Lecture 12

Multiple Access Techniques:

- Frequency Division Multiple Access (FDMA

- Time Division Multiple Access (TDMA)

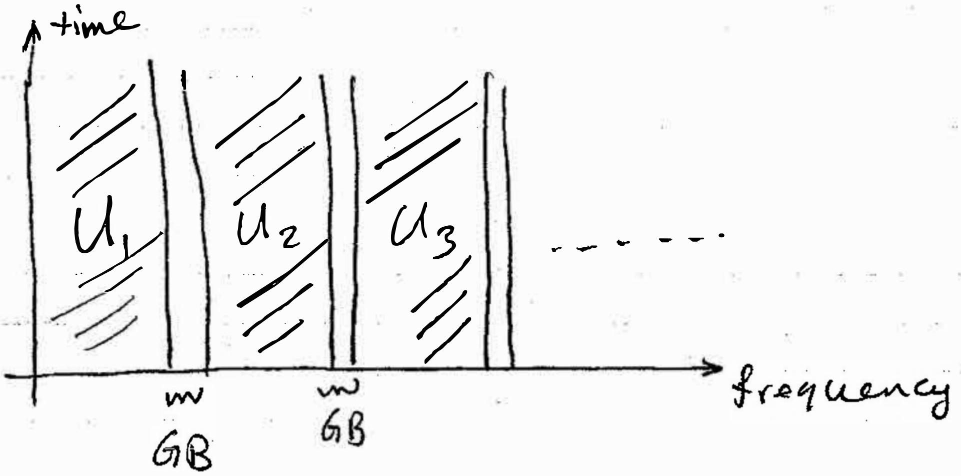
- Hybrid FDMA/TDMA such as Multi-Freque TDMA (MF-TDMA)

- Code Division Multiple Access (CDMA)

- Hybrid CDMA schemes such as Multi-Code CDMA (MC-CDMA) or (MF-CDMA).

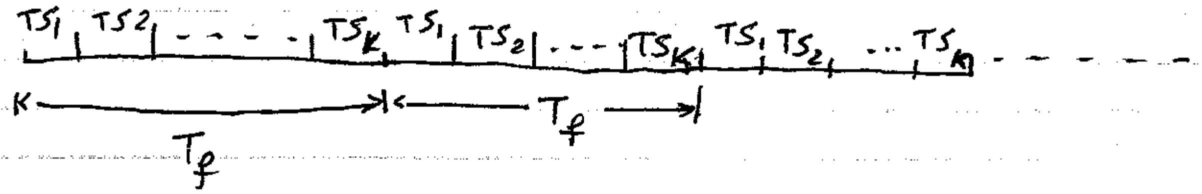
- Space Division Multiple Access (SDMA).

FDMA: in FDMA the available band of frequencies is divided between the users:



That is, a small portion of the bandwidth is assigned to each call for all the time (as long as the call is going on). The disadvantage of FDMA is lack of flexibility. A division of the bandwidth cannot be arbitrarily changed without changing the mixer and the filter at the transmitter and receiver. The advantage is that each user transmits at a rate which is its rate and is $\frac{1}{K}$ th of the total bandwidth where K is the number of the frequency slots. There is a Guard Band (GB) between the users so that they do not interfere with each other.

TDMA: in TDMA the time is divided into frames. These frames repeat R_f times per second where $R_f = \frac{1}{T_f}$ and T_f is the duration of a frame. Each frame is divided into K time slots and when establishing a call a user is assigned one time slot on the forward link and one on the return link (provided both links are TDMA (or TDM).



Each time-slot contains user data plus synchronization and signaling information. In addition part of the time slot will be allocated to Guard Time in order to avoid interference.

The advantage of TDMA is its flexibility. A user can be assigned one or more time slots depending on its requirement.

As an example consider a system with a total rate of 2 Mbps (two mega bits per second). Assume that the time duration of a frame is $T_f = 20$ ms. and the number of time slots in a frame is $K = 100$.

There are $20 \times 10^{-3} \times 2 \times 10^{6} = 40000$ bits in each frame. So, each time slot will be

$\frac{40000}{100} = 400$ bits in each time slot.

So, the effective rate of each user is

$$\frac{400}{20 \times 10^{-3}} = 20 \text{ kbps}$$

as expected from $\frac{2 \times 10^{6}}{100} = 20{,}000.$

However, the physical rate of transmission of each user is,

$$\frac{400}{(20 \times 10^{-3})/100} = 2 \text{ Mbps.}$$

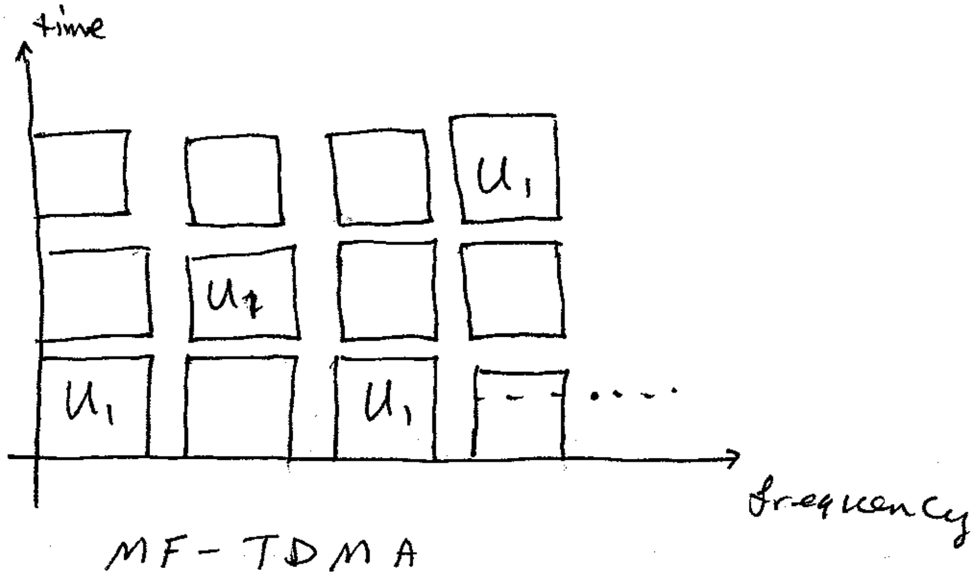
That is, each user holds its data (buffers it during 20 ms. and transmits it during its turn of $\frac{20}{100} = 200\ \mu s$.

Therefore, the peak power will increase by a factor of 100 (or 20 dB). This means that the required power amplifier and antenna should provide 100 times more EIRP.

But the reward for this disadvantage is complete flexibility as we can allocate $1, 2, \ldots, K$ time slots to a user making provision of any rate from 20 kbps to 2 Mbps possible.

Hybrid FDMA/TDMA

A compromise between FDMA and TDMA can be found by dividing the total bandwidth to K_1 frequency bands and have K_2 time slots in each frequency band. Then $K = K_1 * K_2$ users can be assigned. By doing this the rate (and consequently the power) is only increased by a factor of $K_2 < K$.



MF-TDMA

If the users are provided with frequency agility, a user can occupy different frequency band during different frames. This provides further flexibility.

CDMA: In CDMA each user is assigned a Code. The code is a pseudo random number. The Codes are chosen so that they have minimal Correlation (overlap). Each user, before modulation, multiplies its bit Stream by its assigned code. The receiver multiplies its received sequence by the same code and accumulate. Assuming that codes are uncorrelated enough, the receiver, peaks for the data from its desired party and annihilates the data from others.

Capacity of CDMA:

CDMA is an interference limited multiple access scheme. Therefore, its benefits can be realized by reducing the interference to the lowest possible level. Take a system with K users. Let's Concentrate on one of the users and consider the other K-1 users as interference. Assuming that perfect power control is in place, i.e., all users are received at the base station with the same power S. The signal to interference ratio is:

$$\frac{S}{I} = \frac{S}{(K-1)S} = \frac{1}{K-1}$$

If we divide the power, S, by the number of bits per second, i.e., the rate R, we get the energy per bit,

$$E_b = \frac{S}{R} \quad \text{or} \quad S = R E_b .$$

Also, if we denote the total occupied bandwidth by W, the interference spectral density will be:

$$I_0 = \frac{I}{W} = \frac{(K-1)S}{W} \quad \text{or} \quad I = I_0 W$$

Substituting these, we get

$$\frac{S}{I} = \frac{E_b R}{I_o W} = \frac{1}{K-1}$$

or

$$\frac{E_b}{I_o} = \frac{W}{R} \cdot \frac{1}{K-1}$$

The ratio of the total bandwidth to the rate of each user is called the Processing Gain (PG). We denote it by N.

$$N = \frac{W}{R}$$

So

$$\frac{E_b}{I_o} = \frac{N}{K-1}$$

Alternatively, we can find the maximum number of users for a given $\frac{E_b}{I_o}$ as

$$K = 1 + \frac{N}{\frac{E_b}{I_o}}$$

Assume that we use BPSK or QPSK for modulation of coded sequence. Then, ignoring the thermal noise, i.e., letting $\frac{E_b}{N_o} \to \infty$

the bit error probability is:

$$P_e = Q\left(\sqrt{\frac{2E_b}{I_o}}\right) = Q\left(\sqrt{2\frac{W}{R}\frac{1}{K-1}}\right)$$

or

$$P_e = Q\left(\sqrt{\frac{2N}{K-1}}\right)$$

Taking into consideration the fact that the interference is not synchronous, the tex derives

$$P_e = Q\left(\sqrt{\frac{3N}{K-1}}\right)$$

which is a little bit more optimistic. However, I believe that $Q\left(\sqrt{\frac{2N}{K-1}}\right)$ is closer to actual measurements.

When, we also consider thermal noise, we have,

$$\frac{E_b}{I_o+N_o} = \frac{1}{\frac{I_o}{E_b}+\frac{N_o}{E_b}} = \frac{1}{\frac{K-1}{N}+\frac{N_o}{E_b}}$$

and,

$$P_e = Q\left(\sqrt{\frac{2E_b}{I_o+N_o}}\right) = Q\left(\frac{1}{\sqrt{\frac{K-1}{2N}+\frac{N_o}{2E_b}}}\right)$$

Finding the capacity of Cellular CDMA:

Assume that we are given a target BER, say, P_e. We would like to know how many users the system can support.

First, we find the required SNR, i.e., $\frac{E_b}{I_0+N_0}$ from

$$P_e = Q\left(\sqrt{2\frac{E_b}{I_0+N_0}}\right) = Q\left(\frac{1}{\sqrt{\frac{K-1}{2N}+\frac{N_0}{2E_b}}}\right)$$

Then we use,

$$K = 1 + \frac{N}{E_b/I_0}$$

to find the number of users.

From the above formula, we observe that K is inversely proportional to the $\frac{E_b}{I_0}$. So, any technique or phenomenon reducing $\frac{E_b}{I_0}$ has direct effect on capacity improvement.

For example, assume that we use silence detection, i.e., we detect the silent periods during the call and turn off the transmission during silent periods. Then the number of users, will be

$$K = 1 + \frac{N}{\alpha \frac{E_b}{I_o}}$$

where α is the voice activity factor.

Another interference reduction technique is sectoring. In this case, the number of users per sector is

$$K_s = 1 + \frac{1}{\alpha} \frac{N}{E_b/I_o}$$

and the total number of users per cell is

$$K = k N_s = k + \frac{k}{\alpha} \frac{N}{E_b/I_o}$$

where k is the number of sectors.

Example: Consider a CDMA system with $W = 1.25$ MHz., $R = 9600$ bits/sec. and a minimum acceptable $\frac{E_b}{I_o} = 10$ dB.

Find the maximum number of users that can be supported,

a) If omnidirectional antenna is used at the base station without voice activity detection.

b) Three-sectors at base station and voice activity detection with $\alpha = 3/8$ is used.

(Ignore the thermal noise.)

a)

$$K = 1 + \frac{W}{R} \frac{1}{E_b/I_o} = 1 + \frac{1.25 \times 10^6}{9600} \times \frac{1}{10} = 14 \text{ users/cell}$$

b)

$$K_s = 1 + \frac{W}{R} \frac{1}{\alpha \frac{E_b}{I_o}} = 1 + \frac{1.25 \times 10^6}{9600} \times \frac{1}{\frac{3}{8} \times 10} = 35.7 \text{ users/sector}$$

$K = 3 \times 35.7 = 107$ users/cell