Multiple Access

Taxonomy of Multiple-access protocols

Random Access

MA

CSMA

CSMA/CD

CSMA/CA

RANDOM ACCESS

In a random access method, each station has the right to the medium without being controlled by any other station.

However, if more than one station tries to send, there is an access conflict (collision) and the frames will be either destroyed or modified.

To avoid access conflict or to resolve it when it happens, it is necessary a procedure that answers the following questions:

- When can the station access the medium?
- What can the station do if the medium is busy?
- How can the station determine the success or failure of the transmission?
- What can the station do if there is an access conflict?

shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)

shared RF (satellite)

An ideal multiple access protocol

given: broadcast channel of rate R bps

desiderata:

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

Evolution of random-access methods

Aloha method

- Aloha, also called the *Aloha method*, refers to a simple communications scheme in which each source (transmitter) in a network sends data whenever there is a frame to send.

- This protocol was originally developed at the University of Hawaii for use with satellite communication systems in the Pacific.
- In a wireless broadcast system or a half-duplex two-way link, Aloha works perfectly. But as networks become more complex, trouble occurs because data frames collide (conflict).
- The heavier the communications volume, the worse the collision problems become. The result is degradation of system efficiency, because when two frames collide, the data contained in both frames is lost.
- To minimize the number of collisions, thereby optimizing network efficiency and increasing the number of subscribers that can use a given network, a scheme called slotted Aloha was developed. This system employs signals called beacons that are sent at precise intervals and tell each source when the channel is clear to send a frame.

ALOHA network

Every station that need to send a frame to another station first sends it to the base station. The base station receives the frame and relays it to the intended destination. The base station acts as a HOP.

The ALOHA protocol is based on the following rules:

Multiple access: Any station sends a frame when it has a frame to send.

Acknowledgement: After sending the frame, the station waits as ACK. If it does not receive an ACK during the allotted time (2x propagation time) it assumes that the frame is lost; it tries sending again after a random amount of time.

Frames in a pure ALOHA network

Procedure for pure ALOHA protocol

Frames in a slotted ALOHA network

Note

The throughput for pure ALOHA is

$$S = G \times e^{-2G}.$$

The maximum throughput

$$S_{max} = 0.184 \text{ when } G = (1/2).$$

The throughput for slotted ALOHA is

$$S = G \times e^{-G}.$$

The maximum throughput

$$S_{max} = 0.368 \text{ when } G = 1.$$

CSMA (carrier sense multiple access)

CSMA: listen before transmit:

if channel sensed idle: transmit entire frame

- if channel sensed busy, defer transmission

- human analogy: don't interrupt others!

- collisions *can* still occur: propagation delay means two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted
  - distance & propagation delay play role in in determining collision probability

Space/time model of the collision in CSMA

Behavior of three persistence methods

a. 1-persistent

b. Nonpersistent

c. p-persistent

a. 1-persistent

b. Nonpersistent

c. p-persistent

CSMA/CD (collision detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength

CSMA/CD used in Ethernet

- human analogy: the polite conversationalist

Ethernet CSMA/CD algorithm

1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !
4. If NIC detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, NIC enters *binary (exponential) backoff:*
   - after *m* th collision, NIC chooses *K* at random from $\{0,1,2, \ldots, 2^m-1\}$. NIC waits K·512 bit times, returns to Step 2
   - longer backoff interval with more collisions

Collision of the first bit in CSMA/CD

Collision and abortion in CSMA/CD

Example 12.5

A network using CSMA/CD has a bandwidth of 10 Mbps. If the maximum propagation time (including the delays in the devices and ignoring the time needed to send a jamming signal, as we see later) is 25.6 μs, what is the minimum size of the frame?

Solution

The frame transmission time is $T_{fr} = 2 \times T_p = 51.2$ *μs. This means, in the worst case, a station needs to transmit for a period of 51.2 μs to detect the collision. The minimum size of the frame is 10 Mbps × 51.2 μs = 512 bits or 64 bytes. This is actually the minimum size of the frame for Standard Ethernet.*

Flow diagram for the CSMA/CD

In CSMA/CA, the IFS -Inter-Frame Gap can also be used to define the priority of a station or a frame.

- **CSMA/CA used in 802.11**

In CSMA/CA, if the station finds the channel busy, it does not restart the timer of the contention window;
it stops the timer and restarts it when the channel becomes idle.

Flow diagram for CSMA/CA

After transmission of each frame, a transmitter must wait for a period of 9.6 microseconds (at 10 Mbps) to allow the signal to propagate through the receiver electronics at the destination.

This period of time is known as the Inter-Frame Gap (IFG).

While every transmitter must wait for this time between sending frames, receivers do not necessarily see a "silent" period of 9.6 microseconds.

The way in which repeaters operate is such that they may reduce the IFG between the frames which they regenerate.

Control Access

Reservation

Polling

Token Passing

Reservation access method

“Taking turns” MAC protocols

polling:

- master node “invites” slave nodes to transmit in turn
- typically used with “dumb” slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)

Select and poll functions in polling access method

"Taking turns" MAC protocols

token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)

Logical ring and physical topology in token-passing access method

a. Physical ring

b. Dual ring

c. Bus ring

d. Star ring

Token-passing procedure

VLANs across switches

This is called "VLAN Trunking"

CHANNELIZATION

Channelization is a multiple-access method in which the available bandwidth of a link is shared

- *in time,*
- *frequency,*
- *or through code,*

between different stations.

In this section, we discuss three channelization protocols.

Frequency-Division Multiple Access (FDMA)
Time-Division Multiple Access (TDMA)
Code-Division Multiple Access (CDMA)

Frequency-division multiple access (FDMA)

In FDMA, the available bandwidth of the common channel is divided into bands that are separated by guard bands.

In frequency-division multiple access (FDMA), the bandwidth is divided into channels.

- *Each station uses its allocated band to send its data.*
- *Each band is reserved for a specific station.*
- *The band belongs to the station all the time.*
- *FDMA is a data link layer protocol that use FDM at the physical layer .*
- *FDMA is used in cellular telephone and satellite networks*

FDM - Frequency division multiplexing

FDM is an analog multiplexing technique that combines signals.

*FDM (*Frequency division multiplexing) *process*

Example

Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration using FDM

The satellite channel is analog. We divide it into four channels, each channel having a 250-KHz bandwidth.
One solution is 16-QAM modulation.

Example

The Advanced Mobile Phone System (AMPS) uses two bands.

The first band, **824 to 849 MHz**, is used for sending;

and **869 to 894 MHz** is used for receiving.

Each user has a bandwidth of 30 KHz in each direction. The 3-KHz voice is modulated using FM, creating 30 KHz of modulated signal. How many people can use their cellular phones simultaneously?

Solution

Each band is 25 MHz. If we divide 25 MHz into 30 KHz, we get 833.33.

In reality, the band is divided into 832 channels.

Of these, 42 channels are used for control, which means only 790 channels are available for cellular phone users.

Time-division multiple access (TDMA)

In TDMA, the bandwidth is just one channel that is timeshared between different stations.

In time division multiple access (TDMA), the bandwidth is just one channel that is timeshared.

- ***The stations share the capacity of the channel in time.***
- ***Each station is allocated a time slot which it can send data.***
- ***TDMA is a data link protocol that uses TDM at physical layer.***
- ***TDMA is used in the cellular telephone network***

Time Division Multiplexing *TDM*

TDM is a digital multiplexing technique for combining several low-rate digital channels into one high-rate one.

Calculation Involving TDM Frames

Example

Four signal sources (A, B, C, and D) are multiplexed using TDM.

Each source produces 100 characters per second.

- If there is byte interleaving and each frame requires one bit for synchronization, then:
  - the frame rate is 100 frames per second
  - each frame has 8 X 4 + 1 = 33 bits
  - the data rate is 100 X 33 = 3.3 Kbps
- Each frame has the following composition:
  - characterD characterC characterB characterA framing bit

Synchronous time-division multiplexing

Interleaving

TDM multiplexed signal

In a TDM, the data rate of the link is n times faster, and the unit duration is n times shorter.

Example

Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.

Solution

Example

A multiplexer combines four 100-Kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?

Solution

Figure shows the output for four arbitrary inputs.

Statistical Time-division Multiplexing (STDM)

- **Statistical Time-division Multiplexing (STDM)**
- **STDM** is an advanced version of TDM in which both the address of the terminal and the data itself are transmitted together for better routing.
- Using STDM allows bandwidth to be split over 1 line.
- Example:
  - If there is one 10 MBit line coming into the building, STDM can be used to provide 178 terminals with a dedicated 56 k connection (178 * 56k = 9.96 Mb).
- STDM does NOT reserve a time slot for each terminal, rather assign a slot when the terminal is requiring data to be sent/received.

Statistical Time-Division Multiplexing (STDM)

- In the STDM transmission each piece of 8-bit character data requires a terminal address (shown as a 5-bit address).
-
- A total of 78 bits (5 + 8 = 13 bits for each of the 6 time slots) is required to transmit 6 characters.
- Even though the STDM requires more bits to transmit each character, it is more efficient because it transmits only when there are data to transmit. It is therefore able to handle more terminals than TDM because each terminal is not being utilized 100 percent of the time.
- Inverse multiplexing is the opposite of multiplexing. There is one input to and one output from the mux-demux pair and multiple lines to carry the signal between the mux-demux pair. Thus, if there is a need to transmit at a rate of 512 Kbps, four 128-Kbps lines can be used.

In CDMA- Code division multiple access, one channel carries all transmissions simultaneously.

CDMA differs from FDMA because:

One channel occupies the entire bandwidth of the link

CDMA differs from FDMA because:

All stations can send data simultaneously; there is no timesharing

Simple idea of communication with code

Sharing channel in CDMA

Figure 12.27 Digital signal created by four stations in CDMA

Decoding of the composite signal for one in CDMA

CDMA multiplexer another representation

1. **The multiplexer receives one encoded number from each station (-1,-1,0,+1)**
2. **The encoded number sent by station 1 is multiplied by each chip sequence A. (station 2 by chip sequence b, etc)**
3. **All first chips are added, as are all second, third, and four chips => one new sequence**
4. **The sequence is transmitted on through the link**

CDMA demultiplexer

1. **The multiplexer receives the sequence sent across the link**
2. **It multiplies the sequence by the code for each receiver. The multiplication is done chip by chip**
3. **The chips in each sequence are added. The result is always +,-4 or 0**
4. **The result is divided by 4 and decoded to 0, 1 or silence by receiver**

General rule and examples of creating Walsh tables

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

a. Two basic rules

Wn complement of Wn, where each +1 is changed in -1 and vice versa

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

$$W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

b. Generation of W_1, W_2, and W_4

The number of sequences in a Walsh table needs to be $N = 2^m$.

Sequence generation

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

$$W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

A	B	C	D
+1, +1, +1, +1	+1, −1, +1, −1	+1, +1, −1, −1	+1, −1, −1, +1

Prove that a receiving station can get the data sent by a specific sender if it multiplies the entire data on the channel by the sender's chip code and then divides it by the number of stations.

Solution

Let us prove this for the first station, using our previous four-station example. We can say that the data on the channel

$$D = (d1 \cdot c1 + d2 \cdot c2 + d3 \cdot c3 + d4 \cdot c4).$$

The receiver which wants to get the data sent by station 1 multiplies these data by c1.

$$\begin{aligned} D \cdot c_1 &= (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1 \\ &= d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1 \\ &= d_1 \times N + d_2 \times 0 + d_3 \times 0 + d_4 \times 0 \\ &= d_1 \times N \end{aligned}$$

When we divide the result by N, we get d1 .

Properties of Orthogonal Sequences

- Orthogonal sequences have properties that are suitable for CDMA:
  - If we multiply a sequence by -1, every element in the sequence is complemented.
  - If we multiply two sequences, element by element and add the results, we get a number called the "inner product". If the two sequences are the same, we get N (N is the number of sequences); if they are different, we get 0. (AxA=N AxB=0)
  - The inner product of a sequence by its complement is –N (Ax(-A)=-N)

Example

Check to see if the second property about orthogonal codes holds for our CDMA example.

Solution

The inner product of each code by itself is N.
This is shown for code C; you can prove for yourself that it holds true for the other codes.

$$\mathbf{C} \cdot \mathbf{C} = [+1, +1, -1, -1] \cdot [+1, +1, -1, -1] = 1 + 1 + 1 + 1 = 4$$

If two sequences are different, the inner product is 0.

$$\mathbf{B} \cdot \mathbf{C} = [+1, -1, +1, -1] \cdot [+1, +1, -1, -1] = 1 - 1 - 1 + 1 = 0$$

Example

Check to see if the third property about orthogonal codes holds for our CDMA example.

Solution

The inner product of each code by its complement is –N. This is shown for code C; you can prove for yourself that it holds true for the other codes.

$$C \cdot (-C) = [+1, +1, -1, -1] \cdot [-1, -1, +1, +1] = -1 - 1 - 1 - 1 = -4$$

The inner product of a code with the complement of another code is 0.

$$B \cdot (-C) = [+1, -1, +1, -1] \cdot [-1, -1, +1, +1] = -1 + 1 + 1 - 1 = 0$$

WDM Wavelength-Division Multiplexing

Wave Division Multiplexing

WDM is an analog multiplexing technique to combine optical signals.

WDM wavelength-division multiplexing

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fibre by using different wavelengths (colors) of laser light to carry different signals. This allows for a multiplication in capacity, in addition to making it possible to perform bidirectional communications over one strand of fibre.
The term *wavelength-division multiplexing* is commonly applied to an optical carrier (which is typically described by its wavelength),
where as frequency-division multiplexing typically applies to a radio carrier (which is more often described by frequency).

Prisms in WDM multiplexing and demultiplexing

WDM is an analog multiplexing technique to combine optical signals.

WDM multiplexed signal

WDM systems

- *A WDM system uses*
- *a multiplexer at the transmitter to join the signals together*
- *demultiplexer at the receiver to split them apart.*
- *With the right type of fiber, it is possible to have a device that does both simultaneously and can function as an optical add-drop multiplexer.*

- *Most WDM systems operate on single mode fiber optical cables, which have a core diameter of 9 µm.*
- *Certain forms of WDM can also be used in multi-mode fiber cables (also known as premises cables) which have core diameters of 50 or 62.5 µm.*

WDM systems

- *WDM systems are divided into two market segments, dense and coarse WDM.*
- *Systems with more than 8 active wavelengths per fiber are generally considered* ***Dense WDM (DWDM)*** *systems,*
- *Systems with fewer than eight active wavelengths are classed as* ***Coarse WDM (CWDM)****.*

- *CWDM and DWDM technology are based on the same concept of using multiple wavelengths of light on a single fiber, but the two technologies differ in:*
  - *the spacing of the wavelengths,*
  - *number of channels, and*
  - *the ability to amplify signals*

Topologie Conexiuni
GEANT
BSNET
RENAM
BSNET/SEEREN
Satu Mare
Baia Mare
Suceava
Rascani
Iasi
Dej
Oradea
Cluj-Napoca
Tg. Mures
Vaslui
Bacau
Arad
Teius
Alba Iulia
Copsa Mica
Sf.Gheorghe
Timisoara
Deva
Focsani
Sibiu
Brasov
Petrosani
Galati
Resita
Braila
Buzau
Targoviste
Tg.Jiu
Pitesti
Ploiesti
Slobozia
Dr.Turnu Severin
Bucuresti
Ciulnita
Fetesti
Constanta
Calarasi
Negru Voda
Craiova
Giurgiu
Conexiuni
GEANT - 10G
NOC 10G
POP 1G
POP 1G

Dark Fibre
10 Gbps
5 Gbps
2.5 Gbps
622 Mbps
310 Mbps
155 Mbps
34 Mbps
"Dark Fibre" links provide multiple wavelengths at 10 Gbps. "Dark Fibre" links also have back-up IP connections. Details of these can be found at www.geant2.net
IS
NO
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LV
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NL
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LU
DE
PL
CZ
FR
SK
AT
CH
HU
SI
HR
IT
RO
PT
ES
BG
TR
GR
CY
MT
IL
GEANT2
Planned Backbone Topology

Optical Technologies

- CWDM – Coarse WDM
  - To be used in metropolitan networks
- DWDM – Dense WDM
  - Used in long hall networks

CWDM

- Characteristics
  - Span: about 100 km, otherwise requires one amplifier per wavelength
  - Speed: 10 Gbps (theoretically) but 1Gbps widely deployed
  - Number of channels
    - 17-18 maximum (according to ITU-T G.694.2)
    - 8 widely used

- Usage:
  - Metropolitan Area Network
  - *Usually does not support SONET/SDH*

DWDM

- Characteristics
  - Span: NIL about 120 km
  - About 500 to 1000 km with EDFA (one per C band) without OEO regeneration;
  - Speed: 1, 10 and 40 Gbps, also STM 1 to STM 256 per lambda
  - Number of channels
    - Up to 160 - 190
    - Usually 32 or 40 upgradeable to 64 or 80
- Usage:
  - National networks
  - Regional networks

DWDM Systems

The basic DWDM system contains several main components:

1. A DWDM terminal multiplexer.

2. An intermediate optical terminal, or Optical Add-drop multiplexer.

3. A DWDM terminal demux.

4. Optical Supervisory Channel.

DWDM Systems

The basic DWDM system contains several main components:

- ***1. A DWDM terminal multiplexer.***
  - *The terminal mux actually contains one wavelength converting transponder for each wavelength signal it will carry. The wavelength converting transponders receive the input optical signal, convert that signal into the electrical domain, and retransmit the signal using a 1550-nm band laser.*
  - *The terminal mux also contains an optical multiplexer, which takes the various 1550-nm band signals and places them onto a single SMF-28 fiber.*
  - *The terminal mux may or may not also support a local EDFA for power amplification of the multiwavelength optical signal.*
- ***2. An intermediate optical terminal, or Optical Add-drop multiplexer.***
  - *This is a remote amplification site that amplifies the multiwavelength signal that may have traversed up to 140 km or more before reaching the remote site.*
  - *Optical diagnostics and telemetry are often extracted or inserted at such a site, to allow for sectionalization of any fiber breaks or signal impairments.*
  - *In more sophisticated systems (which are no longer point-to-point), several signals out of the multiwavelength signal may be removed and dropped locally.*

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DWDM Systems

The basic DWDM system contains several main components:

- ***3. A DWDM terminal demux.***
  - The terminal demux breaks the multiwavelength signal back into individual signals and outputs them on separate fibers for client-layer systems to detect.
  - Originally, this demultiplexing was performed entirely passively, except for some telemetry, as most SONET systems can receive 1550-nm signals.
  - However, in order to allow for transmission to remote client-layer systems (and to allow for digital domain signal integrity determination) such demultiplexed signals are usually sent to O/E/O output transponders prior to being relayed to their client-layer systems.
- ***4. Optical Supervisory Channel.***
  - This is an additional wavelength usually outside the EDFA amplification band (at 1510nm, 1620nnm, 1310nm or another proprietary wavelength).
  - The OSC carries information about the multiwavelength optical signal as well as remote conditions at the optical terminal or EDFA site.
  - It is also normally used for remote software upgrades and user (ie, network operator) Network Management information.