Lecture 2: Topological Analysis of Networks

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How to Characterise Networks?

• Three issues
  - *Complexity*: measure of network “density”
  - *Performance*: what is target QoS?
  - *Dependability*: how reliable is the network functionality

• Issues are in constant tension
• Examine how to define good tradeoffs
What is a Topology?

- “The way in which the connections are made among all the network entities is called the topology of the network”.

- Network topology specifically refers to the physical layout of the network,
  - e.g., the location of the computers and how the cable is run between them.

- The most common topologies are
  - Bus
  - Star
  - Ring
  - Mesh.
Network Topologies

- Regular networks
  - Grids, rings, etc.
- Real networks
  - Power-law topologies
- Properties of real networks
- Designing networks with particular properties
Issue 1: Network Complexity

• Goals:
  - characterise networks using a measure of “complexity”
  - Examine properties of different network topologies
  - Study how to generate networks with target properties
    • Graph generators
Issues

- Regular networks are most commonly studied
  - Easy to study
- Problem
  - Real networks are not regular
  - Possess power-law structure
- Examples
  - Internet
  - Communications networks
  - Social networks (facebook)
  - Airline, road networks
FDDI- Fibre Distributed Data Interface specifies a 100 Mbit/s token-passing, dual-ring LAN using fibre-optic cable.
Regular Networks

• Standard approach for networking
  - Bus
  - Star
  - Ring

• Methods for creating “simple” networks
  - Simple “models”
Bus Topology

- The bus topology is the simplest and most common.

- It is often used when a network installation is small, simple, or temporary.

- It is a Passive topology. This means that computers on the bus only listen for data being sent, they are not responsible for moving the data from one computer to the next.
BUS Topology

Computer

Computer

Computer

Computer

Computer

Computer

Computer

Computer
Bus Topology

- In an active topology network, the computers regenerate signals and are responsible for moving the data through the network.

- On a bus network, all the computers are connected to a single cable.

- When one computer sends a signal using the cable, all the computers on the network receive the information, but only one (Addressee) accepts it. The rest disregard the message.
Advantages of Bus

• The bus is simple, reliable in very small network, and easy to use.

• The bus requires the least amount of cable to connect the computers together and is therefore less expensive than other cabling arrangements.

• Failure of one node does not affect the rest of network.

• Failure of the bus system causes the entire network to crash
Disadvantages of Bus

• Heavy network traffic can slow a bus considerably.

• A break in the cable or lack of proper termination can bring the network down.

• It is difficult to troubleshoot a bus.
Appropriateness

- The network is small
- The network will not be frequently reconfigured
- The least expensive solution is required
- The network is not expected to grow much
Star Topology
In a star topology, each device has a dedicated point to point link only to central controller, usually called a hub/server/host.

Each computer on a star network communicates with a central hub that resends the message appropriate computer(s).

The hub can be active or passive.

An active hub regenerate the electrical signal and sends it to all the computers connected to it.
Star Topology

- This type of hub is often called a multiport repeater.

- Active hub require electrical power to run.

- A passive hub, such as wiring panels, merely acts as a connection point and does not amplify or regenerate the signal.

- Passive hubs do not require electrical power to run.
Advantages of Star Topology

- It is easy to modify and add new computers to a star network.
- During adding/deleting a node network can function normally.
- When the capacity of the central hub is exceeded, it can be replaced with one that has a larger number of ports to plug lines into.
- Provide for centralised monitoring and management of the network.
- Single computer failure do not necessarily bring down the whole star network.
Disadvantages of Star Topology

- If the central hub fails, the whole network fails to operate.
- It costs more to cable a star network.
- Require dedicated server and hub
Appropriateness

- It must be easy to add or remove client computer.
- It must be easy to troubleshoot.
- The network is large.
- The network is expected to grow in the future.
Ring Topology
Ring Topology

- In a ring topology, each computer is connected directly to the next computer in line, forming a circle of cable.
- It uses tokens to pass the information from one computer to another.
- Every computer is connected to the next computer in the ring, and each retransmits what it receives from the previous computer.
- The message flows around the ring in one direction.
- Rings are an active topology.
  - There is no termination because there is no end to the ring.
Token Passing

- Token passing a method of sending data in a ring topology
- A small packet, called the token passed around the ring to each computer in turn
- If a computer has information to send, it modifies the token, adds address information and the data and sends it down the ring.
- The information travels around the ring until it either reaches its destination or returns to the sender.
- A token can circle a ring 200 meters in diameter at about 10,000 times a second.
Advantages of Ring Topology

- All the computers have equal access to the network.
- Even with many users, network performance is even.
- Allows error checking, and acknowledgement.
Disadvantages of Ring Topology

- Failure of one computer can affect the whole network.
- It is difficult to troubleshoot the ring network.
- Adding or removing computers disturbs the network.
Appropriateness

- The network must operate reasonably under a heavy load.
- A higher-speed network is required.
- The network will not be frequently reconfigured.
Mesh Topology
Mesh Topology

• In a mesh topology, every device has a dedicated point-to-point link to every other device.

• A fully connected mesh network therefore has $n(n-1)/2$ physical channels to link $n$ devices.

• To accommodate that many links, every device on the network must have $n-1$ input/output ports.
Advantages of Mesh Topology

- Because of the dedicated link, no traffic between computers.
- Failure of one node computer does not affect the rest of the network.
- Because of the dedicated link, privacy and security are guaranteed
- Point-to-point links make fault identification and fault isolation easy.
Disadvantages of Mesh Topology

- Due to the amount of cabling and number of input output ports, it is expensive.

- Significant space is required to run the cables.
Variations of the Major Topologies

- **Star Bus**
  - Combines bus and star

- **Hybrid Star**
  - A star network can be extended by placing another star hub where a computer might otherwise go, allowing several more computers or hubs to be connected to that hub.
- The star bus topology combines the bus and the star, linking several star hubs together with bus trunks. If one computer fails, the hub can detect the fault and isolate the computer.
- If a hub fails, computers connected to it will not be able to communicate, and the bus network will be broken into two segments that can not reach each other.
Variations of the Major Topologies

• Hybrid Topologies
  - Often a network combines several topologies as subnetworks linked together is a large topology.
  - For instance one department of business may have decided to use a bus topology while another department has a ring.
  - The two can be connected to each other a central controller in a star topology.
  - When two or more topologies are connected together it forms a hybrid topology.
Wireless Sensor Networks

Data Acquisition Network

- Machine Monitoring
- Wireless Sensor
- Ship Monitoring

Wireless Data Collection Networks

- BSC (Base Station Controller, Preprocessing)
- BST

Medical Monitoring

Data Distribution Network

- Roving Human monitor
- PDA
- Online monitoring
- Printer
- Transmitter
- Server

Wireland (Ethernet WLAN, Optical)

- Notebook
- Cellular Phone
- Notebook Cellular Phone
- PC

Any where, any time to access

- Animal Monitoring
- Vehicle Monitoring

- Wireless Sensor
- Management Center (Database large storage, analysis)
Network of Networks

FIG. 9 - All Digital Network Composed of Mixture of Links
Analysis of Network Topologies

• Issues
  - QoS properties of topologies
  - Robustness
  - Requirements of applications

• Self-healing networks

• Tradeoffs
  - Cost of hardware, wiring
  - QoS
Applications and Network Topology

Bus Network with Backbone
Interconnections Between Different Network Types

Star Network Topology
Token Ring Network Topology
Self-healing Ring Topology

Two rings

http://www.fiber-optics.info/articles/its-networks.htm
FDDI: Fiber Distributed Data Interface
100 Mbps

Ethernet LAN

Packet Switched Network

Fully Connected Point-to-Point Network
The Spider Web Net

Fig. 2--The Spider Web Communications Network
Network Topology

Centralized, Decentralized, Distributed

FIG. 1 - Centralized, Decentralized and Distributed Networks

Neighbor Connectivity and Redundancy

FIG. 2 - Definition of Redundancy Level
Connectivity and Number of Links

Number of links increases exponentially

Figure 4--Number of Links as a Function of Number of Terminal Stations: The Necessity for Switching in a Communications Network
Mesh Networks

Basic 4-link ring element

Two ways to interconnect two rings

Two 2-D mesh networks

New Topology
Alternating
1-way streets

Standard Manhattan

**Edge Binding** - In any network, much of the routing power of peripheral stations is wasted simply because peripheral links are unused. Thus, messages tend to reflect off the boundary into the interior or to move parallel to the periphery.
The Problem of Complexity

Communication Protocols in a network must be restricted and organized to avoid Complexity problems.

Arbitrary flow: inference complexity is NP-complete

Restricted flow (e.g., reentrant flow line)
--- polynomial complexity
Hierarchical Networks

4 x 4 Mesh Net

Hierarchical Clustering

Dual-Ring Hierarchical Structure for level 2

Designation of Primary Communication Ring

Hierarchical Clustering of 8x8 mesh showing all four communication rings

Hierarchical Clustering of 8x8 mesh showing level 3 primary communication ring

Same structure--Consistent Hierarchy

Disable some links
Disable some links to reduce complexity

The disabled links can be used as backups in case of failures

Note- this dual ring structure is a self-healing ring
“Complex” Networks

• The topology of virtually all real-world systems can be modeled using a graph or complex network framework
  - Information network, social networks, engineering, networks, biological networks
  - Examples
    • Internet, WWW
    • Instant message, phone/mobile call, email network
    • Circuits, power grids, control systems, software
    • Gene regulation, protein interaction and metabolic networks
Topological Analysis of Real-world Complex Networks

- Classic Erdos-Renyi (ER) random-graph model
  - $G(n,p)$: Given $n$ vertices connect each pair i.i.d. with probability $p$
  - $G(n,m)$: graphs with $n$ nodes, $m$ edges
  - Does not mimic reality

- A range of new graph models
  - Significant improvement by capturing common topological properties
    - Small-world graph pattern
      - small average shortest path length (or characteristic path length) & highly clustered
    - power law degree distribution
  - Two classes of models
    - Explanatory models
    - Descriptive models

\[ p_k \sim k^{-\alpha} \]
Network types

- Ethernet (1970)
- Fast ethernet (1995)
- Token rings (1994)
- Gigabit ethernet (1999)
Ethernet
Ethernet was developed in the mid 1970's by the Xerox Corporation, and in 1979 Digital Equipment Corporation (DEC) and Intel joined forces with Xerox to standardise the system. The Institute of Electrical and Electronic Engineers (IEEE) released the official Ethernet standard in 1983 called the **IEEE 802.3** after the name of the working group responsible for its development, and in 1985 version 2 (IEEE 802.3a) was released. This second version is commonly known as "Thin Ethernet" or 10Base2, in this case the maximum length is 185m even though the "2" suggest that it should be 200m.

Fast Ethernet
Fast Ethernet was officially adopted in the summer of 1995, two years after a group of leading network companies had formed the Fast Ethernet Alliance to develop the standard. Operating at ten times the speed of regular 10Base-T Ethernet, Fast Ethernet - also known as 100BaseT - retains the same CSMA/CD protocol and Category 5 cabling support as its predecessor higher bandwidth and introduces new features such as full-duplex operation and auto-negotiation.
**Token Ring**
In 1984, IBM introduced the 4 Mbit/s Token Ring network. Instead of the normal plug and socket arrangement of male and female gendered connectors, the IBM data connector (IDC) was a sort of hermaphrodite, designed to mate with itself. Although the IBM Cabling System is to this day regarded as a very high quality and robust data communication media, its large size and cost - coupled with the fact that with only 4 cores it was less versatile than 8-core UTP - saw Token Ring continue fall behind Ethernet in the popularity stakes. It remains IBM's primary LAN technology however and the compatible and almost identical **IEEE 802.5** specification continues to shadow IBM's Token Ring development.

**FDDI**
Developed by the American National Standards Institute (ANSI) standards committee in the mid-1980s - at a time when high-speed engineering workstations were beginning to tax the bandwidth of existing LANs based on Ethernet and Token Ring - the Fibre Distributed Data Interface (FDDI) specifies a **100 Mbit/s** token-passing, dual-ring LAN using fibre-optic cable.
Gigabit Ethernet
The next step in Ethernet's evolution was driven by the Gigabit Ethernet Alliance, formed in 1996. The ratification of associated Gigabit Ethernet standards was completed in the summer of 1999, specifying a physical layer that uses a mixture of proven technologies from the original Ethernet Specification and the ANSI X3T11 Fibre Channel Specification:

Use of the same variable-length (64- to 1514-byte packets) IEEE 802.3 frame format found in Ethernet and Fast Ethernet is key to the ease with which existing lower-speed Ethernet devices can be connected to Gigabit Ethernet devices, using LAN switches or routers to adapt one physical line speed to the other.