Okay, here are the exam summary notes for Chapter 9: The Physical Layer.

Physical Layer (Layer 1) Introduction

- **Purpose**: To physically transmit data units from one network node to another.

Circuits, Lines, and Channels

- **Circuit**: Can refer to the physical medium carrying signals (especially electrical) or the logical connection between sender and receiver.
- **Circuit-Switching**: Bandwidth is reserved when a connection is established, and users typically pay for the connection time regardless of data transmission.
- **Packet-Switching**: Bandwidth is allocated dynamically when a user has a packet to send; users are typically charged per packet or data volume.

Wireless Data Evolution (Illustrating Circuit vs. Packet Switching)

- **2G Technologies**:
  - **CSD (Circuit-Switched Data)**: Early GSM data service, up to 9600bps.
  - **HSCSD (High-Speed Circuit-Switched Data)**: Increased speeds to 14.4kbps, still circuit-switched and charged per unit of time.
  - **GPRS (General Packet Radio Service)**: Introduced packet switching, allowing for "always on" connections and charging per data volume. Offered lower cost than CSD/HSCSD but could have higher latency as bandwidth wasn't reserved.
  - **EDGE (Enhanced Data rates for GSM Evolution)**: A faster version of GPRS, often termed 2.5G, acting as a bridge to 3G.
- **3G Technologies**: Primarily designed as data networks capable of carrying voice.
  - **UMTS (Universal Mobile Telecommunications System)**: Based on GSM. Enhanced by HSDPA (High-Speed Downlink Packet Access) and HSUPA (High-Speed Uplink Packet Access), sometimes called 3.5G.
  - **CDMA2000**: A competing 3G standard.
  - **WiMAX (Worldwide Interoperability for Microwave Access - IEEE 802.16)**: Wireless technology primarily for data, assuming static nodes. Often used as a "last kilometer" solution.
- **4G (LTE - Long Term Evolution)**:
  - Offers significantly higher data rates than 3G.
  - Features native IP support, making it an all-IP packet-switched network.
  - Support for IPv6 is generally considered essential.
  - **LTE Advanced** is considered by purists to meet all 4G requirements.
- **5G**:
  - Provides increased speed and reduced latency compared to 4G.
  - Designed to handle a large number of devices.
  - Often utilizes lower frequency radio waves, leading to smaller cell sizes and

requiring more towers, especially in urban areas.

- **6G**:
    - Expected around 2030, promising even higher speeds and capacity.
    - Aims for convergence with seamless transitioning between Cellular, WiFi, and direct-to-satellite communication.

Fixed-Line Services

Provided by Public Switched Telephone Network (PSTN) or Plain Old Telephone Service (POTS) operators.

- **PSTN/POTS**: Evolved from manual to digital backbones, but the "last kilometer" often remained analogue copper wire carrying voice signals. Data communication required modems.
- **DSL (Digital Subscriber Line)**: Technologies using existing copper "last kilometer" for higher-speed data.
    - Voice uses low frequencies; data uses high frequencies on the same line, separated by DSL filters.
    - **ADSL (Asymmetric DSL)**: Provides more downstream (operator to user) bandwidth than upstream (user to operator).
        - Revisions: ADSL (up to 8Mbps down), ADSL2 (up to 12Mbps down), ADSL2+ (up to 24Mbps down). Upstream typically up to 1Mbps.
        - Billing: Monthly line rental plus ISP fee, often with data caps ("capped ADSL") or without ("uncapped ADSL").
    - Other DSL types include SDSL (Symmetric) and RADSL (Rate-Adaptive). The family is sometimes called xDSL.
- **Leased Lines**: Permanent, dedicated connections with costs based on distance and bandwidth.
    - **E-carrier levels** (used in most of the world except USA/Japan): E1 (2.048 Mbps), E2 (8.448 Mbps), E3 (34.368 Mbps), E4 (139.264 Mbps), E5 (564.992 Mbps).
    - Offers dedicated bandwidth and potentially higher security than VPNs over the public internet, important for critical infrastructure.
- **Packet Switching (X.25)**: An early standard for international packet-switched data communication between telecom operators.
    - Customer equipment or telco-provided PAD (Packet Assembly/Disassembly) facilities were used.
    - Telkom's X.25 network in South Africa was known as Saponet-P.
- **ISDN (Integrated Services Digital Network)**: Digital dial-up service for voice, data, and fax.
    - **Channels**: B channels (Bearer channels, 64kbps each, carry data/voice) and a D channel (Delta channel, for signalling/control). Bandwidth on B channels is reserved.
    - **BRI (Basic Rate Interface)**: 2B+D (D is 16kbps). Allows two simultaneous 64kbps connections or one aggregated 128kbps channel.

    - **PRI (Primary Rate Interface)**: On an E1 carrier (2.048 Mbps) provides 30B+D (D is 64kbps). On a T1 carrier (North America, 1.544 Mbps) provides 23B+D.

Undersea Cables

Critical for international connectivity. Capacities often align with SDH (STM levels) or SONET (OC levels) standards.

- **Examples connecting South Africa**:
    - **SAT3/WASC/SAFE**: SAT3 (120Gbps) and SAFE (140Gbps).
    - **SEACOM**: Connects South Africa (East coast) to Europe and India, with various link capacities (e.g., SA-Kenya ring 1.28Tbps, Kenya-France 640Gbps).
    - **EASSy (Eastern Africa Submarine Cable System)**: Connects countries on Africa's east coast.
    - **WACS (West Africa Cable System)**: Links South Africa to the UK via Africa's west coast.
    - **Equiano (Google)**: Links Portugal to South Africa.
- **SDH/SONET Line Rates**:
    - OC-3 / STM-1: 155.520 Mbps
    - OC-12 / STM-4: 622.080 Mbps
    - OC-48 / STM-16: 2,488.320 Mbps
    - OC-192 / STM-64: 9,953.280 Mbps

Satellites

Used for international and national links.

- **Geostationary (GEO)**: Orbit at 36,000 km above the equator, appearing stationary. Limited orbital slots.
    - **Ku-band**: Narrowly focused beams, relatively high power, allowing small receiver dishes.
    - **C-band**: Broader coverage, lower power, requiring larger dishes.
- **Low Earth Orbiting (LEO)**: Orbit much closer to Earth, appearing to move across the sky.
    - **StarLink**: Constellation of thousands of LEO satellites (~550km altitude) offering broadband internet. Requires earth stations for optimal speed. Raises concerns about space debris and astronomical observation.
    - **Iridium**: Constellation of ~75 LEO satellites providing global voice and data (not broadband) via handheld devices.

Convergence

The blurring of distinctions between fixed-line and mobile services, and between voice, data, and video transmission.

- **Triple Play**: Voice, data, and video over the same network.

- **Quadruple Play**: Triple play with wireless access.
- **Next Generation Networks (NGNs)**: Typically IP-based networks designed to carry any type of data.

Performance Metrics

- **Bandwidth**: Capacity of a medium, usually in bits per second (bps). Engineering bandwidth is in Hertz (Hz). Effective bandwidth can be less than nominal due to sharing (e.g., ADSL).
- **Latency**: Time for a signal (e.g., the first bit of a message) to traverse a circuit, measured in milliseconds or nanoseconds.
- **Propagation Delay**: Time data takes to travel through a medium; significant over long distances like GEO satellite links (approx. 0.12s one way, 0.24s path via satellite).
- **Jitter**: Variation in packet arrival times. High jitter negatively impacts real-time applications like voice.
- **Reliability**: How often a circuit fails (Mean Time Between Failures - MTBF), time to repair (Mean Time To Repair - MTTR), and average error rate. Redundancy improves reliability.
- **Other Issues**: Data caps, security vulnerabilities, signal attenuation (degradation over distance).

Multiplexing

Techniques to divide a single physical channel into multiple logical channels. A multiplexer (mux) combines inputs onto a shared line, and a demultiplexer (demux) separates them at the other end.

- **FDM (Frequency-Division Multiplexing)**: Assigns different carrier frequencies to each logical channel. The demux tunes to specific frequencies.
- **TDM (Time-Division Multiplexing)**: Divides the shared medium into fixed, recurring time slots, with each slot dedicated to a specific input-output pair.
- **STDM (Statistical Time-Division Multiplexing)**: Allocates time slots dynamically based on which input channels have data to send. More efficient than TDM if traffic is bursty, but adds overhead for managing slot allocation.
- **CDM (Code Division Multiplexing)**: Uses spread spectrum techniques. Each sender's data is combined (e.g., XORed) with a unique pseudo-random code (chipping sequence). The receiver uses the same code to extract the intended signal from the combined signals, which appear as noise to other receivers. Each bit is effectively transmitted multiple times, XORed with different parts of the code.
    - Leads to **CDMA (Code Division Multiple Access)** when used as a media access strategy.
- **TDMA (Time Division Multiple Access)**: A MAC strategy derived from TDM, where a central controller (e.g., cellular base station in GSM) assigns time slots to users.

Inverse Multiplexing (Bonding)

Combines multiple slower circuits into a single, higher-speed logical link. A demux at the sending end splits the high-speed data across slow links, and a mux at the receiving end reassembles it.

Media

(This section is largely a placeholder in the source text)

- **Guided / Conducted**:
  - Copper: Coaxial cable, Unshielded Twisted Pair (UTP).
  - Optical fibre.
- **Radiated**:
  - Directed: Microwave, satellite, laser.
  - Broadcast: Radio, IrDA (Infrared Data Association), FIR (Fast Infrared).

Data Representation

How data is encoded onto a medium.

- Signals represent data: e.g., +/-15 Volts for 0/1 on copper; light presence/absence or different colors on optical fibre; amplitude, frequency, or phase of radio waves.
- **States**: The physical layer transmits "states" which may or may not directly correspond to logical bits. States can be binary (e.g., high/low voltage) or have a wider range (e.g., different phase shifts).
- **Baud Rate**: The number of state changes (symbols) transmitted per second. An engineering term for medium capacity.
- **Bit Rate (bps)**: Bits per second. More common for measuring communication speed. The relationship between baud rate and bit rate depends on how many bits are encoded per state (symbol).
- **Analogue Medium**: Carries continuously changing signals (e.g., sound waves).
- **Digital Medium**: Carries discrete states (e.g., high/low voltage levels).

Modulation (Digital data on Analogue medium)

A **modem** (modulator/demodulator) converts digital signals to analogue for transmission and back again.

- **Amplitude Modulation (AM) / Amplitude Shift Keying (ASK)**: Varies the amplitude of the carrier wave.
- **Frequency Modulation (FM) / Frequency Shift Keying (FSK)**: Varies the frequency of the carrier wave.
- **Phase Modulation (PM) / Phase Shift Keying (PSK)**: Varies the phase of the carrier

wave.
- **Combined Techniques**: Modern modems often combine these, e.g., **QAM (Quadrature Amplitude Modulation)** combines AM and PM to represent multiple bits per state.

Line Coding (Digital data on Digital medium)

- **NRZ (Non-Return-to-Zero)**: A common method where, for example, one voltage level represents a '1' and another a '0' for the entire bit duration.
- **Manchester Encoding** (used in IEEE 802.3 Ethernet): Involves a transition in the middle of each bit interval. E.g., a low-to-high transition can represent a '1', and a high-to-low transition a '0' (or vice-versa). This ensures clocking information is embedded in the signal.
- **Differential Manchester Encoding**: A transition always occurs in the middle of the bit interval (for clocking). A transition at the *beginning* of the bit interval signifies one binary value (e.g., '0'), while no transition at the beginning signifies the other (e.g., '1').

Topology

(This section is a placeholder in the source text)
- Bus
- Ring
- Mesh
- Point-to-point
- Multipoint

Miscellaneous Physical Layer Topics

(This section is largely a placeholder in the source text, listing terms)
- **Plugs/Connectors**: RJ-45, RJ-11 (for twisted pair copper); BNC, Vampire taps (for coax); optical fibre connectors.
- **Ethernet Types (Physical Layer context)**: e.g., 10BaseT, 10Base5 (referring to speed, baseband, and cable type).
- **Various Concepts**:
    - Serial/Parallel transmission.
    - Simplex (one-way), Half-duplex (two-way, not simultaneous), Full-duplex (two-way, simultaneous) communication.
    - Hubs (Layer 1 repeaters), Switches (Layer 2 devices, but with physical interfaces).
    - Baseband (digital signaling, entire bandwidth for one signal) vs. Broadband (analogue signaling, can carry multiple signals via FDM).
    - SS7 (Signaling System No. 7 - for telephone network control).
    - Modems, handshaking/protocol negotiation.