Lecture 4: CDMA (Code Division Multiple Access)

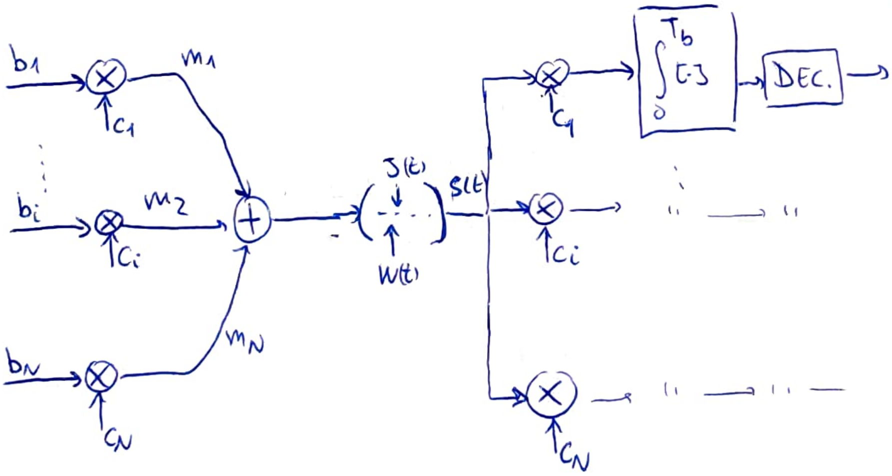
* The most important application related to DSSS
* Techniques to divide a channel
  - ↳ FDMA
    Each user use a certain BW different from the other
    → Freq. axis is divided among the users
    → Time slot is the same for every users
  - ↳ TDMA
    After sampling you give one time slot to one user, another time slot to another user...
    → Time slot is divided among the users
    → Any user is using all the frequencies

* Case of CDMA
  ↳ All the time and all the freqs. are used by the users. Users share the time and the freq. and all the signals are mixed
  ↳ Thanks to the code and orthogonality of the code we can distinguish between users.

Basic Idea

- Context: We are using DSSS, we also have many users ($c_1(t), c_2(t), c_3(t), \dots$) and assume that all codes are orthogonal to each other (set of orthogonal codes)
- Transmission: Each user transmits using its own code. $s(t)$ is the signal obtained when we add all the signals
- Reception: At the receiver the user i multiplies the received signal $s(t)$ by its own code $c_i(t)$
  Due to orthogonallity when I do the correlation at the receiver the contribution of an $c_k \neq c_i$ is zero.

$$\int s(t) \cdot c_1(t)\,dt = \int b_1(t) \cdot c_1^2(t)\,dt + 0 + 0 + 0$$



* The used codes should have:
  → Good Autocorrelation
  → Good Crosscorrelation; If it's low one signal will be very different from other so it can be easily splitted

Problem of CDMA system

* In the real situation the users are at different distances from the receiver, therefore the signals will arrive with a different delays.
* So, even if we start with orthogonal codes after the delay the orthogonallity is not guaranteed anymore. $\int c_1(t)c_2(t)dt = 0$ but $\int c_1(t)\, c_2(t-\tau)\, dt \neq 0$

* The integral $\int c_1(t)\, c_2(t-\tau)\, dt \longrightarrow$ It is the cross-correlation between c_1 and c_2
  ↳ Thus, it is important to have a good cross-correlation.

* The difficulty lies in guaranteeing orthogonality in the receiver

  ⇒ Good CDMA system:
  - Good cross-correlation property between the codes. A low cross-correlation reduces the inter-message interference
  - Good auto-correlation function (white noise like) to have
    - Good spread spectrum
    - Good multipath fading
    - Easier synchronization

Properties and Performance of CDMA

* Hypothesis to obtain results

1. Every carrier is received with the same power level (control strategy to guarantee it) ~ (Near-Far effect)
2. The central freq. of any carrier is the same
3. The phase of different carriers are random variables that are independent one with respect to the other
4. The decoded sequences are perfectly synchronized

* With those hypothesis ⇒ calculate P(E)

$$P_b(E) \doteq Q\left(\sqrt{\frac{E_b}{\frac{N_0}{2} + \frac{N_T-1}{G} E_b}}\right)$$

↓

Prob. of error bit per bit so transmitting 1 bit

- $N_T \rightarrow$ number of users

- For one user and only the white Noise ⇒ $N_T = 1$
  $\Rightarrow P_b(E) \doteq Q\left(\sqrt{\frac{E_b}{N_0/2}}\right)$
  ↳ classic. prob. error in binary antipolar mod

* Users transmit with the samer power so that's why $(N_T-1)\cdot E_b$ is the total power of the interferences But because we work with DSSS these interferences are reduced by the processing gain G
* The contribution of the noise $N_0/2$ is very small compared with the contribution of interferences.

$$P_b(E) \simeq Q\left(\sqrt{\frac{G}{N_T-1}}\right)$$

↳ The prob. of error is mainly dependent on processing gain G and the number of users $N_T - 1$

* To reduce P(E) { ⇒ Increase G or ⇒ Reduce users N_T }

* I want a lot of users N_T ⇒ I need big G ⇒ BW increases $B_T \simeq G \cdot \frac{1}{T_b}$

Rake Receiver

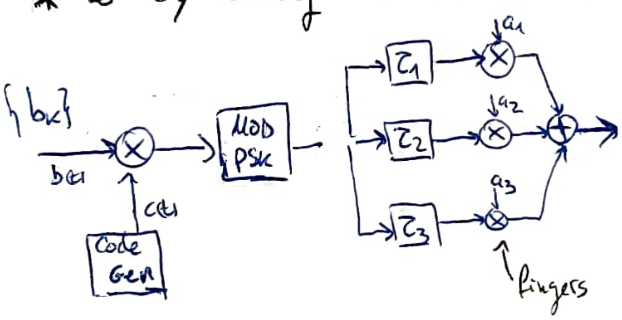
* We have considered multipath fading a problem. But we can consider also that instead of receiving one signal we are receiving multiple versions of the same signal. So, it is not good in principle to discard the multipath, some useful information might be lost

* The various contributions are named: Fingers
  ↳ We use the important ones

* To use as much as possible the information ⇒ Rake Receiver
  ↳ It was possible thank to the property of DSSS

a) Basic Idea

* If I am able to stimate the different time delays and also each attenuation, I can try to realign the different signals.
* So by adding the contributions ⇒ the power of the signal will be increased
  ↳ Remember: Adding just two signals (double the amplitude) the power is multiplied by 4
  ↳ Adding two independent different noise the power of the resulting noise is twice
  ⇒ $4P_{signal} + 2N_{oise}$ ⇒ SNR → 2
  ↳ if I have 3 signals ⇒ SNR → 3



* If I am able to stimate τ_i and a_i is a good improvement (extension of optimal receiver)
  This stimation is not simple but using DSSS and because the autocorrelation of the signal is similar to a noise (quasi impulsive) ⇒ The stimation is possible.

* In the real situation only a few fingers are taken into account

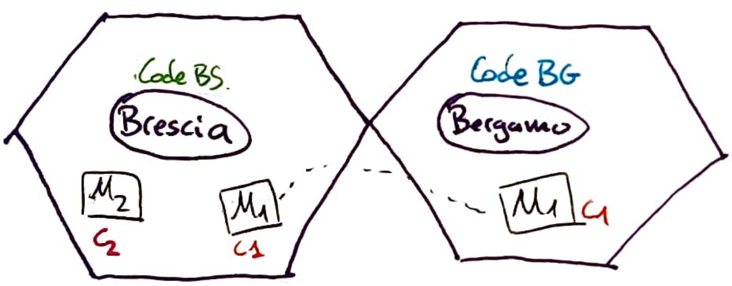
UMTS : Universal Mobile Telephone System

* It is a cell system, the area is divided in different cells. One principal station and the mobiles

* If one mobile is very close to the boundary between two cells, it will transmit the signal for both stations. To avoid confusion the codes used in the two stations should be different.

* The problem: It is difficult to create a lot of different codes

* The solution: Instead of using one single code I will use two different codes.
  - ↳ Channelization code: Is used intra-cell → the same in different cells
  - ↳ Scrambeling code: Is used inter-cell → Only for one cell.



•) Block Diagram