Science and Technology Class 08

Previous Class Topic

- Basics of communication systems and computing
- Fundamental concepts such as **bandwidth**, basic functioning of the internet, and mobile network operations

Bandwidth

- Bandwidth refers to the amount of data transferable over a network per second, influencing network speed directly.
- It defines the frequency range across which a device operates; a larger frequency range permits the transmission of more data per second.
- Analogies such as*water flow through a tap or vehicles on a road*help illustrate that greater bandwidth (**wider pipe or road**) enables higher data flow (**speed**).
- Bandwidth is not always about high speed but about the data-carrying capacity of the medium.

Digital and Analog Signals

Differences and Basic Understanding

- Analog signals change continuously over time, while digital signals operate via discrete steps, commonly encoded as zeros and ones.
- For analog signals (e.g., voice), energy oscillates in a continuous waveform.
- Digital signals encode information in binary (0s and 1s), representing discrete changes.
- Digital systems often use the **ASCII** system, where combinations of 0s and 1s encode characters, numbers, and images.
- Digital processing improves noise management and facilitates reliable programming of various data types.

Modulation

- Modulation enables communication by transferring modulating signals through a carrier wave.
- Variables such as amplitude, frequency, or phase of the carrier wave change in response to the modulating signal, transmitting data over communication channels.

Communication Protocols

- Protocols comprise rules and regulations enabling communication between devices; for example, grammar is the protocol for the English language.
- Examples include the Internet Protocol (**IP**), which assigns a unique address to each device for network identification.
- Devices follow these standard protocols to ensure accurate and secure information exchange.

Transmission Technologies

Optical Fiber Cables

- Comprised of a core and cladding with differing refractive indices, facilitating total internal reflection.
- Light pulses transmit information, supporting long-distance, high-speed data transmission without significant absorption or scattering.
- High bandwidth and long-distance transmission without signal degradation.
- Form the backbone of modern networks, supporting internet and advanced mobile networks.

Air Fiber

- Employs high-intensity radio frequencies via antennas instead of physical cables.
- Functions similar to a large Wi-Fi system, broadcasting signals across localities without the need for fiber lines to individual homes.

Internet Addressing and Protocol Versions

- Devices are uniquely identified by IP addresses; evolution from IPv4 to IPv6 accommodates more devices and complex global networking.
- IPv6 includes alphanumeric formats for broader address space, critical for the rise of the IoT (**Internet of Things**).

Satellite-Based Internet

Overview

- Satellite internet uses geosynchronous or low-earth orbit (LEO) satellites to offer broadband connectivity to regions beyond the reach of traditional fiber networks.
- Traditional VSAT networks relied on geostationary satellites, leading to higher latency (~600 ms) and slower speeds.
- Projects like SpaceX Starlink and OneWeb employ LEO constellations for global high-speed, low-latency (20–30 ms) internet coverage.

Application and Impact

- Covers inaccessible or unprofitable rural regions where fiber cannot reach.
- Enables high-speed internet in mountains, islands, and remote areas.
- Supports critical modern applications such as autonomous vehicles, remote surgery, and online gaming by lowering latency.

Issues and Concerns

Parameter	Traditional (Geostationary)	Modern (LEO/Starlink)	Concerns
Speed	Low	High	
Latency	High (~600 ms)	Low (20–30 ms)	
Coverage	Wide but limited by latency	Global, low latency	
Infrastructure	Bulky antennas	Compact user terminals	
Space Debris	Limited (fewer satellites)	Significant (thousands in LEO)	Space junk, Kessler syndrome risk
Light Pollution	Low	High (many satellites)	Affects astronomy and ground-based telescopes
Privacy/Control	Spread among agencies/companies	Concentrated (SpaceX, etc.)	Potential for control, censorship concerns
Cost	High initially, improves with scale	Decreasing with scale	Regulatory, licensing difficulties across regions

- **Space debris**: Increased launches elevate the risk of collisions and Kessler syndrome.
- **Light pollution**: Dense satellite constellations disrupt astronomical observations by reflecting sunlight.
- **Internet governance**: Control concentrated within a few corporations may lead to regulatory and dependence issues.
- **Security and misuse**: Satellite terminals might be used in unauthorized ways, complicating regulation.
- **Licensing and regulation**: National obligations may complicate universal access and service deployment.
- **Affordability**: Initially high user terminal costs may decrease as economies of scale are achieved.

The resources and websites on internet mainly can be divided into two parts -
1. Surface Web
2. Deep Web

Surface Web, Deep Web, and Dark Web

Surface Web

- Comprises internet resources freely accessible via search engines without authentication or payment.
- Examples include sites like Wikipedia, government sites, and landing pages of e-commerce platforms.

Deep Web

- Contains content protected by authentication, payment, or firewalls.
- Includes private email, banking systems, internal company sites, and OTT platform content.
- Constitutes over 90% of internet content.

Dark Web

- A small, heavily encrypted subset of the deep web, accessible only through specialized browsers like Tor (*The Onion Router*).
- Hosts anonymous sites, often ending with a .onion suffix, not accessible via regular browsers.
- Originally conceived by US intelligence services as a secure channel for covert communication.
- Popular among criminal organizations for activities such as drug trafficking, terror financing, illegal arms sales, and data breaches.
- Also utilized by whistleblowers and dissidents in authoritarian regimes to share information securely.
- Not all activities on the dark web are criminal; it can protect freedom of expression and enable anonymous reporting.
- Note: Incognito modes in web browsers do **not** equate to dark web access; they only hide browsing history locally.

Malware and Information Security

- **Malware** refers to malicious software or viruses designed to compromise systems or steal data.
- Common vectors include deceptive emails or downloads (for example, the "Nigerian prince" scam).
- Stolen personal information is often traded on the dark web.

Virtual Private Networks (VPNs)

- VPNs encrypt user data, masking IP addresses to provide privacy and help bypass geographical restrictions.
- Managed by known service providers, VPNs allow secure access to corporate resources and protect data on public networks.
- VPNs are legal but can be used for both legitimate security/privacy purposes and unlawful activities such as accessing restricted content.

Communication Technologies in Daily Life

Near Field Communication (NFC)

- Utilized in contactless payments (e.g., metro cards, debit/credit cards).
- Depends on electromagnetic induction; communication is established when devices are within 1–3 cm.
- Facilitates secure, low-power, short-range data exchange.

Bluetooth

- Operates at 2.4 GHz frequency and enables short to medium range wireless connections (up to 10 meters).
- Used for direct communication between devices without the need for broader network connectivity.

Radio Frequency Identification (RFID)

- Employs tags and readers operating at specific frequencies (130 kHz, 13.56 MHz, ~900 MHz).
- Used in toll collection (such as FASTag), logistics, and secure identification with encrypted tags.

Wi-Fi

- Utilizes radio frequencies (2.4 GHz, 5 GHz, 6 GHz) to enable wireless internet access.
- Evolves through various standards (from Wi-Fi 1 through 7) that offer differing speeds and capacities.

Application Programming Interface (API)

- APIs allow software applications to communicate with each other.
- They function as intermediaries—like a waiter in a restaurant—facilitating the flow of requests and delivering responses between clients and servers.
- APIs are vital for integrating services and providing complex functionalities across internet-based systems.

Li-Fi (Light Fidelity) and Visible Light Communication

Principle and Operation

- Uses visible light from rapidly flickering LED bulbs to transmit data wirelessly.
- Data transmission occurs as changes in light intensity, which are detected by a photo detector and converted back into electrical signals.
- The flickering happens at rates imperceptible to the human eye but can be detected by specialized sensors.

Advantages

- Offers higher data speeds compared to traditional Wi-Fi.
- Less susceptible to electromagnetic interference from other devices.
- Enhanced security since light cannot penetrate walls, limiting data transmission to the illuminated area.

Limitations

- Transmission is interrupted by physical obstructions such as walls or opaque objects.
- Sensitivity to other bright light sources can interfere with reception.
- Adoption has been limited despite successful demonstrations, largely due to restrictions in range and reliability.

Free Space Optical Communication (FSOC)

- Utilizes laser or visible/infrared light to transmit data through the atmosphere.
- Bridges gaps where optical fiber cannot be physically installed.
- Offers a high-speed, high-bandwidth link with minimal electromagnetic interference.
- Limitations include line-of-sight requirements; transmission can be disrupted by obstacles, weather conditions (rain, fog, snow), and misalignment.
- Enhanced security as the light remains contained within a direct path.

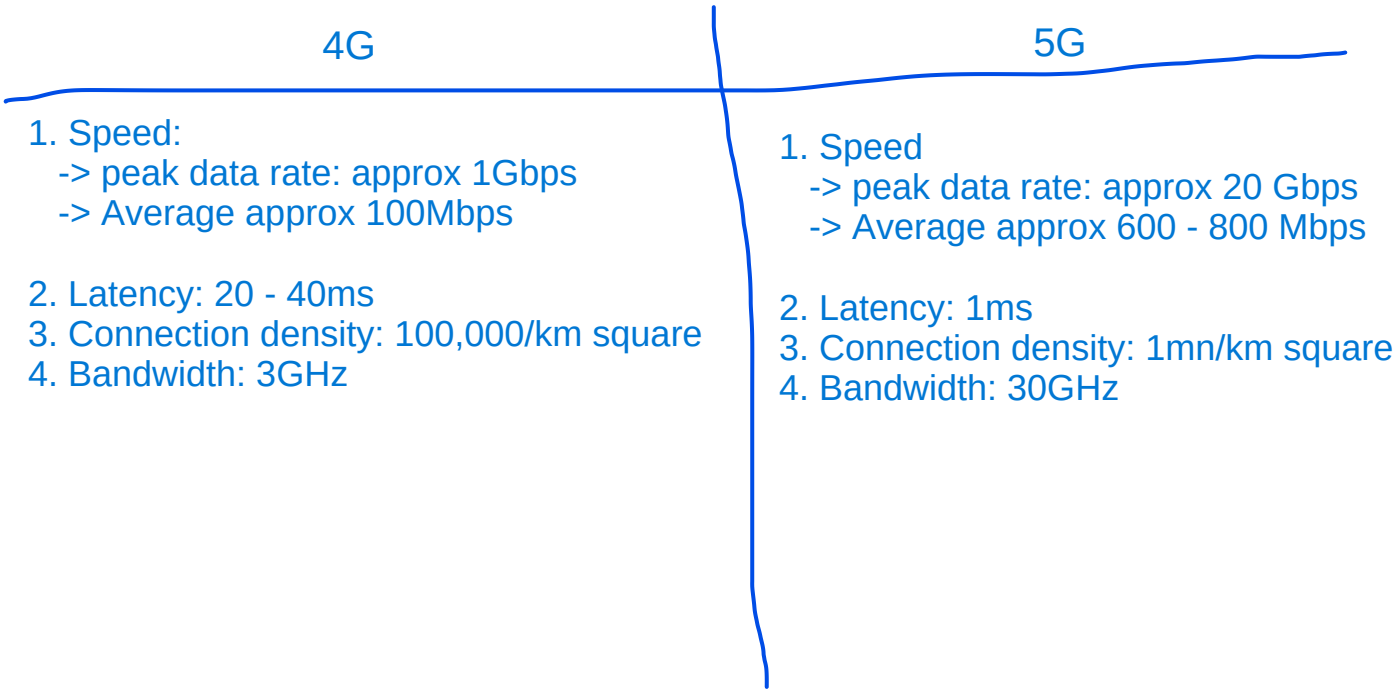
Electromagnetic Spectrum and Spectrum Auction

- Radio frequencies used in mobile networks are considered sovereign property, allocated or auctioned by the government.
- Examples include frequencies for FM radio or mobile networks that are assigned after regulatory processes.
- Governments auction spectrum for commercial use while balancing revenue generation and public interest.
- High spectrum prices can lead to higher consumer costs or reduced infrastructure investment.

Evolution of Mobile Networks: 1G to 5G

Generation	Primary Technology	Key Features	Representative Use Case
1G	Analog	Voice calls only	Basic mobile communication
2G	Digital	SMS, voice	Early mobile phones
3G	Digital	Internet and multimedia	Early smartphones
4G (LTE)	Digital (LTE)	Apps, high-speed internet, VoLTE for voice+data	Modern smartphones and apps
5G	Digital	Ultra-high speed, IoT, low latency, high capacity	Autonomous cars, VR, massive device connectivity

- *Speed*: Peak data rates can reach 20 times higher than 4G, with average speeds around 600–800 Mbps.
- *Latency*: Targeted latency is approximately 1 ms in 5G compared to 20–40 ms in 4G.
- *Connection Density*: Supports up to 1 million devices per km² versus 100,000 for 4G.
- *Bandwidth*: Moves from around 3 GHz in 4G to approximately 30 GHz in 5G.
- Enhanced Mobile Broadband supports streaming, downloads, and interactive applications with significant improvements in speed and responsiveness.
- Implementation and Compatibility: Technologies such as Wi-Fi 6 complement 5G upgrades and require corresponding hardware support on devices.



Standardization Bodies and Regulation

- **International Telecommunication Union (ITU)**: A UN agency responsible for global bandwidth/spectrum allocation and setting major international standards, including for 5G.
- **Third Generation Partnership Project (3GPP)**: A global collaboration of standard-setting organizations that develops technical specifications and systems for mobile networks.
- **Institute of Electrical and Electronics Engineers (IEEE)**: A professional association overseeing Wi-Fi standards (e.g., Wi-Fi 1–7) to ensure interoperability between Wi-Fi and mobile standards.

Protocols and Data Standards

- **ASCII** defines coding rules for alphanumeric characters and symbols, ensuring data compatibility across systems.
- IP address standards govern how networked devices are uniquely identified worldwide.
- All hardware and software developments must comply with standardized communication rules to maintain global interoperability.

Technologies of 5G

- 5G employs a range of radio frequencies and multiple technical advancements to enhance network capacity, speed, and reliability.
- It utilizes both existing and higher (millimeter-wave) frequency bands, thereby expanding the total available bandwidth.
- Supports higher device densities, ultra-low latency applications, and advanced IoT deployments.
- Facilitates the convergence of mobile and Wi-Fi networks for an improved user experience.

Topic to be Discussed in the Next Class

- Continuation of 5G technologies and related communication advancements
- Introduction to computing with a focus on supercomputers

-> Handouts also.