*, The complete Reference, Springer

Self-Learning Material

1. Sengupta, S., *Digital Voice and Picture Communication*, NPTEL Course Material, Department of Electrical and Electronics Communication Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/117105081/

Preparatory Material

1. Katsaggelos, A.K., Fundamentals of Image and Video Processing, Coursera, Northwestern University, https://www.coursera.org/learn/digital

Title	**Mulsemedia Techniques and Systems**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech., and Ph.D.	Type	Stream Core Course
Prerequisite	Signals and Systems		

Objectives

The Instructor will:

1. introduce concept of mulsemedia in the context of virtual experiences
2. expose student to basic concepts in immersive signals

Learning Outcomes

The students are expected to have the ability to:

1. analyze and develop immersive Virtual Reality based systems for different use-cases

Contents

From audiovisual data to mulsemedia:
Augmenting virtual reality with sensory modalities like touch (haptics), smell (olfaction), humidity and air motion, enhanced immersion (2 lectures)
Components of mulsemedia centric VR experience:
Visual stimuli: concepts of depth, contrast (dynamic range), motion perception, visual saliency, importance in immersive visual content (3D, 8K HDR-HFR, 360 degree etc.) (8 lectures)
Audio stimuli: auditory event and localization, sound image capture, 3D audio encoding and decoding, (ambisonics A, B formats and binaural rendering) (8 lectures)
Haptic stimuli: kinesthetic and tactile signals, force feedback, rendering (8 lectures)
Olfaction: physiological aspects of smell, olfactory display, digital olfaction, smell dispensers (4 lectures)
Production of other sensory inputs: humidification devices, controlled air circulation, temperature control mechanisms (1 lecture)
Discussion of Use-cases:
AR/VR: simulation of walkthrough through outside environment (eg. forest), visual stimuli (trees, sky), spatial sound (eg. due to birds, air, trees), air circulation, temperature control (eg. sunny vs cold), discussion of end-to-end set up and inherent limitations (6 lectures)
Mulsemedia for technology enhanced learning (TEL): Dynamic Adaptive Streaming over HTTP (DASH) based framework, metadata based description of sensory data (visual, audio, haptic etc.), QoE aspects (5 lectures)

Note: instructor is free to discuss other emerging use-cases which demonstrate end-to-end application of mulsemedia concept.

Textbook

1. Ghinea, G., Andres, F., and Gulliver, S. R., (2012), *Multiple Sensorial Media Advances and Applications: New Developments in MulSeMedia*, IGI Global
2. Rumsey F., (2012), *Spatial Audio*, Routledge Publisher
3. https://www.newtonproject.eu/

Title	**Introduction to Multimedia Standards**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M. Tech., and Ph.D.	Type	Stream Core Course
Prerequisite	Fundamentals of Data compression		

Objectives

The Instructor will:

1. provide knowledge of evolution of multimedia standards
2. introduce use-cases and selection criteria of multimedia standards

Learning Outcomes

The students are expected to have the ability to:

1. analyze, implement and improve upon recent standards in multimedia compression technology

Contents

Evolution of video coding standards: the need for continuous improvements in standards, from H.264/AVC to MPEG-I, the birth of Moving Picture, Audio and Data Coding by Artificial Intelligence (MPAI) (1 lecture)
H.265 (HEVC): intra and inter frames, mode decision, motion compensated temporal prediction (3 lectures)
Coding tree units (CTU), adaptive macroblock sizes, directional modes, in-loop filtering (7 lectures)
Scalable video coding: SVC (annex G ext. of H.264/MPEG-4 AVC) and SHVC (scalable ext. of HEVC) (6 lectures)
MPEG-I (Coded Representation of Immersive Media):
H.266 (VVC): differences from H.265, improved intra and inter frame predictions, rectangular partitioning, enhanced in-loop filtering (6 lectures)
Use-cases: Eg. Immersive media streaming (8K HDR, 360 degree video etc.) (3 lectures)
MPEG PCC: LIDAR point cloud compression (L-PCC) for dynamically acquired data, Surface point cloud compression for (S-PCC) for static point cloud data, Video-based point cloud compression (V-PCC) for dynamic content (8 lectures)
Use-cases: Eg. Immersive AR/VR (2 lectures)
MPEG 21: evolution from MPEG 1,2 and MPEG 7, multimedia content management and description standards, applications and implementations (6 lectures)

Textbook

1. https://www.mpegstandards.org/standards/MPEG-I/
2. Richardson, I.E., (2010), The H.264 Advanced Compression Standard, 2nd Edition, John Wiley & Sons, Ltd

Self Learning Material

1. Motion Pictures Experts Group (MPEG), ISO/IEC JTC 1/SC 29/WG 11, https://mpeg.chiariglione.org/

Preparatory Course Material

1. Katsaggelos, A.K., *Fundamentals of Image and Video Processing*, Coursera, Northwestern University, https://www.coursera.org/learn/digital
2. Wiegand, T., Sullivan, G.J., Bjontegaard, G., Luthra, A., Overview of the H.264/AVC video coding standard, IEEE, 2003

M Tech Program Electives (All approved courses are part of annexure)

Title	**Optical Communication Systems Lab**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	0–0–2 [1]
Offered for	B. Tech., M.Tech., and Ph.D.	Type	Elective
Prerequisite	Optical Communication Systems		

Objectives

The instructor will:

1. Provide hands-on experience with various optical components and measurement techniques.
2. Provide hands-on experience in designing optical fiber and free-space links.
3. Provide exposure towards the evaluation of the BER performance in practical communication systems.

Learning Outcomes

The students are expected to have the ability to:

1. Implement an end-to-end optical communication system using optical transmitters and receivers.
2. Use various instruments such as OTDR, Splicing Machine, BER meter.
3. Evaluate the BER performance for different channel impairments.

Contents

Lab 1 - Prepare the end-face of an optical fiber, use an objective lens to couple light from an optical source into a single mode fiber for maximum coupling. Use Multimode fiber to observe the speckle pattern and multiple modes.

Lab 2 - Join a broken fiber using a splicing machine. Perform the fiber joining exercise using mechanical connectors (such as v-grooves), and compare the results. Measure the fiber bend losses; obtain the location of a fiber break, connector, splice, and termination using an OTDR.

Lab 3 - Achieve a free-space optical communication link by collimating the fiber beam,and using another fiber as receiver. Use SMF and MMF, and examine the impacts.

Lab 4 - Create a turbulent environment in the lab. Measure the absorption of the medium for different physical properties of the medium.

Lab 5 – Characterize the Optical Source (LED, LD) and detectors (PIN, APD).

Lab 6 - Design and implement the optical transmitter and receiver circuits for achieving an optical communication link in optical fiber and free-space.

Lab 7 - Obtain the eye diagram with an input from a PRBS generator. Measure BER and SNR for the communication system with different fibers (varying dispersion), and under atmospheric turbulence and pointing errors.

Lab 8, 9 - Implement a multi-hop FSO communication system using different relaying schemes under different turbulence conditions with pointing errors. Measure BER and SNR for the link.

Lab 10 – Design and characterize passive optical components such as splitters/combiners, WDM mux/demux, couplers, isolators and circulators.

Lab 11 - Use EDFA module to amplify a signal propagating in optical fiber. Use EDFA in the optical link and compare the system performance with or without amplification.

Textbook

1. Ghassemlooy, Z., Popoola, W., and Rajbhandari, S., (2019), *Optical Wireless Communications: System and Channel Modelling with MATLAB®*, 2nd Edition, CRC Press.

Self Learning Material

1. User manual for optical transmitter, receiver, and spectrum analyzer.

Title	**Queuing Theory**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and Ph.D.	Type	Elective
Prerequisite	Fundamentals of Probability and Data Communications		

Objectives

The Instructor will:

1. Provide students the fundamental understanding of the concepts, models and results in queuing systems and their applications to communication networks.

Learning Outcomes

The students are expected to have the ability to:

1. Model and analyse complex queuing systems and networks.

Contents

Introduction [4 Lectures]:
Review of Probabilistic concepts, Markovian process, Introduction to Queuing Theory and its timelines

Queuing Models [16 Lectures]:
Birth-death process, Markov chain of B-D process & its state equations, Steady state solution to State Dependent Birth Death process, Kendall's Notation (4 Lectures)
M/M/1 queue, Burke's Theorem, Little's Formula, M/M/N/N queue and Erlang B formula for Probability of Blocking (4 Lectures)
Engset Traffic Model , Server Repair Problem, M/G/1 queue, Imbedded Markov Chain Approach (5 Lectures)
2-D Markov Chains and Composite Server queues (3 Lectures)

Network of Queues [10 Lectures]:
Circuit Switch and Packet Switch networks and ARPA, Kleinrocks Independence Assumption, Basic formulas for total traffic, packet delay in a network. (4 Lectures)
Traffic flow Matrix of a network of queues, Open Jackson Networks, Closed Jackson Networks, Cascaded queues (6 Lectures)

Fast Packet Switched Networks [6 Lectures]
Assumptions and structure of Fast Packet Switch networks, Input Queuing (3 Lectures)
Output Queuing, Throughput calculation (3 Lectures)

Applications in Random Access Networks [6 Lectures]
Introduction to contention based channel access mechanisms (2 Lectures)
Markov Analysis of slotted and unslotted channel access mechanisms (4 Lectures)

Textbooks

1. Shortle, J. F., Thompson, J. M., Gross, D., Harris, C. M., (2018), *Fundamentals of Queueing Theory*, 5th Edition, John Wiley & Sons.

Self Learning Material

1. Selvaraju, N., Introduction to Queuing Theory, NPTEL Course Material, Department of Mathematics, Indian Institute of Technology Guwahati, https://archive.nptel.ac.in/courses/111/103/111103159/

Title	**Optical Communication Systems**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P[C]	3–0–0 [3]
Offered for	B. Tech., M. Tech., and Ph.D.	Type	Elective
Prerequisite	Concepts of Communication Systems and Engineering Electromagnetics		

Objectives

The Instructor will:

1. Provide students an understanding of the concepts related to transmission and reception techniques for optical communication systems

Learning Outcomes

The students are expected to have the ability to:

1. Analyze and design basic optical communications systems
2. Compare and contrast the features of various optical communication techniques

Contents

*Introduction to Optical Communication Systems [*2 lectures*]:*
Basic building blocks, optical transmitters, optical receivers, optical channel, optical amplifiers [2L].

Optical Channel considerations [10 lectures]:
Attenuation, dispersion, pulse broadening and chirping, line coding schemes, eye pattern [5L]
channel noise effects, turbulence models, weather conditions viz. fog, haze, drizzle, under-water impairments [5L].

Optical Modulation [12 Lectures]:
LiNbO3 - MZ, III-V semiconductor EAM modulators, High speed silicon modulators: Operating principles, Design, Performance criterion [5L]
Modulator Drivers, Reliability and Bias Control [5L]
Integration with Laser and packaging [2L].

Photodetection [8 Lectures]:
Photoconductivity, PN, P-I-N, Avalanche Photodiodes [3L]
Phototransistors, Responsivity, Quantum Efficiency, Noise in detection, SNR, Linearity and Dynamic Range, NEP, Bandwidth [5L]

System Performance [10 Lectures]:
Principles of Coherent and Incoherent systems, Intensity Modulation/Direct Detection system, SIM, homodyne and heterodyne detection [5L]
SNR, BER performance in coherent and non-coherent modulation schemes and channel impairments, Rise time and Power budgeting, channel capacity [5L]

Textbook

1. Keiser, G. (2017), Optical Fiber Communications, 5 th Edition, McGraw Hill
2. Chadha, D. (2013), Terrestrial Wireless Optical Communications, 1 st Edition, McGraw Hill.
3. Chen A. and Murphy, E. (2011), Broadband Optical Modulators: Science, Technology and Applications, 1st Edition, CRC Press.

Self Learning Material

1. Kumar, K. P., *Fiber-Optic Communication Systems and Techniques,* NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108/104/108104113/

Title	**Optical Fiber Communications**	Number	**EEL7370**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and Ph.D.	Type	Elective
Prerequisite	Concepts of EM Theory		

Objectives

The Instructor will:

1. Provide the fundamental principles and the practices followed in the area of optical communications.
2. Enable the appreciation of the global connectivity achieved via optical fiber technology.

Learning Outcomes

The students are expected to have the ability to:

1. Design and implement an end-to-end fiber optic communication link using commercially available LASERs, LEDs and Photodetectors.

Contents

Optical Fibers [17 Lectures]:
Vector Nature of Light, Optical Fiber – Single and Multimode, Step index and Graded Index Fibers [2L], Ray [2L] and Wave picture of propagation [4L], Cut-off, mode field diameter, group delay, Gaussian field approximation [1L].
Transmission Characteristics: Attenuation and dispersion in Optical Fibers [2L], Material, Waveguide, Polarization, Intermodal and Intramodal Dispersion [3L], Group velocity Dispersion, Dispersion modified single mode fibers [2L]. Fiber Fabrication Methods [1L].

Optical Sources [10 Lectures]:
LASERS: Coherence, Population inversion and feedback, Spontaneous and Stimulated emission, Injection LASERS, Gain and Index Guided LASERS, DFB, DBR Lasers, VSCELS, LASER Characteristics, modulation and Driver Circuits, Fiber Coupling. LED: Structure, Characteristics, modulation and Driver Circuits.

Optical Receiver Structures [5 Lectures]:
Low, high and transimpedance front end, Low noise Preamplifiers [2L]. Design of High speed transimpedance receivers [3L].

Optical Link [10 Lectures]
Fiber joints, connectors, Splicing operation [3L], design of couplers and isolators [3L], System Planning considerations: Choice of components, Link Design, Impact of nonlinear effects on communication systems [4L].

Textbooks

1. J. M. Senior, (2010), Optical Fiber Communications: Principles and Practice, Prentice Hall
2. Keiser, G. (2017), Optical Fiber Communications, 5 th Edition, McGraw Hill
3. G. Agrawal, (2010), Fiber optic Communication Systems, John Wiley and sons

Self Learning Material

1. NPTEL Lectures on Advanced Optical Communication by Prof. R.K. Shevgaonkar, IIT Bombay(https://nptel.ac.in/courses/117101002/)
2. The RP Photonics Encyclopedia (https://www.rp-photonics.com/encyclopedia.html)

Preparatory Course Material

1. Concepts from "M.O. Sadiku and S.V. Kulkarni, Principles of Electromagnetics", Oxford University Press, 6th edition, 2015.