Duplexing and Multiple-Access Techniques

This lecture deals with various ways of sharing a channel between different directions of communication (duplexing) and between different users (multiple access).
After this lecture you should be able to: classify a communication system as full-duplex, half-duplex or simplex; show how time and frequency are divided up between directions and users for TDD, FDD, TDMA, and FDMA; classify multiple-access techniques according to their suitability for constant-rate and bursty data; explain the shape of the graph of the Aloha throughput versus offered load.

Duplexing

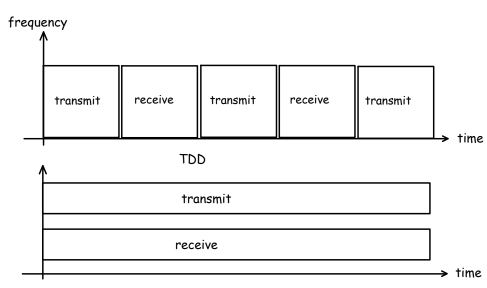
A full duplex communication system allows speech signals to flow in both directions simultaneously. If only one party can talk at a time this is called half duplex. If the system is only used in one direction it is called simplex.

Exercise 1: Is a phone call half-duplex, full-duplex or simplex? How about a radio broadcast? A typical police dispatch radio?

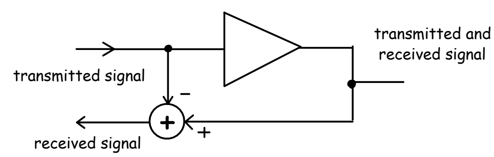
Full duplex can be implemented in three different ways:

FDD - Frequency Division Duplexing: the channel is split into two frequency ranges and one range is used in each direction. For example the upper half of the channel is used in one direction and the lower half in the other direction. The receivers use filters called "duplexers" that filter out the transmitted signal and allow through only the signal from the remote end. This is the older method. It is used by most cellular radio systems and older voiceband modems.

TDD - Time Division Duplexing: the two directions alternate in time, for example each side alternately transmits for 100ms and receives for 100ms. This technique is possible with digital systems that digitize short segments of speech and transmit it at a higher rate. This method is used by most



Active Duplexing - A circuit that can separate out the signals propagating in the two directions allows full duplex operation at the same time on the same frequency. This method has the advantage that the full bandwidth can be used in both directions simultaneously. This technique is only practical for wired systems because for wireless systems there is too large a difference in transmitted and received signal levels.



Circuits or devices that can do this include directional couplers and hybrids. Typically, separating the two directions also requires digital signal processing to accurately estimate and subtract the transmitted signal and its variously-delayed and attenuated echoes (the "active" part).

This method is used by higher-speed voiceband modems and 1 Gb/s Ethernet. VoIP systems also use active duplexing to cancel echoes that would otherwise be distracting.

Multiple Access

Often the channel must also be shared between different users. Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) are the two basic ways that the time and frequency resources can be shared between users.

Carrier-Sense Multiple Access (CSMA) is used by Local Area Network (LAN) devices to share a channel efficiently when the data is bursty.

FDMA

In FDMA each band is divided up into equal-bandwidth ranges called channels. Users use one channel for the duration of a call. Implementing FDMA requires only analog channelization filters and for this reason it was the earliest technique used to divide up the available bandwidth between users.

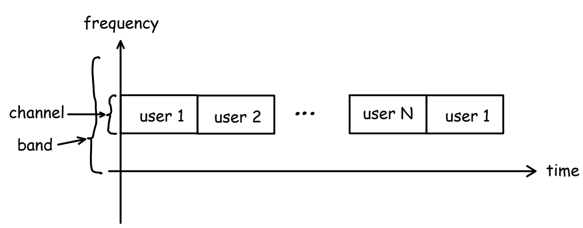
FDMA is used by all analog wireless systems. This includes many broadcast (radio and TV) and "legacy" two-way radio systems.

TDMA

In TDMA the band is divided up into channels, but the capacity of each channel is higher than is needed by one user. Data from/to different users is interleaved in time on the same channel.

TDMA can only be used with digital modulation. There is typically a master station (e.g. cellular base) that synchronizes transmissions from different users.

One advantage of TDMA is that filters are not needed to separate users and so the receiver can be simpler and less expensive.



In addition to guard bands between channels, when different users use different time slots a "guard time" must often be left between slots to allow for propagation delays and transmitter timing uncertainty.

TDMA is used by many multi-user wireless systems such as some second-generation cellular systems (GSM) and many digital broadcast systems.

Exercise 2: GSM cellular systems use FDD and TDMA. Each user gets to transmits 114 bits in one of eight "slots" per frame and each frame lasts is 4.615 ms long. What is the average data rate for each user? GSM channels are spaced every 200 kHz. An operator has one 5 MHz frequency allocation for each direction ("paired" spectrum). How many channels can this operator use?

CSMA

CSMA (Carrier-Sense Multiple Access) is the multiple access technique most commonly used for data communication because it provides the most efficient sharing of a channel among many users that need bursty (infrequent) access to a channel.

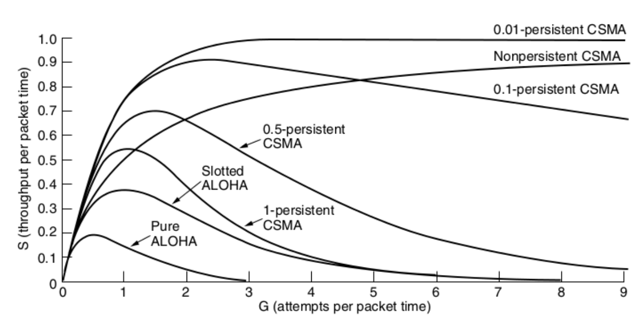
The simplest type of CSMA is known as Aloha. Users transmit a frame as soon as it is available. If the frame is not acknowledged by the destination then the sending station waits a random time and retransmits the frame.

The problem with Aloha is that two users may decide to transmit at the same time thus causing a "collision" and requiring that both frames be retransmitted. This reduces throughput.

CSMA/CD (CSMA with collision detection) improves on Aloha by having stations listen to the channel so they wait until the channel is free (carrier sense) and if they detect a collision (collision detection) they stop transmitting. This increases efficiency and throughput. CSMA/CD is the multiple access technique used by the original Ethernet protocol although modern Ethernet systems avoid collisions by connecting each user to a central switch using separate point-to-point links.

Wireless systems can't detect collisions because of the large difference in transmitted and received signal strengths so they must use different variants of CSMA to improve throughput.

The following graph[1] shows the throughput of various CSMA variants as a function of offered load (the total amount of traffic presented to the network). At low offered load the traffic increases linearly because there are no collisions and nearly all frames transmitted are received. The slope of the curve decreases as the offered load increases and number of collisions also increases. For Aloha the throughput actually decreases as the offered load increase past a certain point because each frame requires a large number of retransmissions.



[1]From *Computer Networks* by Andrew Tanenbaum.