Multiple Access and Duplexing

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.

Code Division Multiple Access (CDMA) is a way of multiplexing different users' signals on the same carrier by multiplying different users' signals with different (often orthogonal) codes.

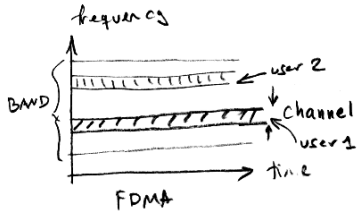
Carrier-Sense Multiple Access (CSMA) is used by Wireless Local Area Network (WLAN) devices to share a channel efficiently when the data is bursty.

Space Division Multiple Access (SDMA) is a way to use directional antennas to reduce interference and allow more users to share the same frequency/time/code resources.

Orthogonal Frequency Division Multiple Access (OFDMA) is a variant of FDMA where the carrier frequencies assigned to different users are orthogonal.

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.

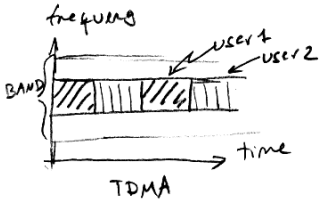


A certain amount of bandwidth (a "guard band") must be left between each channel to allow for the frequency roll-off characteristics of the receiver channelization filters, the excess bandwidth of the transmit signal and, in some cases, transmitter frequency uncertainty. This reduces the spectral efficiency of FDMA.

FDMA is used by all analog wireless systems. This includes many broadcast 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. It is sometimes possible to combine signals meant for different users in the same transmission (e.g. cellular forward channel).

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

One disadvantage of TDMA is that the instantaneous data rate increases compared to FDMA. This means the transmit power must also be higher to achieve the same range.

Another problem is that is that the on/off frequency of the signal is often in the audible range. The transmitted signal energy is often demodulated by audio equipment such as telephones and audio amplifiers and results in audible "buzzing" interference.

Exercise 1: The GSM TDMA frame duration is approximately 5ms. What frequency would you expect to hear if the GSM RF signal was rectified and output to 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. This reduces the spectral efficiency of TDMA.

Exercise 2: How much uncertainty is there in the round-trip propagation delay if the distance from a subscriber to a base station can be between 0 and 30km?

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

CSMA

CSMA is the multiple access technique commonly used for bursty data. The variant of CSMA used by 802.11 WLAN devices is called CSMA/CA (CA is "collision avoidance").

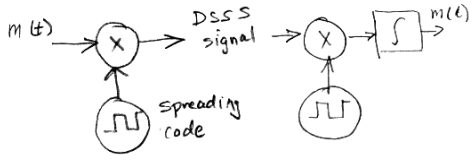
When using CSMA/CA a station that wants to transmit waits a randomly-chosen number of time slots after the end of a previous transmission and transmits only if no other station has started transmitting. This is efficient for bursty data but is not as efficient for isochronous (constant-rate) data because of the contention overhead and the random channel-access delay.

Many CSMA systems include additional features to improve performance such as the optional use of RTS/CTS reservation frames and exponential increases of the back-off delays when a collision (two simultaneous transmissions) is detected.

Exercise 3: In 802.11g/n the delay before transmitting is in multiples of 9μs. Assuming the average frame is 140 bytes long and is transmitted at 12 Mb/s, what fraction of the channel time is consumed by a contention delay of 4 slots between frames?

CDMA

Code Division Multiple Access is a method of multiplexing the data for different users by multiplying different users' signals by different and mutually orthogonal codes. The receiver can separate out users by multiplying by the spreading code of the desired user and integrating over the period over which the codes are orthogonal.



The codes use a higher data rate than the data signal and thus increase the bandwidth of the signal. For this reason they are known as "spreading codes". The individual code elements (typically bits) are called "chips," the ratio of the chip rate to the data rate is called the "spreading factor". However, because more users can be carried on one carrier the bandwidth efficiency is not necessarily lower than for TDMA or FDMA. In addition, the integrator averages out the noise and so the SNR is also not affected by the apparently larger bandwidth.

There are many different implementations of CDMA using many different spreading codes and chip rates. In some cases different codes are assigned to different users in other cases the same spreading code is used for all users but with different time offsets.

One advantage of CDMA is that the spreading and de-spreading hardware is typically only a code generator and an adder. This is inexpensive compared to the filters required for FDMA. The signal can also be transmitted continuously unlike TDMA.

One disadvantage of CDMA is that if the codes are not orthogonal (for example because of different propagation delays) then different users will interfere with each other.

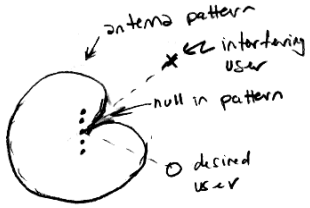
CDMA was used by some second-generation cellular systems (IS-95) and all third-generation cellular systems (wideband CDMA or "WCDMA").

Exercise 4: Two spreading codes, $s_1 = \{+\sqrt{2}, +\sqrt{2}\}$ and $s_2 = \{+\sqrt{2}, -\sqrt{2}\}$ are used to separate the signals from two users. Are these codes orthogonal over a period of two chips? Orthonormal? The first user transmits the value $+5$ and the second user transmit the value -2. Calculate the output of the individual spread signals, the composite CDMA signal and the outputs of the two correlators.

SDMA

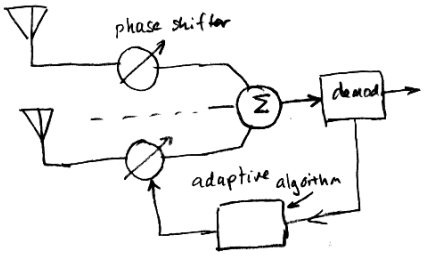
Space Division Multiple Access (SDMA) refers to using antenna patterns to re-use the same time-frequency resources at different locations. A simple example is a directional antenna that can separate signals received from users in different directions.

However, the term SDMA is typically reserved for antennas whose antenna patterns are formed by antenna arrays whose patterns are adjusted dynamically to optimize the SIR for a specific user.



A phased-array receive antenna consists of a number of conventional antennas whose outputs are phase-shifted and combined before demodulation.

By varying the phases (and sometimes the amplitudes) it is possible to reduce the signal received from interfering users and increase the signal from the desired user. Different patterns for different users can be created from the same set of physical antennas.



Adaptive antenna arrays are sometimes called "smart antennas" or "phased arrays".

The same principle can also be applied to transmissions in order to minimize interference to receivers.

One of the challenges of adaptive arrays is estimating the phase of the channel between each transmit antenna and the various users.

OFDMA

OFDMA assigns different users to different groups of orthogonal "subcarriers" of an OFDM signal. This avoids the need for guard bands between users. The OFDM subcarriers can be efficiently separated by using an FFT.

Fourth-generation cellular systems use use OFDMA and optionally SDMA.

Duplexing

In the case of two-way communication, time and frequency resources must also be shared between the two directions.

Full-Duplex and Half-Duplex

If a user can communicate in both directions at the same time the system is called Full Duplex. If the user can only use it in one direction at a time it is called Half Duplex. If it is only used in one direction it is called Simplex.

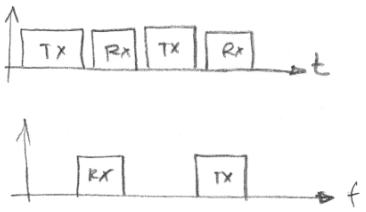
Exercise 5: Is a cellular phone call half-duplex, full-duplex or simplex? How about a radio broadcast? A typical taxi dispatch radio?

TDD, FDD

Full Duplex can be implemented in two different ways:

TDD - Time Division Duplexing: the two directions alternate in time, for example each end alternately transmits for 5ms and receives for 5ms.

FDD - Frequency Division Duplexing: the channel is split into two frequency ranges and one range is used in each direction.



Most, but not all, cellular systems use FDD. There is one frequency band for forward channels and one frequency band for reverse channels. Each the forward channel is paired with one reverse channel. The receivers use filters called "duplexers" that filter out the transmitted signal and allow through only the signal from the remote end so that a device can transmit and receive simultaneously. However, a full-duplex TDMA system (TDD or FDD) can assign a user different slots for forward and reverse transmissions thus avoiding the need for duplexers.

The advantage of using TDD for cellular systems is that different amounts of channel time can be allocated to the forward and reverse directions. However, TDD suffers from the same drawbacks associated with TDMA (higher peak powers, discontinuous transmit power, need for guard times).