Multiplexing and Multiple-Access Techniques

This lecture deals with various ways of sharing channel resources (time and bandwidth) 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

Full-Duplex and Half-Duplex

If the same channel is used for communication in both directions at the same time it is called Full Duplex. If it is used in one direction at a time is called Half Duplex. If it is only ever used in one direction it is called Simplex.

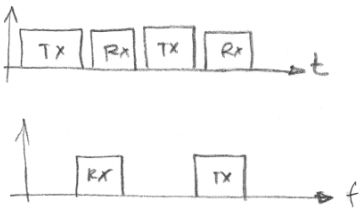
Exercise 1: Is a phone call half-duplex, full-duplex or simplex? How about a radio broadcast? A typical taxi dispatch radio?

TDD, FDD

Full Duplex can be implemented in three different ways:

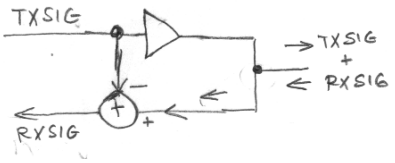
TDD - Time Division Duplexing: the two directions alternate in time, for example each end alternately transmits for 100ms and receives for 100ms.

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.



A third alternative, is to do full duplex at the same time on the same frequency. This requires circuits capable of separating out the signals propagating in the two directions. One type of circuit that can do this is called a directional coupler or hybrid. Separating the two directions can also be done completely (or partially) using digital techniques. This is sometimes called an active duplexer.

This method has the advantage that the full bandwidth can be used in both directions simultaneously. This technique is not practical for wireless systems because of the large differen in transmitted and received signal levels.



Multiple Access

Time and frequency (bandwidth) are resources that must be shared between users of a communication system. 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 Wireless Local Area Network (WLAN) devices to share a channel efficiently when the data is bursty.

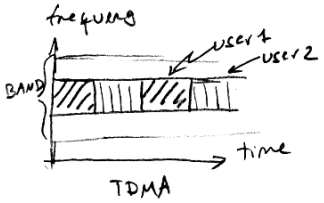
FDMA

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.

An interesting side-effect of TDMA is that is that the on/off frequency of the signal is often in the audible range. The transmitted signal energy can be demodulated by audio equipment such as telephones and audio amplifiers and results in audible "buzzing" interference.

Exercise 2: The GSM TDMA frame duration is approximately 5ms. What frequency would you expect to hear if the GSM RF signal was rectified and output by a speaker?

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.

CSMA

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

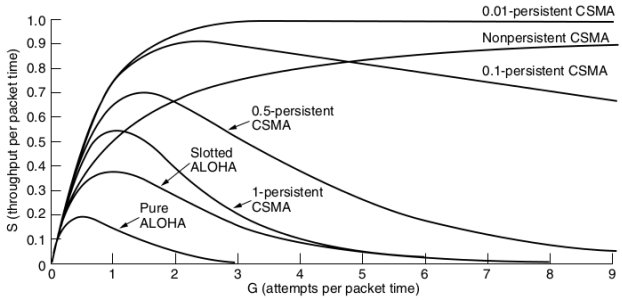
The simplest type of CSMA is known as Aloha. Users transmit a frame as soon as it is available. If the frame is not acknowledged by the destination the sending station waits a random time and retransmits the frame.

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). For Aloha the throughput actually decreases as the offered load increase past a certain point because of the high likelihood of collisions.



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