Computer Networks

COMP 3670 Introduction to Computer Netwotks

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Preface

These are lecture notes for the computer network course taught at the school of computer science, University of Windsor in summer 2021. I used several sources to create these lecture notes, but the main references are [For17] and [KR16]

Please email me if you notice any mistakes or typos.

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1 Computer Networks Fundamentals

What is a Network?

Definition
A large system consisting of many similar parts that are connected together to allow movement or communication between or along the parts, or between the parts and a control centre *[Cambridge Dictionary]*

Definition
A group or system of interconnected people or things *[Oxford Dictionary]*

Computer Networks: Definition

What is a network?
A network is a collection of things or entities; usually, these entities are connected one way or another to serve a specific purpose.

What is computer network?
A system of connected computing devices that enable sharing resources between these devices.

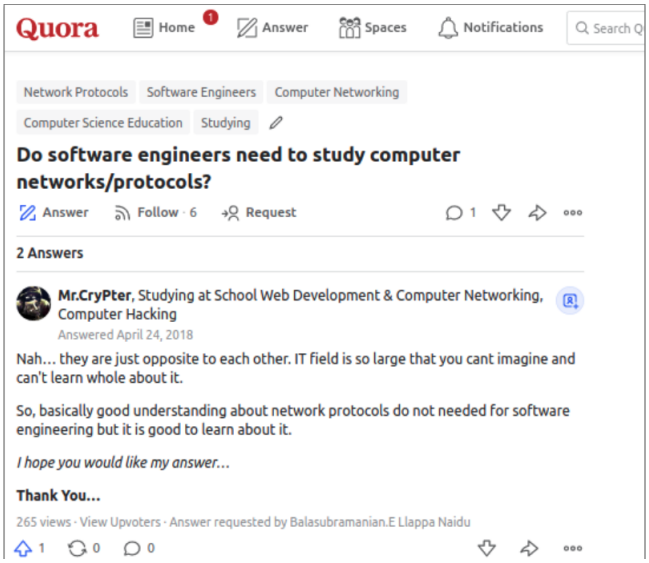
Computer Networks: Sharing Resources

What resources we could share over a computer network?
The shared resources are either data or computational power. The computing devices within the network usually exchange data (e.g. sending a message from one device to another) or computational services (e.g., calculating the shipping cost of a parcel)

Computer Networks: Art & Science

Is designing computer networks an art or a science?
Design and building computer networks are both science and art [Bra07].

- We have to apply some formal reasoning and follow a systematic process when designing computer networks.
- There is enough space for creativity and personal preference when we are crafting the design.



- Any computer network design is open to interpretation and can mean different things to different network engineers. Simply every network design is debatable to some degree.

Studying Computer Network

2 Network Architecture & Protocols

Network Architecture

What is network architecture?

It is an abstract description of the way network devices and services are structured to satisfy the needs of network users.

The network architecture provides an overview of:

- network resources (nodes, appliances)
- network layers and protocols.
- network topology.
- services and software.

Network Topology

What is network topology?
It is an abstract description of the network that could cover both logical and physical layout of the network.

- The physical network topology illustrates the arrangement of actual connections (cables, wires, wireless) and nodes.
- The common network typologies are: star, tree, bus, ring, mesh, line, complete graph.
- The logical topology focus on showing connectivity between nodes and the flow of communications between the nodes within the network (common in cloud and virtualization environments).

Network Design: Layered Architecture

What is Layered Architecture?
It is a common architecture pattern in system design (hardware, software, communication) in which system functions or services are organized into isolated layers, so that changes can be made in one layer without affecting the other layers.

Network Design: End-to-End Principle

What is the end-to-end principle?

- It is a network design method that argue the placement of functions (feature, services, etc) within the network stack [SRC84, BC01].
- This principle states that in computer networks application-specific features reside in the communicating end nodes of the network, rather than in intermediary nodes.

Network Design: Protocols

Computer Networks are Heterogeneous Systems

Computer Networks contain nodes of different :

- hardware
- operating systems
- software applications.
- communication mediums.

The only way to enable nodes with different hardware and software to communicate is to use a well defined set of communication rules (protocol).

Network Design: Protocols

- One important concept in the computer network is a network protocol.
- Studying computer networks is mainly about studying and understanding network protocols.

What is a network protocol?
A network protocol is a set of rules that describe how two nodes communicate over the network by exchanging messages. The rules describe the messages order, syntax and semantic.

Network Design: Protocols

What are the key functions of network protocols?
The most common functions a network protocol provide are:

- Formatting and Encoding Data
- Detecting and Correcting Errors.
- Controlling Data Flow.
- Guaranteeing the Order of Transmitted Data.
- Identifying Nodes.
- Maintaining Session State.

Network Design: Protocol Suite/Stack

- To enable two or more network nodes to communicate, we usually use a collection of different network protocols.
- We use the term network protocols family or suite to refer to protocols that enable the network devices to communicate within the same network.
- The implementation of a given network protocol suite is called a protocol stack. The protocols of the same protocols suite or stack are organized in a layered architecture.

Network Design: The OSI Model

What is the OSI Model?

- OSI stands for Open Systems Interconnection Model.
- It is a theoretical/ conceptual model that describes how network devices could communicate.
- The OSI model uses a layered architecture of seven layers to structure network communication protocols.
- The OSI model was proposed to standardize the communication functions between network devices to build a computer network from devices made by different vendors.

The OSI Model

The OSI Model Part

Physical Layer

The lowest layer of the OSI model. It is mainly responsible for carrying the data across the psychical communication links (e.g. Ethernet cables, fibre optic, etc).

Data-Link Layer

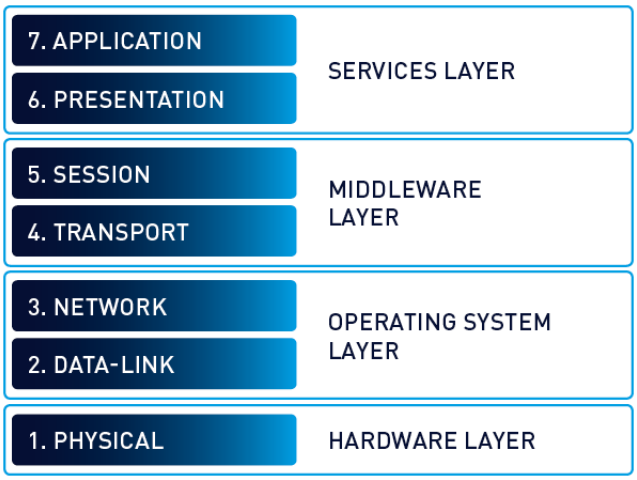


Figure 1: The OSI Model [1]

The data-link layer focus transferring data between two devices on the same network. The data-link layer specify the physical addresses on the sender and receiver devices.

Network Layer
This layer is mainly responsible for transferring the data between devices the belong to different networks. If the two devices communicating are on the same network, then the network layer is unnecessary.

Transport Layer
This layer implements an end-to-end communication between the two devices. It hides the fact that the communication occurs over one or more computer networks. This layer is also responsible for protocols that perform flow control and error control.

Session Layer
This is the layer that responsible for session management between the communicating devices (processes). The session starts when the connection is open and ends when the connection is closed. In addition, session layer ensures that the established session is valid and capable of transferring the data.

Presentation Layer

This layer is responsible for data encoding and decoding or marshalling and unmarshalling of the data between the applications on one device and the application on another device. Two communicating devices communicating may be using different data format or encoding (e.g. an integer variable on one machine is 4 bytes and on another machine 8 bytes)

Application Layer
This layer contains the network applications the end-users interact with to send and received data and access resources over the network. The protocols in the application layers are application-specific protocols that enable distributed applications to communicate over the network.

The Internet Protocol Suite

- The TCP/IP suite is the most common adapted communication protocol suite in modern computer networks and the Internet.
- The most common communication protocols in this suite is the Transmission Control Protocol (TCP) and the Internet Protocol (IP).
- There are several implementation of the TCP/IP suite.
- The TCP/IP suite is inspired by the OSI model and uses a layered architecture of four layers.

The Internet Protocol Suite

Data Encapsulation

- Each layer interacts only with the layer above and below it.
- Each layer is able to encapsulate the data from the layer above so it can move between the layers.
- Data transmitted by each layer is called a protocol data unit (PDU).
- In each layer the PDU contains the payload data that is being transmitted.
- In addition to the payload, each layer append to the payload received from the layer above a headers and footers fields.

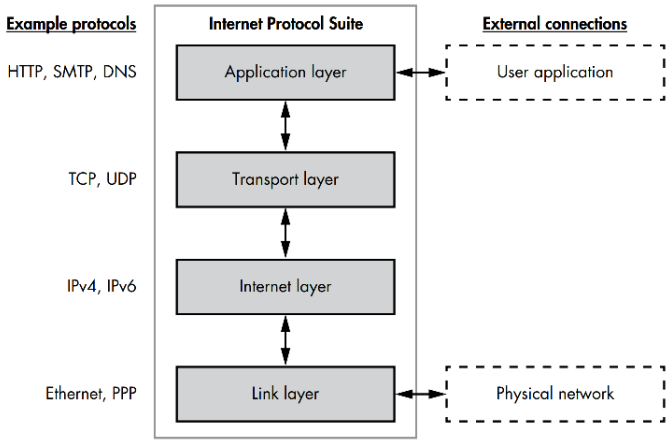


Figure 2: Internet Protocol Suite layers

Data Encapsulation

Data Encapsulation

3 Computer Network and the Internet

Computer Networks: LAN vs.WAN

What is Local Area Network (LAN)?

A local area network (LAN) is a computer network that connect a group of computers over small or limited geographic area (usually within the same building).

What is Wide Area Network (WAN)?

A wide are network is a computer network that connects a group of computers over large distances. The computers inside the WAN are organized into different LANs. In other words we constract a WAN by connecting multiple LANs together. In general, any large network that spreads out over a wide geographic area is a WAN.

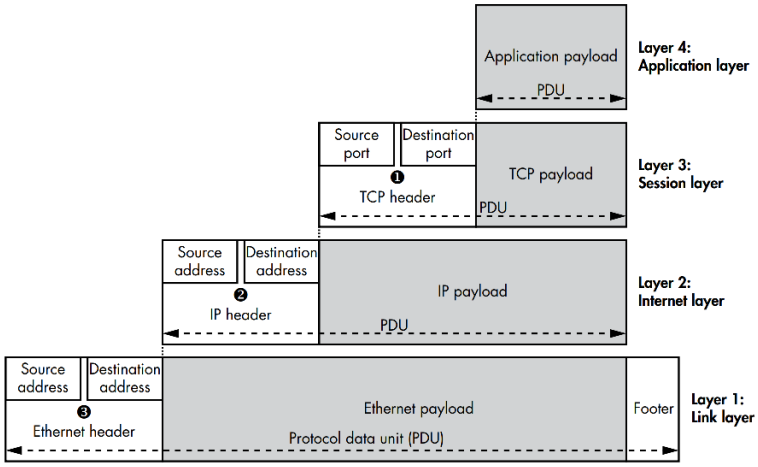


Figure 3: TCP/IP Data Encapsulation

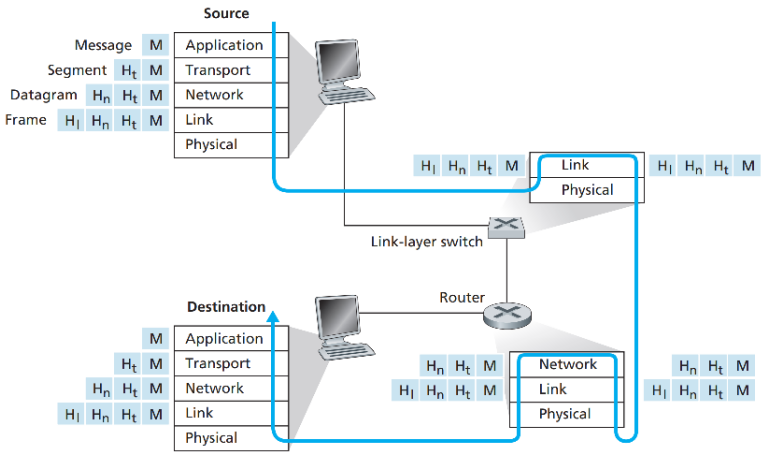


Figure 4: Different Network Nodes and How they Process the Encapsulated Data

Computer Networks: Packet-Switched Network

What is the difference between LAN and WAN?

- In computer networks, devices are connected through communication links.
- The communication links provide different data transmission speeds/rates, capacity, and made of various physical media.
- The computers are structured into several packet switching networks using routers and switches (link-layer switches).

Computer Networks: Packet-Switched Network

What is Packet-Switched Network?

It is a data communication network that, on sending the data, it will divide the data into small chunks known as packets. Then, deliver the packets to the receiver through a network of routers and switches. Finally, at the receiver side, the packets are reassembled to reconstruct the original data.

How does a packet switching network work?

In simple words, a packet switching network will take a packet arriving at one of its incoming communication links. Then, using some algorithm will redirect the packet to one of its outgoing communication links.

Computer Networks: Packet-Switched Network

- Most packet switches use store-and-forward transmission.
- In store-and-forward, the router or the switch must must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link.

What is Cut-Through Switching?

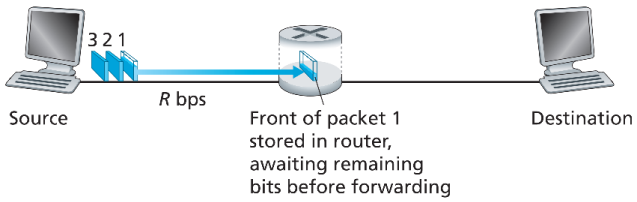


Figure 5: Store-and-forward packet switching

Computer Networks: The Internet

- The Internet is the largest computer network to exist; it consists of millions of connected computing devices.
- The Internet is a network of networks. Initially,the Internet mainly connected computers (mainframes, servers, workstations, desktop PCs, and laptops).
- Today, many unconventional computing devices are connected to the Internet, such as smartphones,smart TVs, watches, home appliances, cars, utility infrastructure and more.

What is the Internet of Things (IoT)?

The Internet: Infrastructure

- The Internet as a system that consists of different hardware and software components. These software and hardware components utilize a set of networking infrastructures to enable connectivity.
- We use the word hosts or end systems to refer to any computing device connected to the Internet.
- The hosts or the end systems connect through communication links. The communication links provide different data transmission speeds/rates and made of various physical media.
- The end-systems are structured into several packet switching networks using routers and switches.

Why we call nodes connected to the internet host or end-system?

The Internet: Infrastructure

What is the main service the Internet provide to end-systems?
The main service the Internet provides to any network of end systems is connectivity. This connectivity service enables one end system in a given network to communicate with another end system in a different network.

Who is responsible for providing Internet Connectivity?
he primary entity that provides this connectivity service is the Internet Service Provider (ISP). An ISP refers to any company or organization that provides services for accessing, connecting or using the Internet.

The Internet: Internet Service Provide

What are the different types of ISPs?
While there are different classification for ISPs, we are interested in classifying ISPs by the access and coverage level they provide. Therefore, we can classify ISP into:

- Access ISPs: end systems are usually connected to access ISPs. An access ISP will typically cover a small geographical area such as town or city.
- Regional ISPs: Enables two or more access ISPto communicate. A regional ISP will cover one or more city or even an entire country.
- Global ISPs: also known as Tier 1 ISPs which connects two or more regional ISPs

The Internet: Hierarchical Structure

The Internet: IXP and CDN

What is Internet Exchange Point (IXP)?
A third-party company can create an Internet Exchange Point (IXP), which is a meeting point where multiple ISPs can peer together. An IXP is typically in a stand-alone building with its own switches.

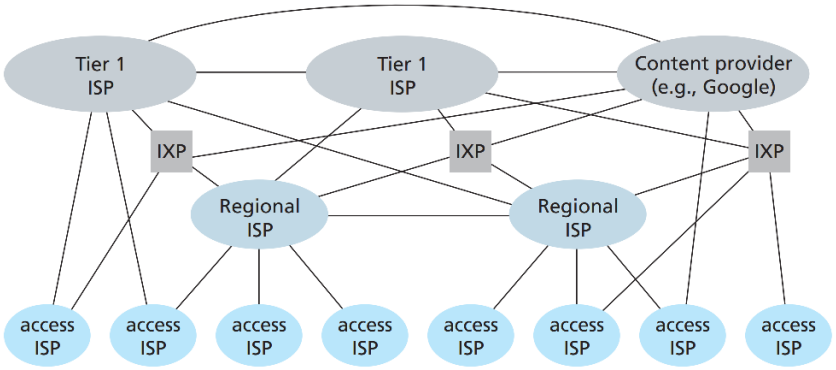


Figure 6: Hierarchical Structure of the Internet

What is content delivery network (CDN)?
A third-party company can create its own distributed private network (TCP/IP) of data centers. Google is currently one of the leadinge xamples of such a content-provider network. As of this writing, it is estimated that Google has 50–100 data centers distributed across the world. [Why?]

Structure of the Internet Bird Eye View

- Computers and devices that run the network application or services are usually called end systems or endpoints because they are placed at theedge of the network.
- End system are also referred to as host because they host application, services, and data
- There is no significant difference between host and end system, both can be interchangeable each other. in computer network all devices are called hosts and end systems.
- The term node is more general and usually means any device connected to the network.
- The end system could be client or server or both.

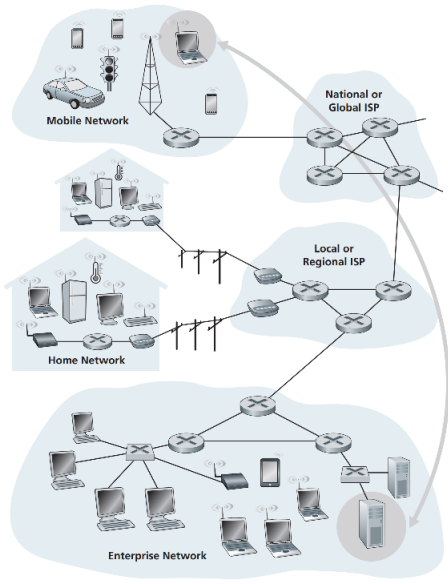


Figure 7: Structure of the Internet Bird Eye View

The Access Network

- The access network is the part of the internet that give the end user access to the network.
- There are different type of access networks, such as Home Network, Mobile Network, and Enterprise Network.
- The access network is connected to the internet through one or more edge router.

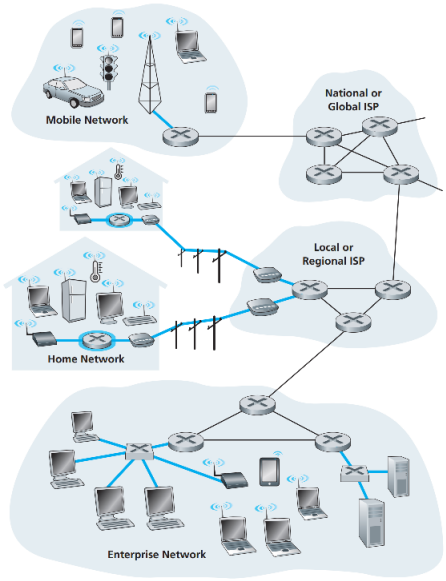


Figure 8: Access Network of the Internet

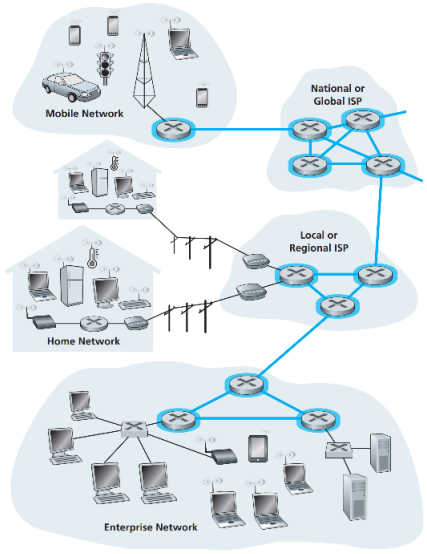


Figure 9: Network Core of the Internet

The Network Core

- End system and hosts are not connected to the network core directly.
- The network devices at the network core only run the IP/TCP suite (physical, link, and network layer).
- The network core does not process the transport layer and the application layer.
- The network core is a mesh of packet switches network of switches and routers.
- The primary services implemented by the network core are forwarding and routing.

4 Developing Computer Network Applications

Network Based Application

What is a network based application?
An application consists of two or more processes that communicate over a computer network (using networking protocols) by exchanging messages.

- Network application is the opposite of stand-alone application, in the case of network application, either the program we are using or the data we are working with or both reside on a computer network.
- There are many architecture and design patterns we can apply when developing network based application.
- Network based application is a sub-class of distributed applications or systems.

Basic Components of Network Applications

- **Program:** the code written by the developers.
- **Process:** is the instance of a computer program that is being executed.
- **Message:** network processes communicate by exchanging messages.

- **Packet:** the communication message is divided into small fragments of the same size before it could be send over the network.
- **Protocol:** a well defined set of rules, that specify the syntax, the semantic, and the order of communication messages.
- **Network:** the communication infrastructure we use to allow network processes to communicate.

Network Applications Requirements

What are the main requirements for network applications?

1. Availability
2. Scalability.
3. Fault-Tolerant.
4. Consistency.
5. Security.

What else?

Fallacies of Distributed System Development

In the early 90s, Peter Deutsch and James Gosling define 8 fallacies (false assumptions) that software developers and architects are likely to make when developing distributed systems.

- The network is reliable.
- Latency is zero.
- Bandwidth is infinite.
- The network is secure.
- Topology does not change.
- There is one administrator.
- Transport cost is zero.
- The network is homogeneous.

Next Week

- Application Layer and Application Protocols.
- Lab 1 (Basic Network Commands,Traceroute and Wireshark)
- Quiz 1 (3%) cover this week topic "Computer Network Basics"

References

References

[BC01] Marjory S. Blumenthal and David D. Clark, *Rethinking the design of the internet: The end-to-end arguments vs. the brave new world*, no. 1, 70–109.

[Bra07] R. Bradford, *The art of computer networking*, Pearson education, Pearson/Prentice Hall, 2007.

[For17] James Forshaw, *Attacking network protocols: A hacker's guide to capture, analysis, and exploitation*, 1st ed., No Starch Press, USA, 2017.

[KR16] James F. Kurose and Keith W. Ross, *Computer networking: A top-down approach*, 7 ed., Pearson, Boston, MA, 2016.

[SRC84] J. H. Saltzer, D. P. Reed, and D. D. Clark, *End-to-end arguments in system design*, ACM Trans. Comput. Syst. **2** (1984), no. 4, 277–288.