Space Division Multiple Access [SDMA]

Medium access control(MAC)

The **Media Access Control** (**MAC**) data communication protocol sub-layer, also known as the Medium Access Control, is a sublayer of the Data Link Layer specified in the seven-layer OSI model (layer 2). The hardware that implements the MAC is referred to as a **Medium Access Controller**. The MAC sub-layer acts as an interface between the Logical Link Control (LLC) sublayer and the network's physical layer. The MAC layer emulates a full-duplex logical communication channel in a multi-point network. This channel may provide unicast, multicast orbroadcast communication service.

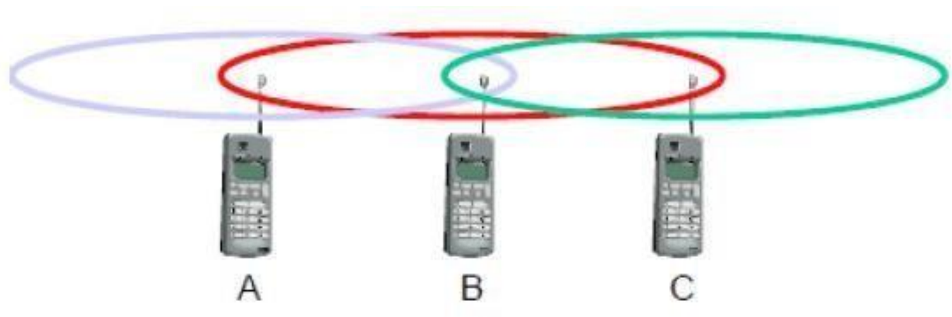
MOTIVATION FOR A SPECIALIZED MAC:

One of the most commonly used MAC schemes for wired networks is carrier sense multipleaccess with collision detection (CSMA/CD). In this scheme, a sender senses the medium (a wire or coaxial cable) to see if it is free. If the medium is busy, the sender waits until it is free. If the medium is free, the sender starts transmitting data and continues to listen into the medium. If the sender detects a collision while sending, it stops at once and sends a jamming signal. But this scheme doest work well with wireless networks. The problems are:

a) Signal strength decreases proportional to the square of the distance
b) The sender would apply CS and CD, but the collisions happen at the receiver
c) It might be a case that a sender cannot “hear” the collision, i.e., CD does not work
d) Furthermore, CS might not work, if for e.g., a terminal is “hidden”

Hidden and Exposed Terminals

Consider the scenario with three mobile phones as shown below. The transmission range of A reaches B, but not C (the detection range does not reach C either). The transmission range ofC reaches B, but not A. Finally, the transmission range of B reaches A and C, i.e., A cannot detectC and vice versa.



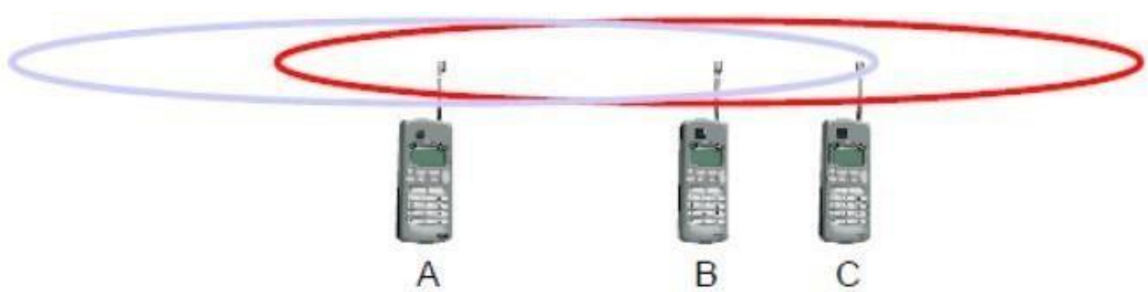
Hidden terminals

a) A sends to B, C cannot hear A
b) C wants to send to B, C senses a “free” medium (CS fails) and starts transmitting
c) Collision at B occurs, A cannot detect this collision (CD fails) and continues with itstransmission to B
d) A is “hidden” from C and vice versa

Exposed terminals

a) B sends to A, C wants to send to another terminal (not A or B) outside the range
b) C senses the carrier and detects that the carrier is busy.
c) C postpones its transmission until it detects the medium as being idle again but A is outsideradio range of C, waiting is **not** necessary
d) C is “exposed” to B

Hidden terminals cause collisions, where as Exposed terminals causes unnecessary delay.



Near and far terminals

Consider the situation shown below. A and B are both sending with the same transmission power.

a) Signal strength decreases proportional to the square of the distance
b) So, B's signal drowns out A's signal making C unable to receive A's transmission
c) If C is an arbiter for sending rights, B drown out A's signal on the physical layer makingC unable to hear out A

The **near/far effect** is a severe problem of wireless networks using CDM. All signals should arrive at the receiver with more or less the same strength for which Precise power control is to be implemented.

Space Division Multiple Access [SDMA]:

- **Space Division Multiple Access (SDMA)** is used for allocating a separated space to users in wireless networks.
- A typical application involves assigning an **optimal base station to a mobile phone user**. The mobile phone may receive several base stations with different quality.
- A MAC algorithm could **now decide which base station is best**, taking into account which frequencies (FDM), time slots (TDM) or code (CDM) are still available.
- The basis for the SDMA algorithm is **formed by cells and sectorized antennas** which constitute the infrastructure implementing **space division multiplexing (SDM).**
- SDM has the unique advantage of not requiring any multiplexing equipment.
- **It is usually combined with other multiplexing techniques** tobetter utilize the individual physical channels.*Space division multiple access* (SDMA) controls the radiated energy for each user in space. It can be seen from Figure 8 that SDMA serves different users by using spot beam antennas. Thesedifferent areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA system) or different frequencies (in an FDMA system). Sectorized antennas may be thought of as a primitive application of SDMA. In the future, adaptive antennas will likely be used to simultaneously steer energy in the direction of many users at once and appear to be best suited for TDMA and CDMA base station architectures.

The reverse link presents the most difficulty in cellular systems for several reasons.

First, the base station has complete control over the power of all the transmitted signals on the forwardlink. However, because of different radio propagation paths between each user and the base station, the transmitted power from each subscriber unit must be dynamically controlled to prevent any single user from driving up the interference level for all other users. Second, transmit power is limited by battery consumption at the subscriber unit, therefore there are limitson the degree to which power may be controlled on the reverse link. If the base station antenna ismade to spatially filter each desired user so that more energy is detected from each subscriber, then the reverse link for each user is improved and less power is required.

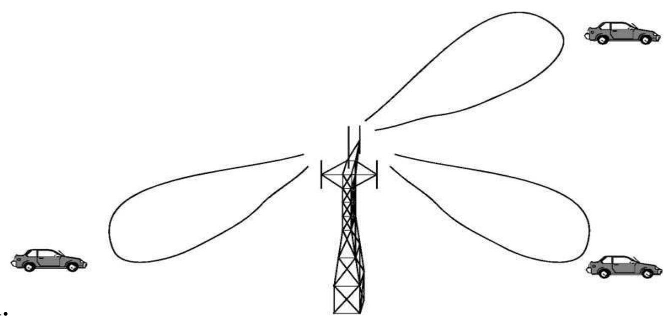


Figure 8 A spatially filtered base station antenna serving different users by using spot beams.

Adaptive antennas used at the base station (and eventually at the subscriber units) promise to mitigate some of the problems on the reverse link. In the limiting case of infinitesimal beam- width and infinitely fast tracking ability, adaptive antennas implement optimal SDMA, thereby providing a unique channel that is free from the interference of all other users in the cell. With SDMA, all users within the system would be able to communicate at the same time using the same channel. In addition, a perfect adaptive antenna system would be able to track individual multipath components for each user and combine them in an optimal manner to collect all of the available signal energy from each user. The perfect adaptive antenna system is not feasible since it requires infinitely large antennas.

OFDM (Orthogonal Frequency Division Multiplexing)

In modulations, information is mapped on to changes in frequency, phase or amplitude (or a combination of them) of a carrier signal. Multiplexing deals with allocation/accommodationof users in a given bandwidth (i.e. it deals with allocation of available resource). OFDM is a combination of modulation and multiplexing. In this technique, the given resource (bandwidth) is shared among individual modulated data sources. Normal modulation techniques (like AM, PM, FM, BPSK, QPSK, etc..,) are single carrier modulation techniques, in which the incoming information is modulated over a single carrier. OFDM is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques (BPSK, QPSK, QAM etc..,).

Why OFDM

OFDM is very effective for communication over channels with frequency selective fading (different frequency components of the signal experience different fading). It is very difficult to handle frequency selective fading in the receiver , in which case, the design of the receiver is hugely complex. Instead of trying to mitigate frequency selective fading as a whole (which occurs when a huge bandwidth is allocated for the data transmission over a frequency selective fading channel), OFDM mitigates the problem by converting the entire frequency selective fading channel into small flat fading channels (as seen by the individual subcarriers). Flat fading is easier to combat (compared to frequency selective fading) by employing simple error correction and equalization schemes.

Difference between FDM and OFDM:

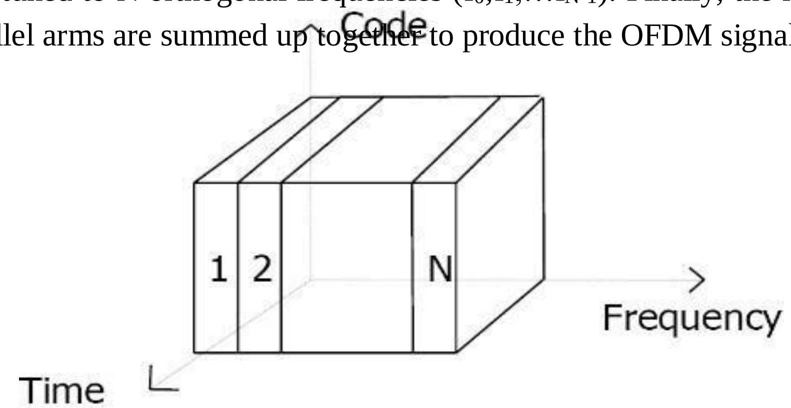
OFDM is a special case of FDM (Frequency Division Multiplexing). In FDM, the givenbandwidth is subdivided among a set of carriers. There is no relationship between the carrier frequencies in FDM. For example, consider that the given bandwidth has to be divided among 5 carriers (say a,b,c,d,e). There is no relationship between the subcarriers ;a,b,c,d and e can anything within the given bandwidth.If the carriers are harmonics, say (b=2a,c=3a,d=4a,d=5a , integral multiple of fundamental component a) then they become orthogonal. This is a special case of FDM, which is called OFDM (as implied by the word – ‘orthogonal’ in OFDM)

Designing OFDM Transmitter:

Consider that we want to send the following data bits using OFDM : D = {d0,d1,d2,…). The first thing that should be considered in designing the OFDM transmitter is the number of subcarriers required to send the given data. As a generic case, lets assume that we have N subcarriers. Each subcarriers are centered at frequencies that are orthogonal to each other (usually multiples of frequencies).

The second design parameter could be the modulation format that we wish to use. An OFDM signal can be constructed using anyone of the following digital modulation techniques namely BPSK, QPSK, QAM etc.., .The data (D) has to be first converted from serial stream into parallel stream depending on the number of sub-carriers (N). Since we assumed that there are N subcarriers allowed for the OFDM transmission, we name the subcarriers from 0 to N-1. Now,the Serial to Parallel converter takes the serial stream of input bits and outputs N parallel streams (indexed from 0 to N-1). These parallel streams are individually converted into the required digital modulation format (BPSK, QPSK, QAM etc..,). Lets call this output $S_0, S_1, .. S_N$. The conversion of parallel data (D) into the digitally modulated data (S) is usually achieved by a constellation mapper, which is essentially a look up table (LUT). Once the data bits are converted to required modulation format, they need to be superimposed on the required

orthogonal subcarriers for transmission. This is achieved by a series of N parallel sinusoidal oscillators tuned to N orthogonal frequencies ($f_0, f_1, \ldots f_{N-1}$). Finally, the resultant output from the N parallel arms are summed up together to produce the OFDM signal.



The following figure illustrates the basic concept of OFDM transmission (note: In orderto give a simple explanation to illustrate the underlying concept,the usual IFFT/FFT blocks that are used in actual OFDM system, are not used in the block diagram) .