Science and Technology Class 09

Previous Class Topic

- **Criteria** for mobile networks to be classified as 5G.
- **Standard-setting organizations** for mobile networks.

Millimeter Waves and Frequency Bands

Millimeter Waves in 5G

- 5G utilizes **millimeter waves**, which are radio waves with frequencies between 30 and 300 gigahertz (GHz).
- Called ‘millimeter waves’ because their wavelengths range from 1 to 10 millimeters; for example, at 30 GHz, wavelength (λ) is 10 mm; at 300 GHz, λ is 1 mm.
- The formula*λ = C/f (C = speed of light)*shows frequency and wavelength are inversely proportional.
- Satellite communication has long used these frequencies; mobile networks are adopting them for the first time on a large scale.

$C = f\lambda$

$\lambda = \dfrac{3\times10^8}{30\times10^9}$

= 1/100 m
= 10mm

Conventional vs. 5G Frequency Usage

- Earlier mobile networks operated on lower frequencies (e.g., 600-800 megahertz and up to a few GHz).
- 5G networks employ bands from 24 to 40 GHz, marking a substantial increase.
- **ITU** (International Telecommunication Union) regulates frequency allocation, with satellite communications using L band (1–2 GHz), S band (2–4 GHz), C band (4–8 GHz), Ku and Ka bands, among others.
- It is beneficial to recognize these bands even without precise memorization.

Characteristics and Challenges of Millimeter Waves

- Higher frequencies allow greater bandwidth, enabling higher data speeds.
- Millimeter waves are more susceptible to attenuation and scattering due to atmospheric conditions (rain, snow) and obstacles (metallic objects).
- Range decreases from several kilometers at lower frequencies to under a kilometer at millimeter wave frequencies.
- This requires a denser network of "small cell" stations to ensure coverage; small cell stations are compact and can be placed in more urban locations, roughly every kilometer.

Technologies Enabling 5G Networks

Small Cell Stations

- Short-range but numerous antenna installations, essential for 5G due to reduced propagation distance of higher frequencies.

Massive MIMO (Multiple Input, Multiple Output) and Beamforming

- **Massive MIMO** uses multiple antennas at each base station to send/receive signals from numerous devices simultaneously, increasing data rates and capacity.
- **Beamforming** creates highly directional transmission, focusing energy towards intended devices, reducing interference and improving both range and quality.

Network Slicing

- Network slicing allows a single physical network to be partitioned into multiple virtual networks.
- Each slice can be configured for specific applications or users, optimizing resource usage for different requirements (e.g., low-latency for critical communications).

Edge Computing

- Brings data processing and storage closer to the location where it is needed, reducing latency and improving speed.
- Complements cloud computing rather than replacing it, handling processing locally for smaller, real-time tasks and leaving large-scale processing to central cloud resources.

Other Communication and Internet Technologies

HTTP vs. HTTPS

- **HTTP** stands for Hypertext Transfer Protocol, the base protocol for the web.
- **HTTPS** (Hypertext Transfer Protocol Secure) adds a layer of encryption, improving security for website access.

Li-Fi and FSOCC

- **Li-Fi** (Light Fidelity) uses visible LED light to transmit data—very high speed but limited range and higher costs restrict its widespread adoption.
- **FSOCC** (Free Space Optical Communication Channel) uses laser light across air, employing complex modulation methods (e.g., frequency and phase); does not require government licensing as visible spectrum is unregulated.

Wi-Fi and Evolving Standards

- IEEE and similar bodies ensure Wi-Fi evolves in tandem with changing specifications of mobile networks, promoting interoperability and improvement.
- Wi-Fi standards are distinct but aim for compatibility with mobile frameworks.

Net Neutrality

- Net neutrality mandates equal treatment of all data by internet service providers; no preferential treatment, blocking, or throttling for specific services, apps, or websites, provided content is legal.
- Ensures a level playing field for all online participants—the wealthy and resource-limited entities alike.
- *Example*: India adopted net neutrality after rejecting selective free internet initiatives.
- Promotes fair competition and innovation by preventing discriminatory bandwidth allocation or blocking.
- The absence of net neutrality could have hindered early-stage companies such as Facebook from growing in competition with established platforms.

Broader Applications and Challenges in 5G Ecosystem

Frequency Range Flexibility in 5G

- 5G can operate in low (*less than 1 GHz*), mid (2-8 GHz), and high (24–40 GHz and above) frequencies.
- Companies select frequency bands based on application requirements and regional context; high-frequency (millimeter) bands require more dense infrastructure.

Physical Constraints: Scattering and Absorption

- High-frequency millimeter waves are more easily scattered and absorbed due to interaction with molecules and atmospheric constituents, leading to reduced range.

Internet of Things, Cyber-Physical Systems, and Edge Computing

Internet of Things (IoT)

- Refers to interconnected devices capable of communicating and acting based on data, often without direct human input.
- Examples include smartwatches (syncing health data), smart bulbs, and home automation features.
- IoT potential lies in automatic coordination among appliances (e.g., thermal sensors signaling ACs to shut off in unoccupied rooms).

Edge Computing

- Designed to work alongside IoT for efficient, real-time processing closer to data sources.
- Reduces latency and server load by allowing actions/processing to occur locally rather than via distant cloud servers.
- A notification or response (like an AC turning off when a room is empty) happens instantly across devices on the same local network.
- Inspired by the principle of subsidiarity and decentralized systems; tasks are handled locally unless they require broader resources.

Cloud Computing

- Involves storing and processing data on remote, Internet-accessible servers ("cloud") rather than exclusively on local computers.
- *Origin story*: Amazon developed spare computing capacity for festive sales and began renting it out to others (known today as Amazon Web Services).
- Includes services like data backup (Google Photos, Apple's iCloud), remote-accessible software (SaaS model), and storage accessible on multiple devices.
- Key for global IT outsourcing and everyday activities, such as Gmail and DigiLocker.

Comparison Table: Cloud vs. Edge Computing

Feature	**Cloud Computing**	**Edge Computing**
Processing Location	Remote servers/data centers	Near data source/device
Latency	Higher (distant servers)	Lower (local processing)
Security	Dependent on network/server	Improved (less exposure to networks)
Scalability	High	Limited (local resources)
Applications	Backups, heavy analytics, SaaS	IoT actions, immediate responses

Standalone Devices, CPS, and IoT Differences

- Not all sensor-equipped devices are IoT; network connectivity and data-sharing are essential for IoT classification.
- **Cyber-Physical Systems (CPS)** is a broader term; while all IoT devices are CPS, some devices may be CPS without network connectivity.

Misconceptions and Safety with 5G

Concerns about 5G Radiation

- 5G radiation is a form of non-ionizing electromagnetic radiation (radio wave); substantially lower in frequency than visible light.
- It is harmless at regulated intensities, with no credible scientific basis for claimed harms to birds, humans, or the Earth's magnetic field.
- Harm is a function of both intensity and frequency; for example, high-intensity lasers (not used in communication) can cause damage.

Specific Absorption Rate (SAR)

- **SAR** measures the energy absorption rate in the body from devices like mobile phones.
- Regulatory frameworks ensure SAR values remain within safe limits.
- Prolonged direct exposure (e.g., long calls) may increase exposure but not beyond regulated safety guidelines.

Separating Correlation and Causation

- Incidents like bird deaths near towers are often misattributed to radiation without factual causality; alternative explanations may include pollution or other environmental factors.
- Scientific practice requires distinguishing correlation from proven cause for accurate health risk assessments.

Socio-Political and Economic Dimensions of 5G in India

Spectrum and Cost

- High cost of spectrum allocation can impact final data usage prices and industry competition.
- Indian data is inexpensive due to a high population and intense price competition; yet, spectrum costs have led to market consolidation.
- Two major players (**Jio** and **Airtel**) now dominate the Indian telecom market.

Digital Divide and Infrastructure

- 5G requires dense and fast infrastructure, potentially increasing the urban-rural divide if not systematically addressed.
- Significant investment in infrastructure and technology is needed to extend benefits evenly.

High Energy Consumption and Foreign Dependence

- Operating denser high-frequency networks may significantly elevate energy requirements.
- Reliance on foreign technologies (especially in hardware) presents a technological and strategic challenge.

Cybersecurity

- Increased connectivity heightens cybersecurity risks as more data transits over networked infrastructure.
- Continuous investment is needed to protect privacy and ensure security resilience.

Sensors, Actuators, IoT, and CPS

Role of Sensors and Actuators

- Sensors detect and record physical properties (e.g., temperature, motion, pressure, infrared).
- Actuators respond to sensor data, performing actions (e.g., ACs shutting off, taps running automatically, escalators operating).
- These underpin both IoT and broader CPS networks.

Communication Protocols: RFID and NFC

- IoT and CPS devices may communicate using technologies like **RFID** (Radio Frequency Identification) and **NFC** (Near Field Communication), allowing data transfer and control actions wirelessly.

Smart Devices and Networks

- Examples extend from home automation (bulbs, thermostats) to industrial supply chains and urban services (metro escalators, water taps).
- Autonomous vehicles exemplify advanced CPS systems by using sensors and local processing to navigate independently.

Advanced Computing Paradigms

Biocomputers

- Biocomputers operate by leveraging biological molecules (proteins, DNA) to perform computations, aiming to mimic complex biological processes.
- The technology is under development but demonstrates potential for unique problem-solving capabilities.

Brain-Computer Interfaces

- Brain-Computer Interfaces (BCI) connect the human brain directly to machines, enabling control of devices through cognitive signals.
- Used primarily for medical aid, such as prosthetics for paralyzed individuals or those with vision impairment.
- **Neuralink** is at the forefront, developing implants for seamless machine-brain interaction.

Ethical and Security Considerations

- Ethical challenges include potential cognitive augmentation beyond restoration, impacting fairness and privacy.
- Data privacy remains a paramount concern as brain data may be highly sensitive and valuable.
- Ongoing development must address these ethical and technical challenges.

Augmented Reality, Virtual Reality, Mixed Reality, and Metaverse

Augmented Reality (AR)

- AR overlays 3D holographic projections or digital images/video onto the real environment, enhancing the user's experience.
- Utilized for education, interactive demonstrations, and visualization of complex concepts.

Virtual Reality (VR)

- VR immerses users in an entirely simulated digital environment, often requiring specialized headgear (e.g., Oculus Quest).
- Applications span gaming, medical training (e.g., surgery simulations), trauma therapy, distance education, and tourism via virtual experiences.

Mixed Reality (MR) and Extended Reality (XR)

- MR blends AR and VR, allowing users to interact with digital projections while remaining aware of their real surroundings.
- XR serves as an umbrella term encompassing AR, VR, and MR.

Metaverse

- Metaverse represents a persistent virtual universe where users interact through avatars; activities include socializing, economic transactions, and entertainment.
- Conceived as the next phase of digital interaction, but widespread adoption and legal frameworks remain limited.

Supercomputers

Nature and Capabilities

- Supercomputers are highly specialized, powerful machines capable of solving complex computational problems and running large-scale simulations.
- They use parallel processing to execute billions of instructions simultaneously, outperforming standard computers.
- Performance is measured in **FLOPS** (Floating Point Operations per Second); current top machines reach petaflops (10^15 flops) and exaflops range.

Key Hardware Characteristics

Characteristic	Typical Supercomputer	Standard Computer
CPUs/GPUs	Specialized, parallel (many cores)	General-purpose CPUs, fewer cores
RAM and Storage	Massive (for handling big data)	Limited to personal/office use
Processing Mode	Parallel (many tasks at once)	Mostly sequential

Applications of Super computers -

- **Weather Forecasting and Climate Modeling**: Integrate massive environmental data sets for accurate short- and long-term predictions.
- **Supply Chain Management**: Companies (e.g., Amazon, Asian Paints) use supercomputers for logistics optimization and consumer demand forecasting.
- **Big Data Analytics**: Extract patterns and correlations across diverse datasets for recommendations (e.g., YouTube, Spotify), public service delivery, and risk assessment.
- **Pharmaceutical Research**: Molecular simulations for drug development streamline initial testing by predicting potential outcomes.
- **Cosmology and Astronomy**: Model evolution of the universe, solar system formation, and related phenomena.
- **Civil and Material Engineering**: Simulate stresses and performance under various operating conditions.
- **Deep Learning**: Support training of large-scale artificial intelligence systems.
  Examples:
- *Weather prediction*: Supercomputers process data from weather balloons and sensors to forecast parameters like rainfall and temperature.
- *Social services*: Cross-linked analytics to identify deserving beneficiaries in welfare schemes.
- *Online services*: Algorithms recommend content by analyzing user history and broader trends.

Development and Initiatives in India

- **Param 8000**: Developed in 1991 by C-DAC after the US denied India's technology request, marking a milestone in indigenous supercomputing.
- **Current Leading Machines**: Pratyush, Erawat, Param Siddhi AI, and Mihir.
- **National Supercomputing Mission (2015)**:
- Objective to establish at least 70 supercomputing facilities across research institutions.
- Managed by the Department of Science & Technology and Ministry of Electronics & IT.
- Progress includes over 28 installed supercomputers, with several above 1 petaflop in capacity.
- Focuses on indigenization (local assembly), workforce training (BTech/MTech programs), and high-speed grid networking across facilities.

-> Param Ganga in IIT Roorkee has 1.66PF capacity.

Implemented by C-DAC and IISC Banglore

Quantum Technologies: Overview and Foundational Concepts

Meaning of Quantum

- "Quantum" refers to discrete, fundamental units, especially as applied in quantum mechanics and quantum technologies.
- Classical mechanics (Newtonian physics) suffices at everyday scales but fails at the atomic and subatomic levels.

Wave-Particle Duality

- Light, initially thought to be either a wave (Huygens, Maxwell) or particle (Newton), is actually both (as shown by the photoelectric effect).
- *Photoelectric effect*: Light of certain frequencies (e.g., blue) can immediately release electrons from metals, an observation Einstein explained using “quanta” (now known as photons).
- All particles (including electrons, shown in double-slit experiments) exhibit wave-like as well as particle-like properties.
- The mathematical treatment (not everyday intuition) accurately encapsulates this duality.

Heisenberg’s Uncertainty Principle

- It is impossible to determine certain pairs of physical properties (e.g., position and velocity) of a particle with absolute precision at the same time.
- The act of measuring one property more precisely results in increased uncertainty in the other.
- This is not a technological limitation but a fundamental law of nature, observed universally in experiments.

Development of Quantum Mechanics

- Scientists like Erwin Schrödinger and Paul Dirac combined ideas to formulate the modern theory of quantum mechanics in the early 20th century.
- All entities at microscopic scale possess dual (wave-particle) nature and are described probabilistically.
- Quantum technologies now build upon these principles for innovation in fields such as computing and secure communication.

Topic to be Discussed in the Next Class

- Quantum technologies, including basic principles of quantum mechanics.
- Applications and implications of quantum computing and communication.