# Computer Networks: Theory, Modeling, and Analysis

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COM3510



# What is COM3510 about?

- Understand the basic principles of networking:
  - Description of existing networks, and networking mechanisms
  - Understanding of networks modeling and analysis tools
- Covers:
  - Terminology, layering concept, physical layer, data link layer, basics of queuing theory, medium access control (MAC), basics of routing, flow control (window/rate control)
- Does not cover: higher layers (applications, compression, TCP/IP programming, etc.)

# Course Outline

- Introduction to networking and to 7-layer OSI architecture
- Error detection, retransmissions strategies, and framing
- Introduction to Markov chains and queuing theory
- Multiple access schemes (MAC sublayer):
  - aloha, CSMA, ethernet, token rings, wireless, etc.
- Routing algorithms: Unicast and Multicast
  - Dijkstra, Bellman-Ford algorithms and RIP and OSPF protocols
- Packet Scheduling:
  - Max-Min Fairness, Weighted Fair Queuing.



# Lecture 1 Outline

- Networking Concepts and Terminology
- Protocols Layering

# Basic Terminology

- **Network**: set of nodes interconnected through communication links
- **Node**: host, router, switch
- **Link**: twisted-pair, coaxial cable, optical fiber, wireless
- **Protocol**: set of rules and conventions used between peer entities to communicate
- **Message:** sequence of bits/application level (e.g., email, document)
- **Packet:** messages are broken into packets that can transmitted between network nodes
- **Session:** transaction consisting of a sequence of message exchanges



# Types of Networks

- Several taxonomies exist…
- Transmission technology based differentiation:
  - Point-to-point networks
  - Broadcast networks (generally small area: ethernet)
- Scale based differentiation:
  - Local Area Network (LAN): privately owned networks, up to few miles in size (e.g., ethernet)
  - Metropolitan Area Networks (MAN): larger than LANs, may cover a city (e.g., IEEE802.6 DQDB)
  - Wide Area Network (WAN): covers a large geographical area (e.g., country, continent)

# Performance Issues

- Packets arrival modeling assumed (simplicity) either:
  - *Poisson Process* (data packets)
  - *ON/OFF flow* model (for digitized voice)
- Common performance metrics:
  - latency and throughput,
  - delay-jitter, and rate-jitter (maximum - minimum)

*Latency* = *PropagationDelay* + *TransmissionDelay* + *QueuingDelay*
*PropagationDelay* = *Distance/SpeedOfLight (independent of message size)*
*TransmissionDelay* = *MessageSize/Bandwidth*
*QueuingDelay* = delay due to time spent waiting in queues



# Sessions Characteristics

- Message arrival rate:
  - Poisson arrivals, deterministic arrivals, uniformly distributed
- Session holding time: duration of the session
- Expected message length and length distribution
- Allowable delay: depends on the application type
  - Interactive, real-time, email, voice, video-on-demand
- Reliability: depends on the application (FER)
  - Voice/video (tolerant), email (strict), sensing etc.
- Message & packet ordering: depends on the application
  - Databases, email, etc.

# Types of Applications

- Interactive terminal and computer sessions:
  - Small packet length, small delay, high reliability
- File transfer:
  - High packet length, high delay, high reliability
- High resolution graphics:
  - High packet length, small delay, low arrival rate
- Voice application:
  - Small packet length, small delay, small reliability, high arrival rate



# Sessions Transmission Paradigms

- Circuit Switching
- Store-and-Forward Switching

# Circuit Switching

- On session establishment a path from source to destination is selected. Resources are allocated over all the links of the path. Route does not change during session life.
- Links can be shared by different sessions through mechanisms such as *time-division multiplexing* (TDM) or *frequency-division multiplexing* (FDM).
- For any link: the sum of rates of sessions using the link is at most the bandwidth of the link.
- Example: telephone networks.
- Guarantees: rate and in order packets delivery.



# Store-and-Forward Switching

- Links are shared on a "*demand basis*" vs. fixed allocation
- Packets wait in a queue before being transmitted

# Inefficiency of Circuit Switching

- Broadly speaking: when a session is idle, the reserved resources are lost.
- Simple analysis of session *s*:
  - $\lambda$: message arrival rate;
  - $1/\lambda$ : inter-arrival time between messages
  - $\overline{X}$: expected transmission time
  - $\overline{L}$: expected message length
  - Bit rate allocated to *s*: $r_s = \frac{\overline{L}}{\overline{X}}$
  - Link utilization = $\lambda\overline{X}$
  - $T$ <0.01 for interactive app.

P: propagation delay
Q: queuing delay

$$\overline{X} + P + Q \le T \Rightarrow \lambda\overline{X} < \lambda T$$

$$if \lambda T << 1 \Rightarrow utilization - is - poor$$



# Circuit Switching vs. Store-and-Forward Switching

- Advantage of Store-and-Forward over Circuit Switching:
  - Network utilization is better (each link is utilized when there is some traffic)
  - Lower delays
- Drawbacks of Store-and-Forward:
  - Necessity of having control flow mechanisms to avoid buffer congestion and maintain acceptable delays. This is generally achieved through some feed-back to the senders.

# More Taxonomy

- Message store-and-forward
- Packet store-and-forward
- Packet switching = store-and-forward switching

- Virtual circuit switching = packet switching + fixed path
- Dynamic routing => each packet finds its own path

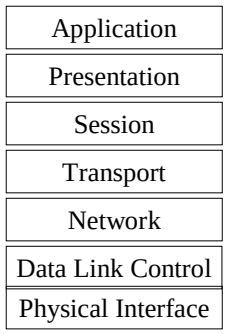


# Layering

- Layering: is a form of "*hierarchical modularity*"
- The role of each layer is to provide services for higher layers (abstracting lower layers)
- What is important is the functional relation between Inputs and Outputs
- Each layer has and interface to higher/lower layers (constituted of service access points: SAP)
- Entities at the same layer on different nodes are called *peer-entities*. They communicate through protocols
- A set of consecutive layers is called a *Protocol Stack*
- Drawback of layering: may hide important information (e.g., TCP over wireless links)

# OSI Reference Model

- Open systems Interconnect (OSI) defined a reference for a layered architecture of data networks
- Existing protocol stacks (e.g., TCP/IP) ) are quite different from the OSI RM but it is still an interesting conceptual model because of its clean structure






# Physical Layer

- Function: provides a "*virtual bit pipe*"
- How: maps bits into electrical/electromagnetic signals appropriate for the channel
- The physical layer module is called a *modem* (modulator/demodulator)
- Important issues:
  - Timing: synchronous, intermittent synchronous, asynchronous (characters)
  - Interfacing the physical layer and DLC (e.g., RS-232, X.21)

# Data Link Control Layer (DLC)

- Receives packets from the network layer and transforms them into bits transmitted by the physical layer. ***Generally*** guarantees order and correctness.
- Mechanisms of the DLC:
  - Framing: header, trailer to separate packets, detect errors…
  - Multiple access schemes: when the link is shared by several nodes there is a need for addressing and controlling the access (this entity is called MAC sublayer)
  - Error detection and retransmission (LLC sublayer)



# Network Layer

- Provides naming/addressing, routing, flow control, and scheduling/queuing in a multi-hop network
- Makes decisions based on packet header (e.g., destination address) and module stored information (e.g., routing tables)
- General comment: each layer looks only at its corresponding header (here packet header)
- Routing is different on virtual circuit networks than on datagram networks

# Datagram vs. Virtual Circuits

- In virtual circuits after an initialization phase all packets follow the same path. We generally assume that packets are delivered once and only once, and in order.
- In a datagram network packet are routed individually. They may be lost or delivered out-of sequence.
- Sometimes referred to as: *connection-oriented service* and *connectionless service*.



# Flow control & Congestion

- Flow control avoids sending data faster than the destination can absorb
- Congestion control avoids sending data faster than the the network can handle.
- Requires:
  - efficient feedback mechanism, buffer management, route load-balancing
- In a connectionless service it is not easy to negotiate an equitable service between users

# Transport Layer

- Provides a reliable mean to transmit messages between two end-nodes through:
  - Messages fragmentation into packets
  - Packets reassembly in original order
  - Sessions multiplexing and splitting
  - Retransmission of lost packets
  - end-to-end flow control and congestion control



# Session Layer

- Was intended to handle the interaction between two end points in setting up a session:
  - Two connections
  - Service location (e.g., would achieve load sharing)
  - Control of access rights
- In many networks these functionalities are inexistent or spread over other layers

# Presentation Layer

- Was inteded to provides data encryption, data compression, and code/types conversion from one architecture to another.



# Application Layer

- What's left over…
- Examples:WWW, Email, Telnet, …

# Simple Distributed Problem

- Three armies: two on the same side (A), one enemy B.
- If the two A armies attack they win, but if only one attacks it looses.
- Communication between A armies goes through an area controlled by B army.
- Can A armies find a strategy to defeat B.



# Summary

- Networking terminology and basic concepts
- Layering in networking
- 7-layers OSI reference model
- Brief introduction of each layer