TDMA, FDMA, and CDMA

Telecomunicazioni

Undergraduate course in Electrical Engineering

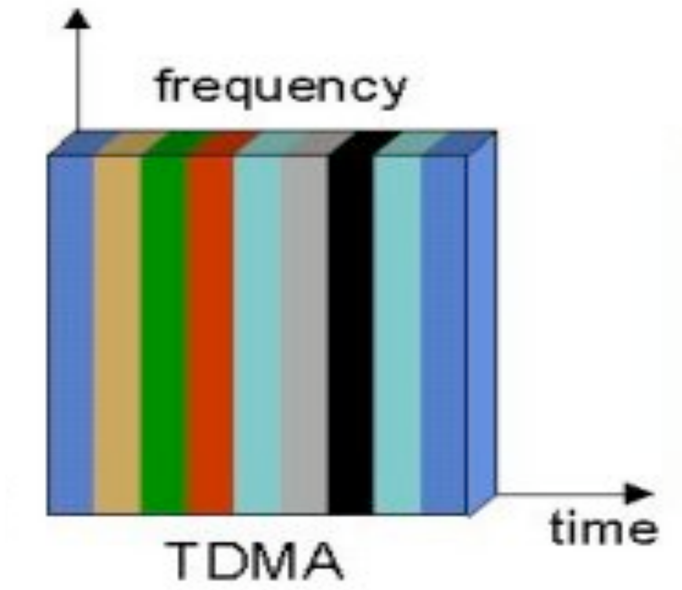
University of Rome La Sapienza

Rome, Italy

2007-2008

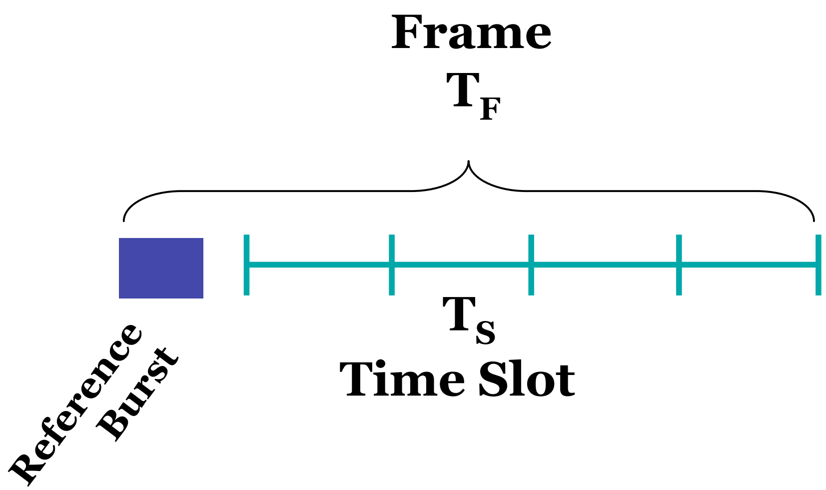
Time Division Multiple Access (TDMA)

- Each user is allowed to transmit only within specified time intervals (Time Slots). Different users transmit in differents Time Slots.
- When users transmit, they occupy the whole frequency bandwidth (separation among users is performed in the time domain).

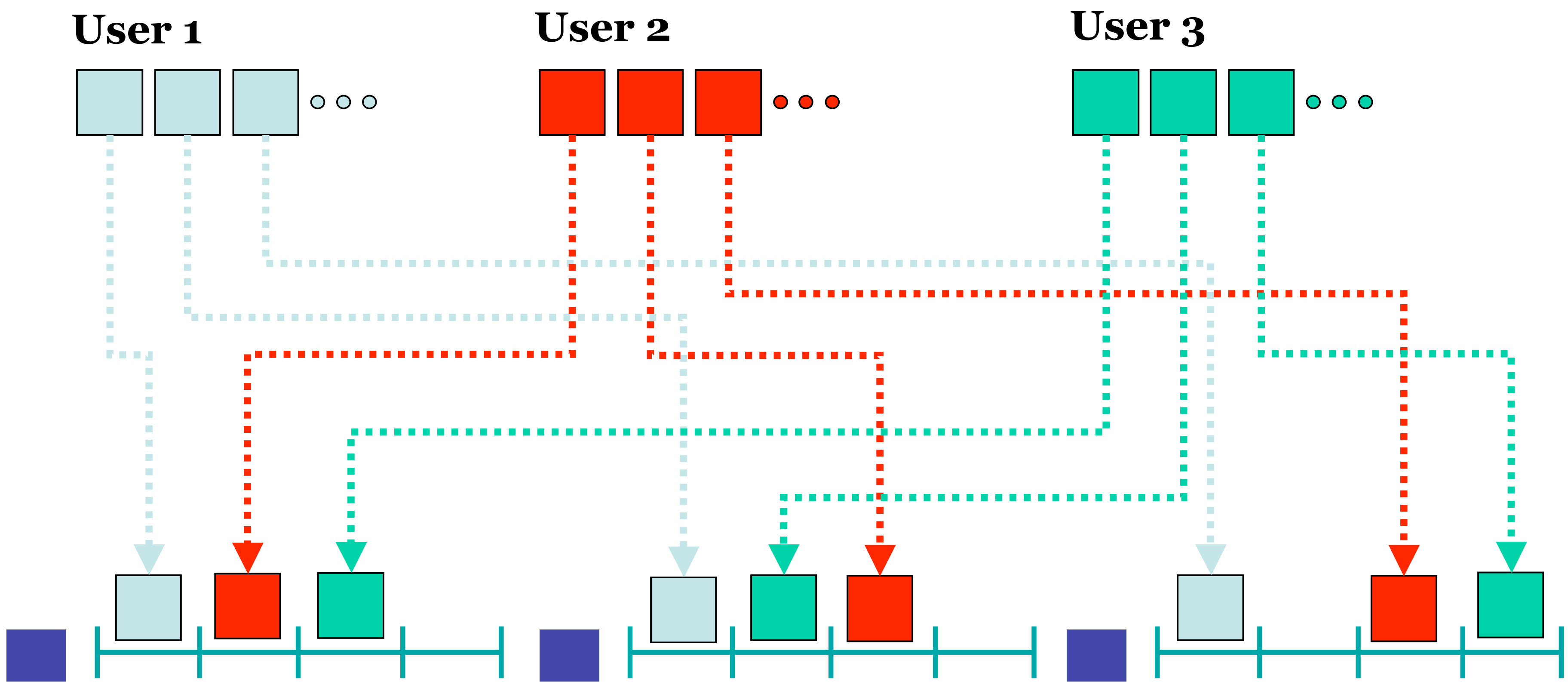


TDMA : Frame Structure

- TDMA requires a centralized control node, whose primary function is to transmit a periodic **reference burst** that defines a frame and forces a measure of synchronization of all the users.
- The frame so-defined is divided into time slots, and each user is assigned a Time Slot in which to transmit its information.

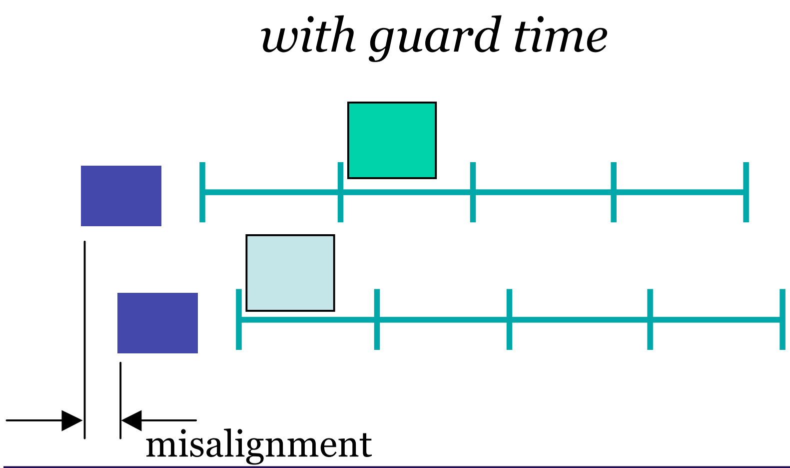


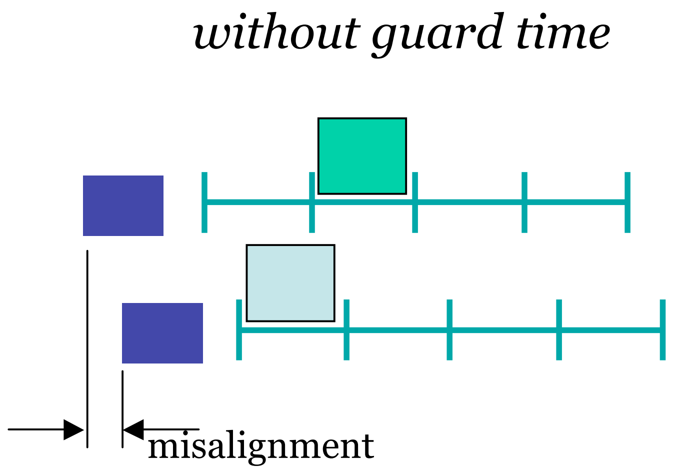
TDMA : Frame Structure



TDMA : guard times

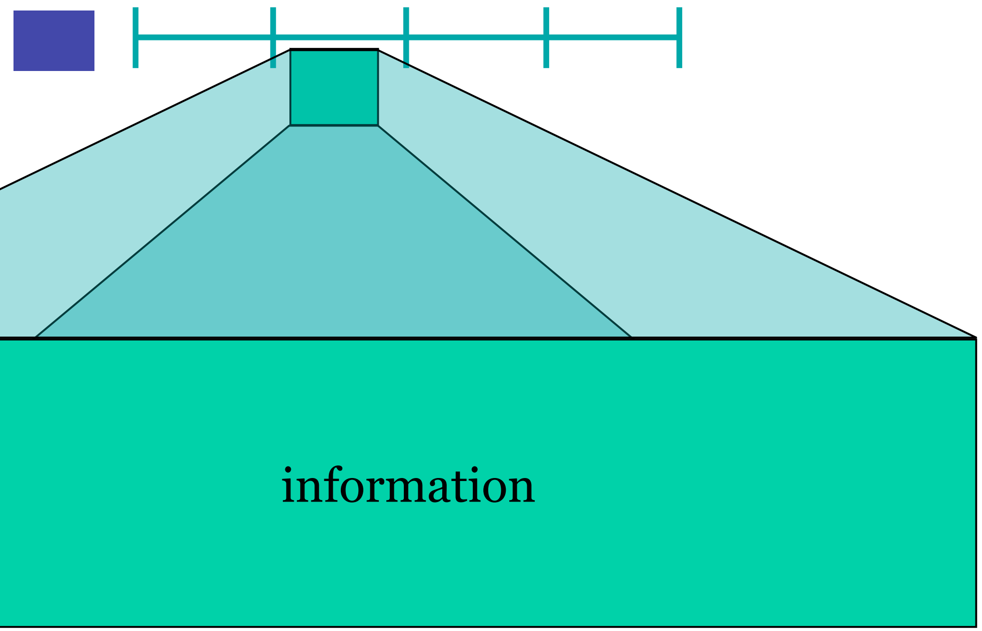
- Since there are significant delays between users, each user receives the reference burst with a different phase, and its traffic burst is transmitted with a correspondingly different phase within the time slot.
- There is therefore a need for **guard times** to take account of this uncertainty.
- Each Time Slot is therefore longer than the period needed for the actual traffic burst, thereby avoiding the overlap of traffic burst even in the presence of these propagation delays.



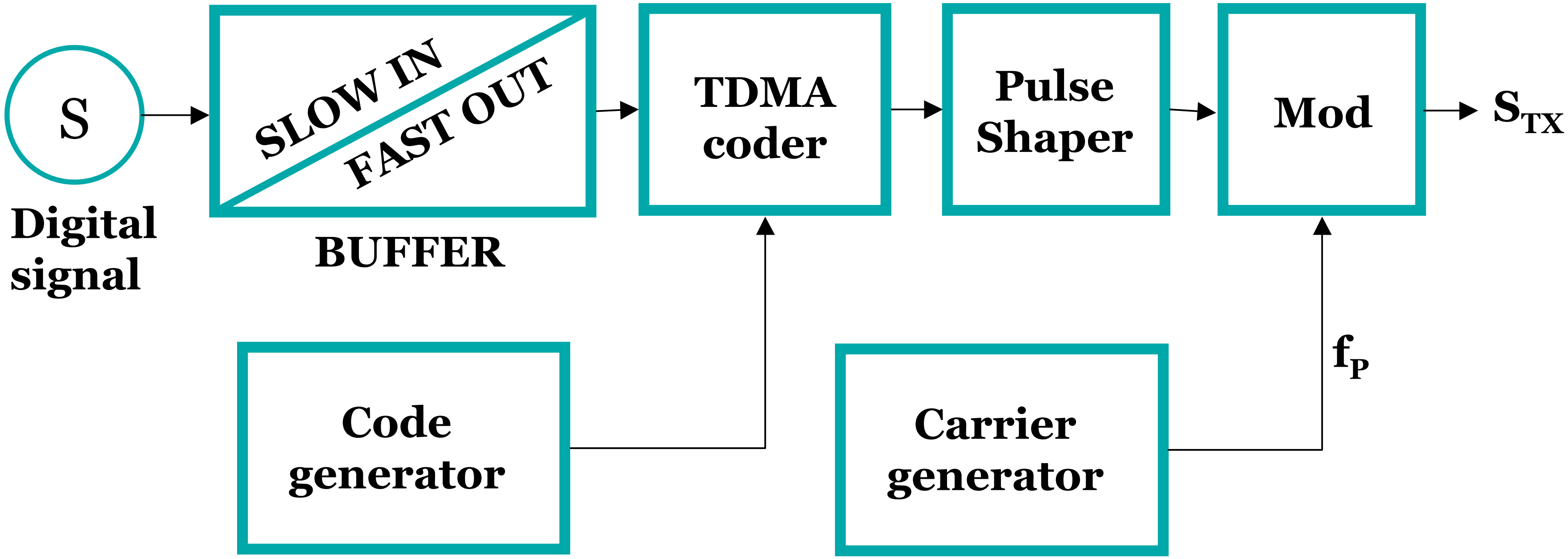


TDMA : preamble

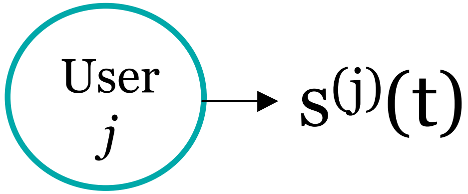
- Since each traffic burst is transmitted independently with an uncertain phase relaive to the reference burst, there is the need for a **preamble** at the beginning of each traffic burst.
- The preamble allows the receiver to acquire on top of the coarse synchronization provided by the reference burst a fine estimate of timing and carrier phase.



TDMA: reference transmitter scheme



TDMA: a case study



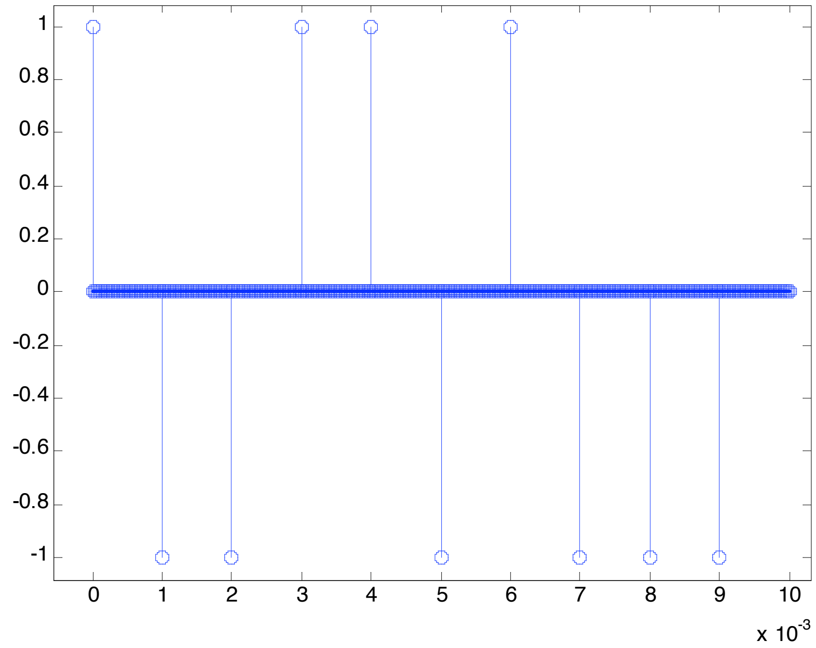
$$s^{(j)}(t) = \sum_k a_k^{(j)} \delta(t - kT)$$

Digital signal of user *j*

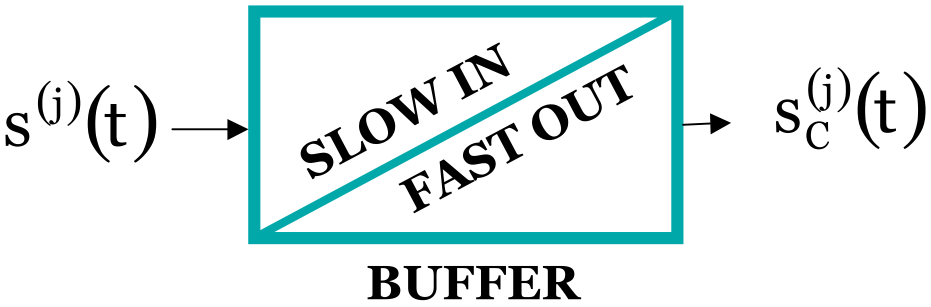
Sequence of equally spaced binary antipodal symbols

$a_k^{(j)}$: *k*-th binary antipodal symbol generated by user *j*

T : time period between symbols

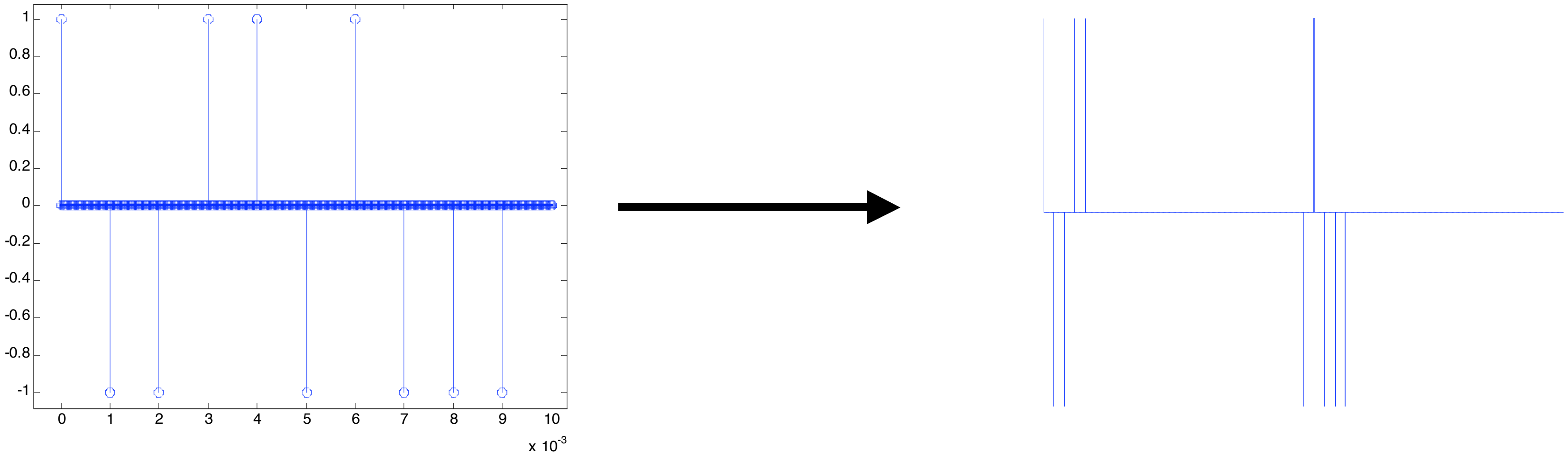


TDMA: a case study



Compressed signal

The symbols of the original signal are organized in groups of N_{bps} symbols. Each group is transmitted in a single Time Slot of duration T_S. Time Slots are organized in frames of duration T_F.

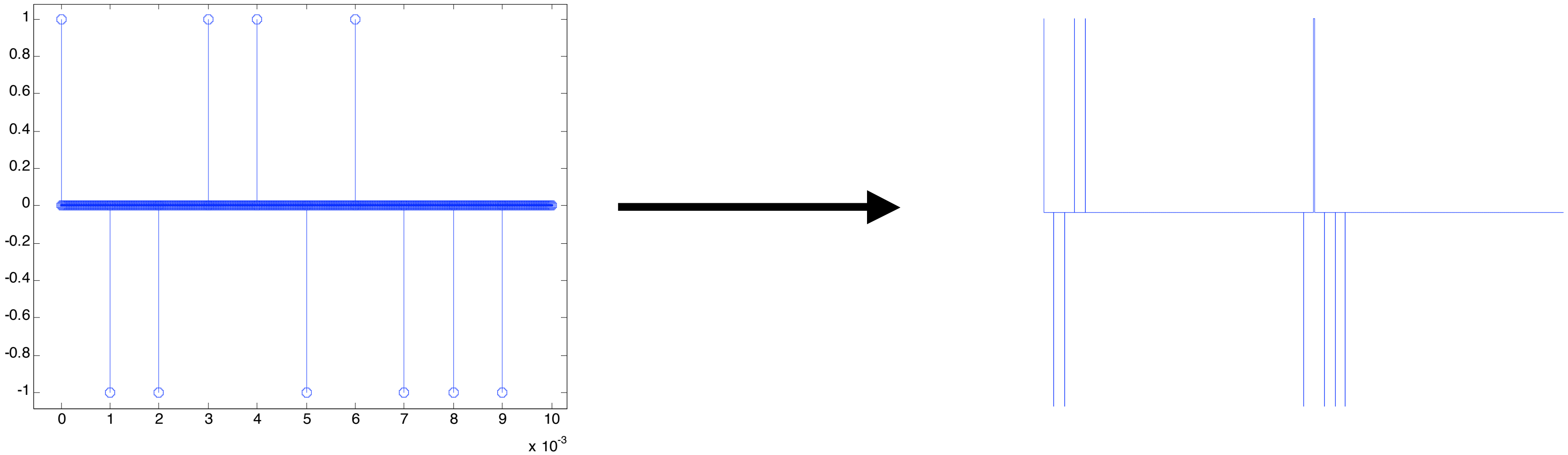


TDMA: a case study

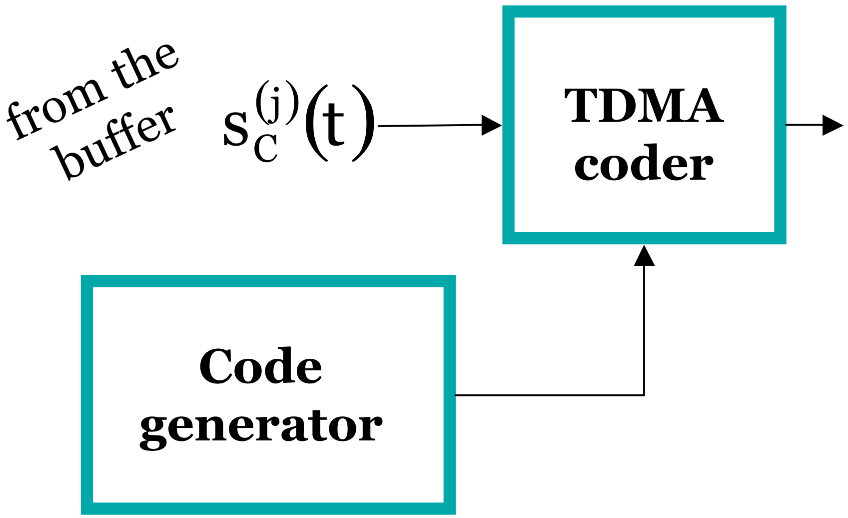
$$s^{(j)}(t) = \sum_k a_k^{(j)} \delta(t - kT)$$

$$s_C^{(j)}(t) = \sum_m \sum_{k=1}^{N_{bps}} a_{k+mN_{bps}}^{(j)} \delta(t - kT_C - mT_F)$$

T_C : time interval between symbols after compression



TDMA: a case study

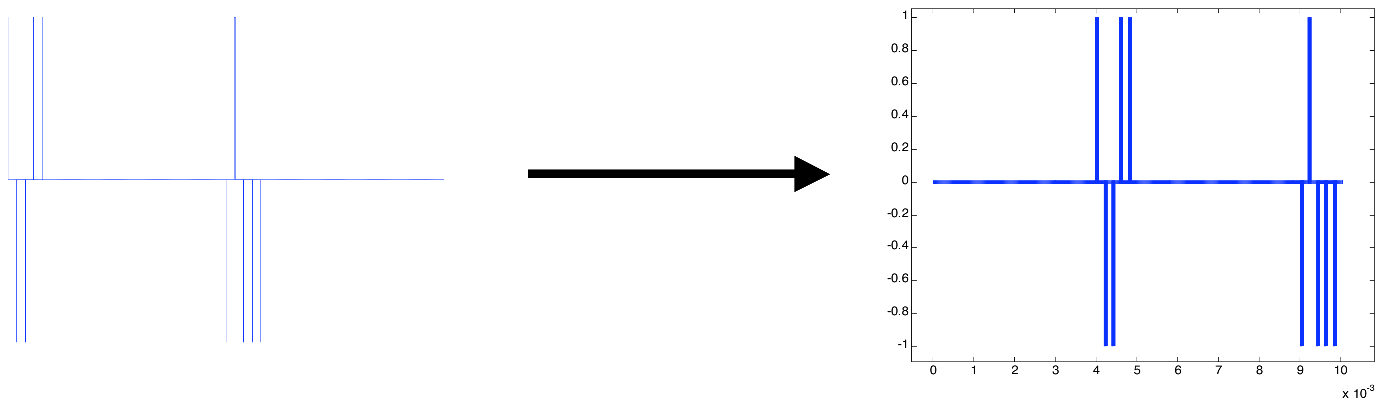


$s_{TDMA}^{(j)}(t)$

TDMA Coded Signal

The position in time of each group is modified according to the TDMA code, which is assigned to the user.

In other words, the TDMA code indicates which slot inside each frame must be occupied by the user.

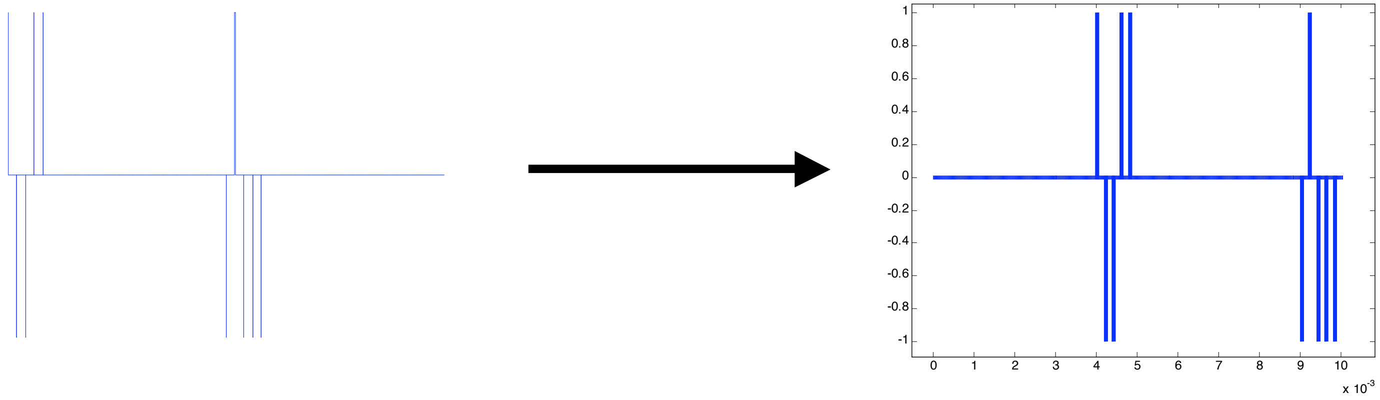


TDMA: a case study

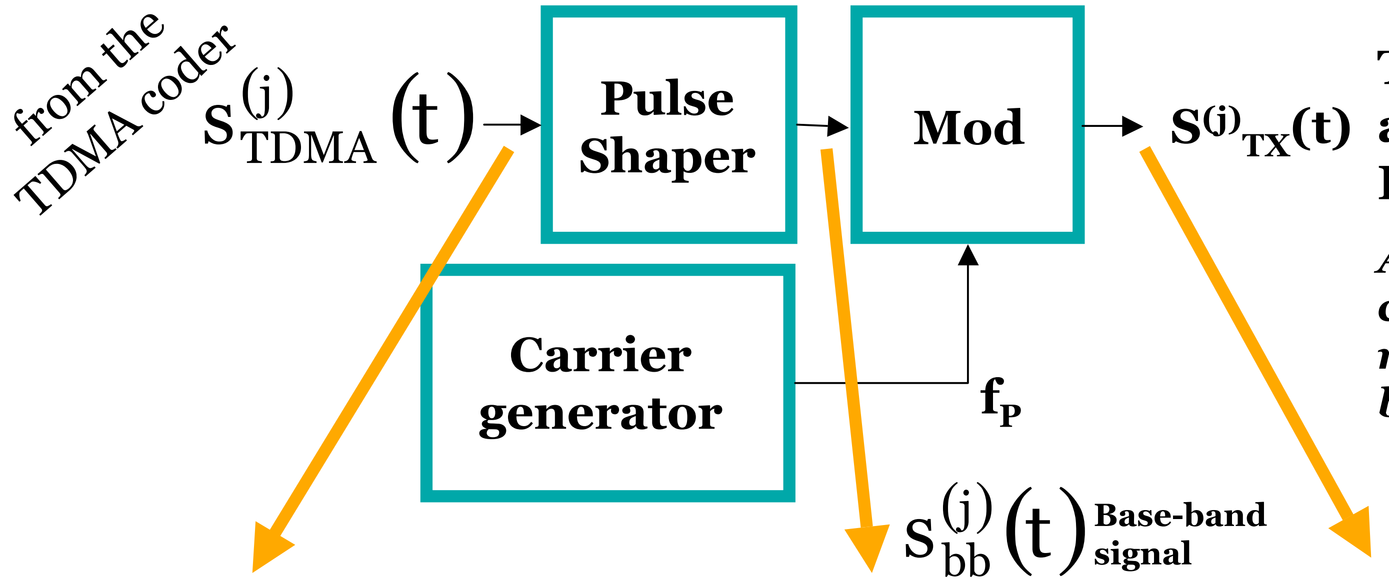
$$s_C^{(j)}(t) = \sum_m \sum_{k=1}^{N_{bps}} a_{k+mN_{bps}}^{(j)} \, \delta\left(t - kT_C - mT_F\right)$$

$$s_{TDMA}^{(j)}(t) = \sum_m \sum_{k=1}^{N_{bps}} a_{k+mN_{bps}}^{(j)} \, \delta\left(t - kT_C - c_m^{(j)} T_S - mT_F\right)$$

$c_m^{(j)}$: TDMA code assigned to user *j* for the *m*-th frame

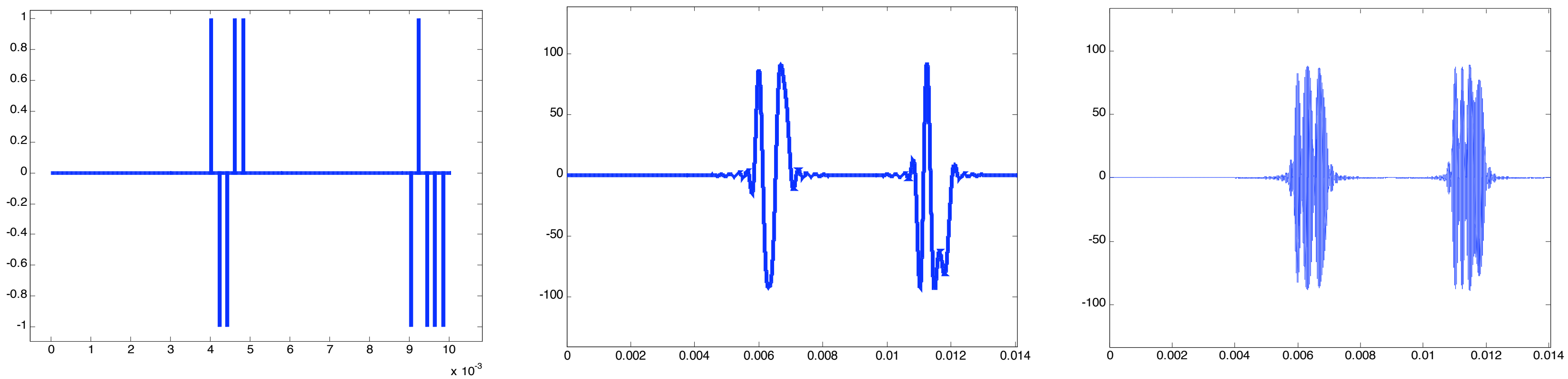


TDMA: a case study



Transmitted signal at Radio Frequencies

All users adopt the same carrier frequency f_p for modulating the base-band signal



TDMA: a case study

$$s_{TDMA}^{(j)}(t) = \sum_m \sum_{k=1}^{N_{bps}} a_{k+mN_{bps}}^{(j)} \delta\left(t - kT_C - c_m^{(j)} T_S - mT_F\right)$$

For the sake of simplifying the notation,
let us consider the simple case of BPSK
(in phase carrier modulation)

$$s_{TX}^{(j)}(t) = \sqrt{2P_{TX}} \left(s_{TDMA}^{(j)}(t) * g_o(t)\right) \sin\left(2\pi f_P t + \varphi^{(j)}\right)$$

$g_O(t)$: energy-normalized impulse response of the Pulse Shaper. It has unitary energy.

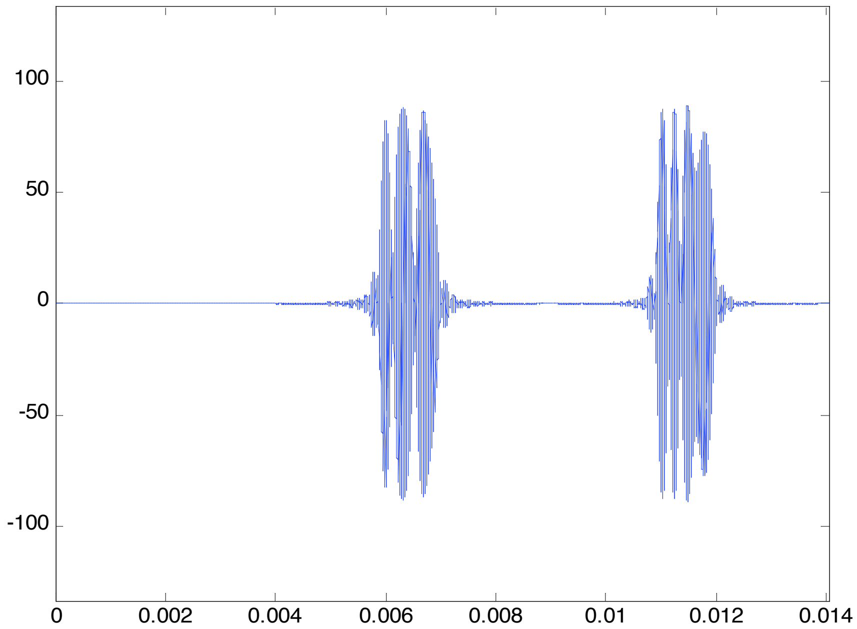
P_{TX} : transmitted power

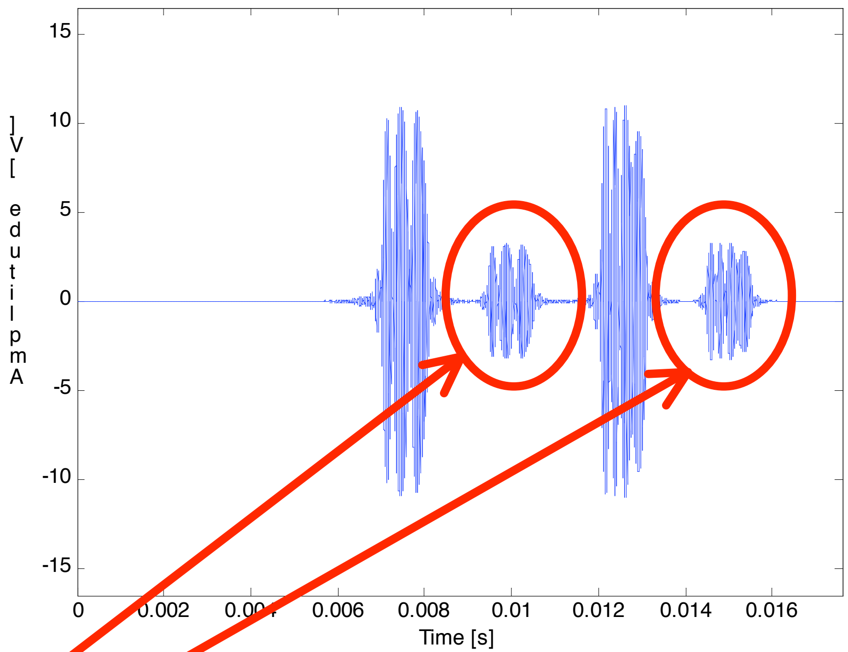
f_P : carrier frequency

$\varphi^{(j)}$: istantaneous phase

TDMA: a case study

$$s_{TX}^{(j)}(t) \qquad\qquad s_{RX}^{(j)}(t)$$





BEWARE!

At risk for multi user interference!

Received signal after propagation over a two-paths channel

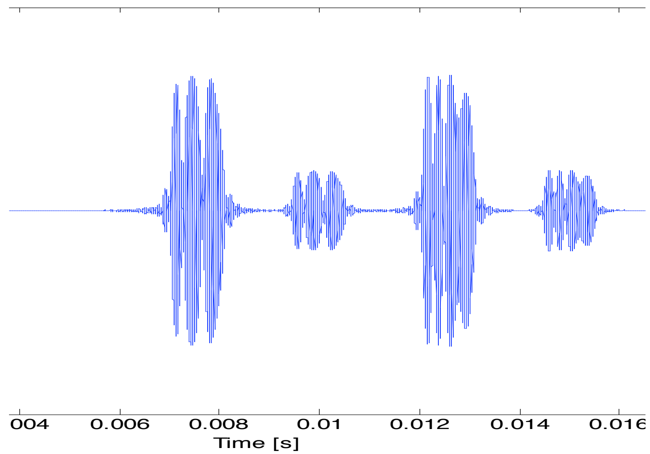
TDMA: a case study

Front-end filtering

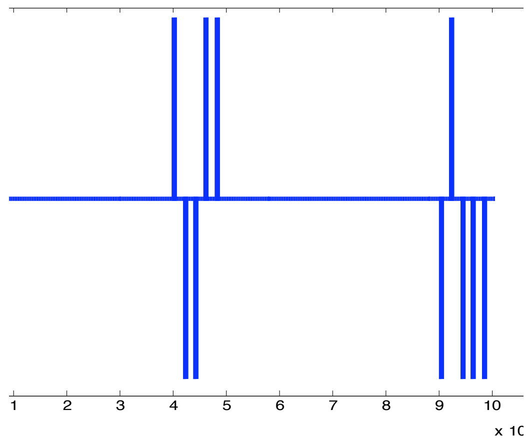
Demodulation

Sampling

Threshold detection



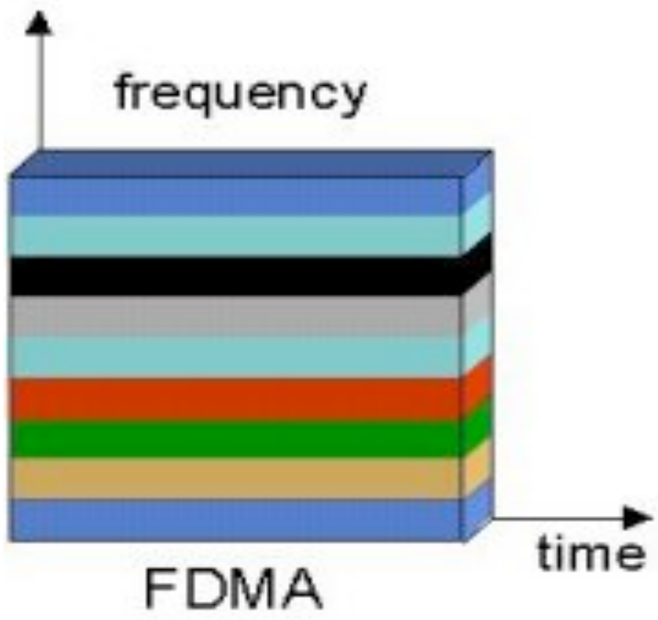
Received waveform

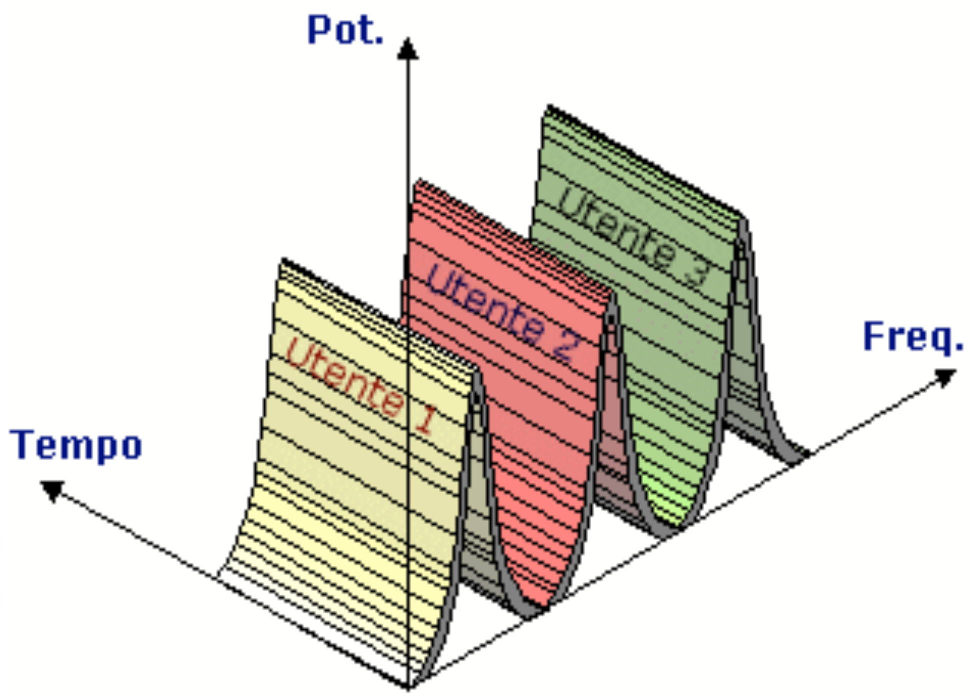


Received binary antipodal signal

Frequency Division Multiple Access (FDMA)

- Each user transmits with no limitations in time, but using only a portion of the whole available frequency bandwidth.
- Different users are separated in the frequency domain.

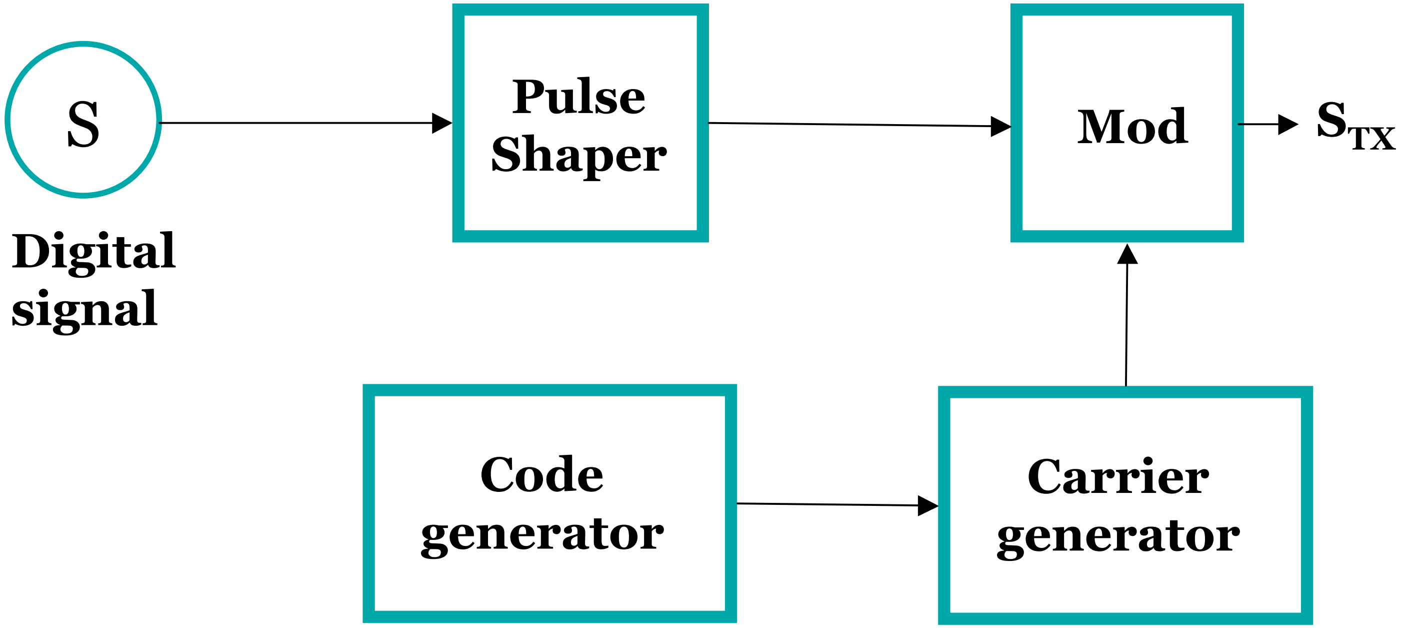




FDMA vs. TDMA

- Frequency division is very simple: all transmitters sharing the medium have output power spectra in non-overlapping bands.
  - Many of the problems experienced in TDMA due to different propagation delays are eliminated in FDMA.
- The major disadvantage of FDMA is the relatively expensive and complicated bandpass filters required.
  - TDMA is realized primarily with much cheaper logic functions.
- Another disadvantage of FDMA is the rather strict linearity requirement of the medium.

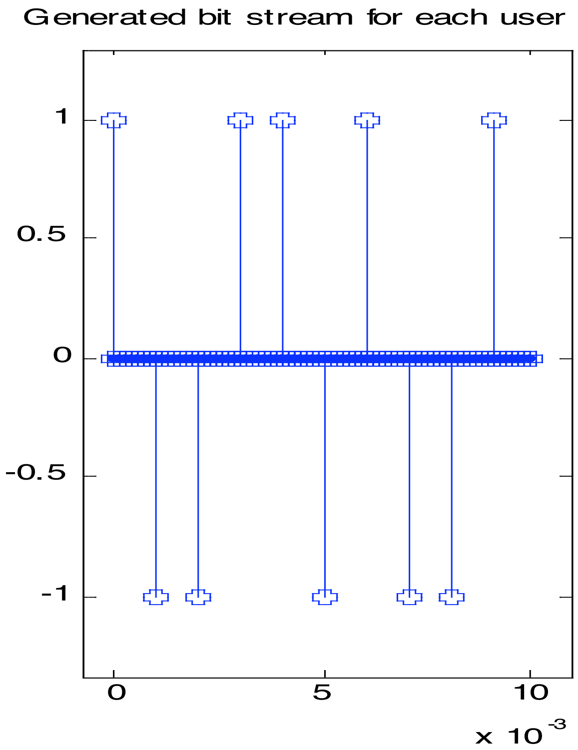
FDMA: reference scheme



FDMA: a case study

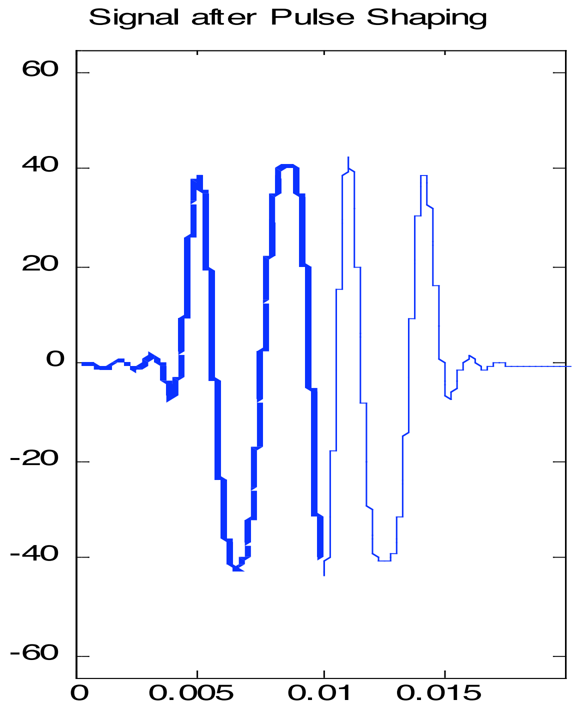
Digital binary signal

$$s^{(j)}(t)$$



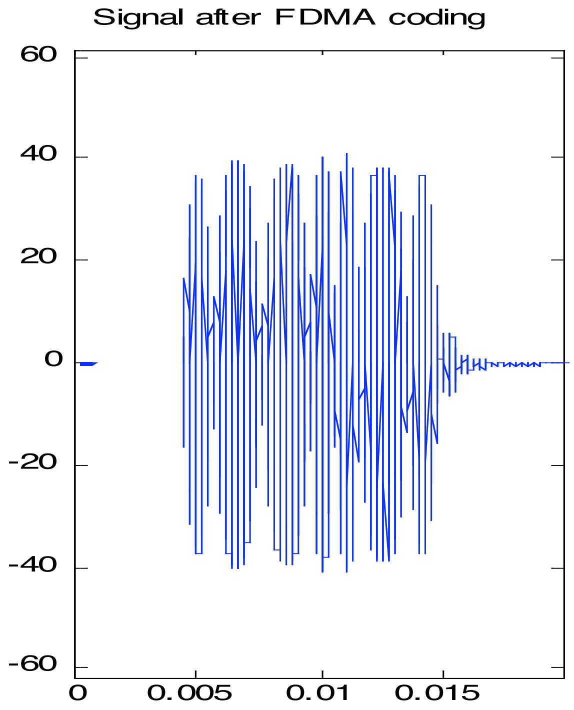
Base-band signal

$$s_{bb}^{(j)}(t)$$



FDMA-coded signal

$$s_{FDMA}^{(j)}(t)$$



FDMA: a case study

Digital binary signal

$$s^{(j)}(t) = \sum_k a_k^{(j)} \delta(t - kT)$$

Base-band signal

$$s_{bb}^{(j)}(t) = s^{(j)}(t) * g_o(t)$$

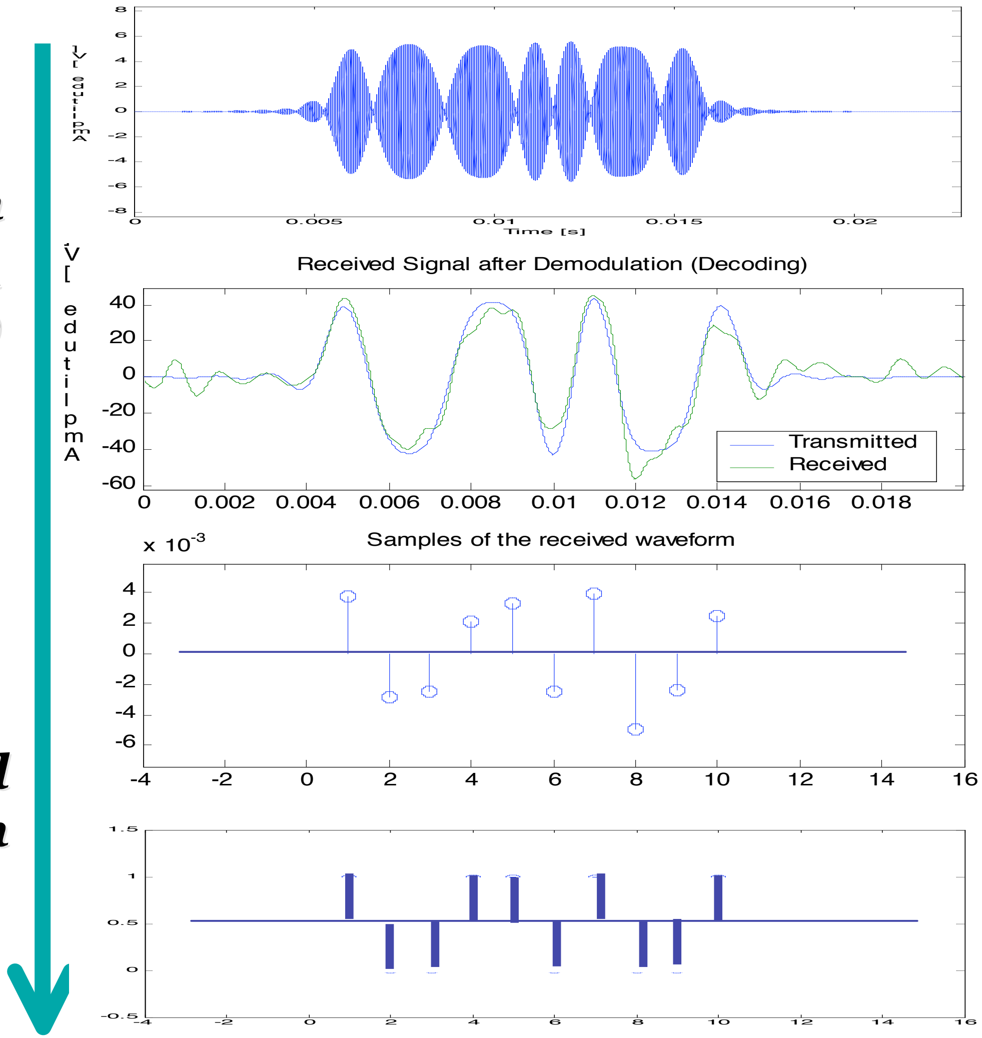
FDMA-coded signal

$$s_{FDMA}^{(j)}(t) = \sqrt{2P_{TX}}\, s_{bb}^{(j)}(t) \sin\left(2\pi\left(f_P + c^{(j)}(t)\Delta f\right)t + \varphi^{(j)}\right)$$

$S_{TX}^{(j)}(t)$

Δf : frequency spacing between adjacent users
$c^{(j)}$: FDMA code assigned to user j

FDMA: a case study



Propagation

Demodulation (Decoding)

Sampling

Threshold detection

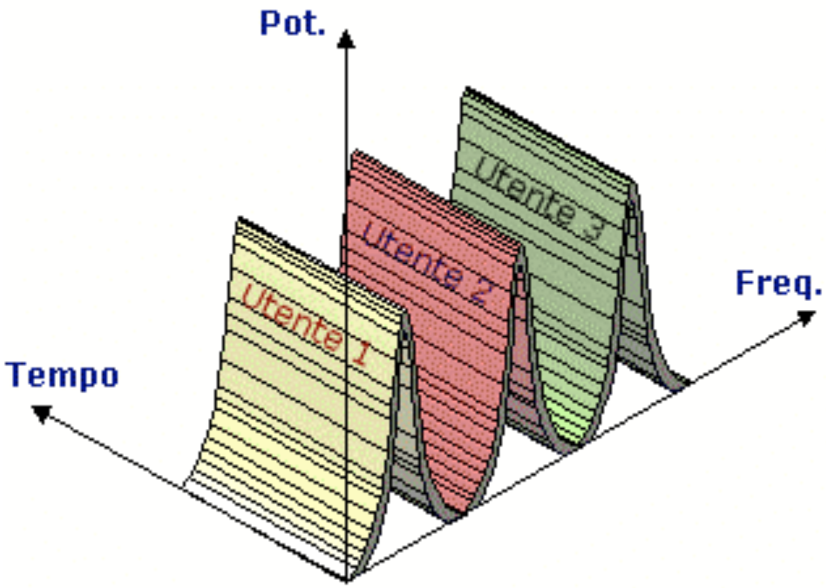
Transmitted signal at RF

Received base-band waveform

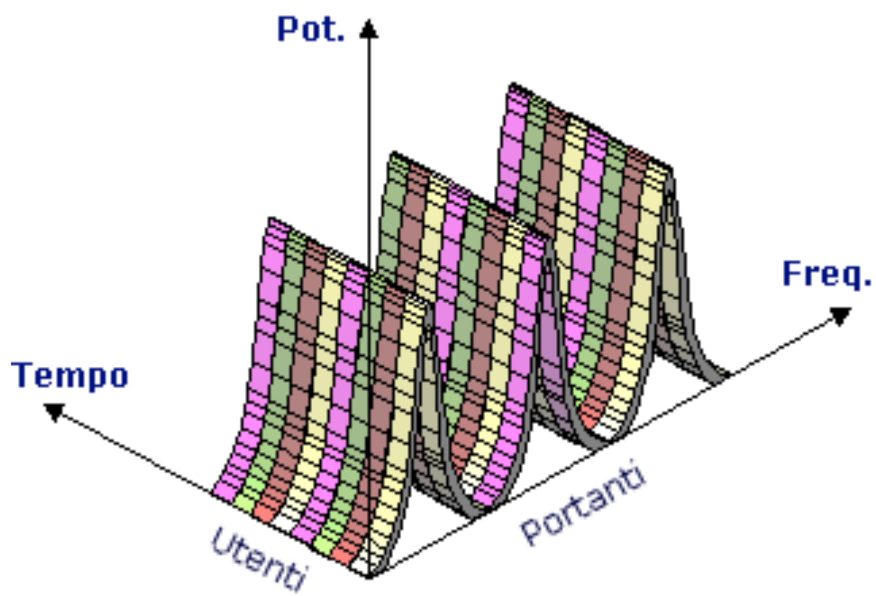
Samples at the receiver output

Received binary stream

TDMA + FDMA

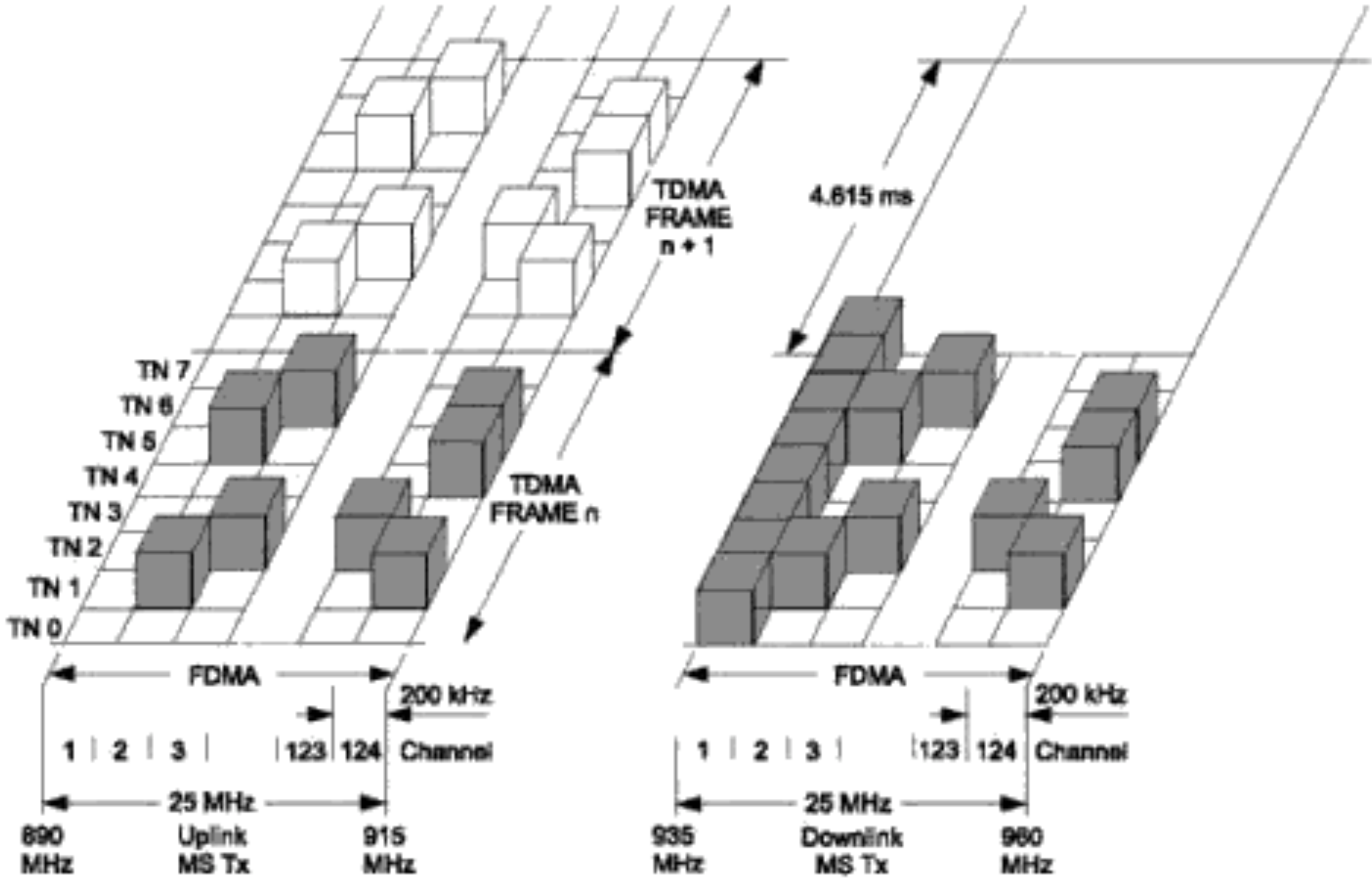


FDMA

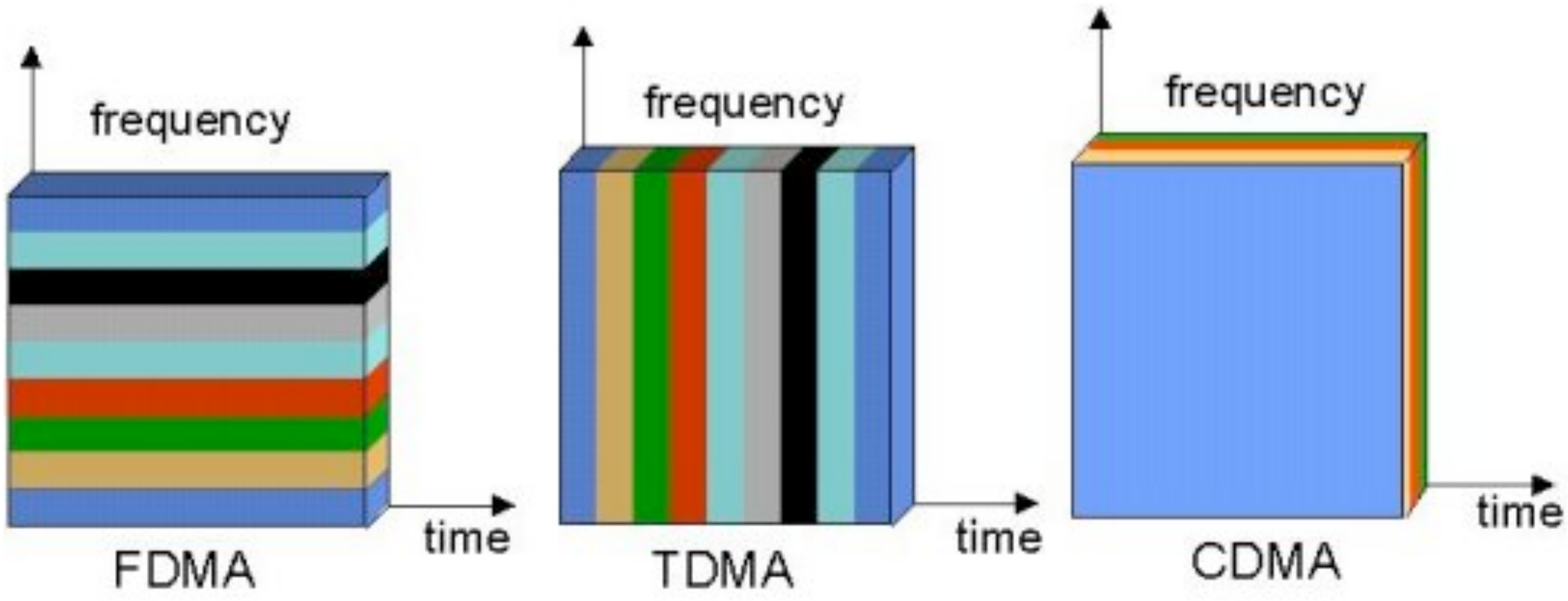


TDMA + FDMA

TDMA + FDMA in GSM900 standard



Code Division Multiple Access (CDMA)



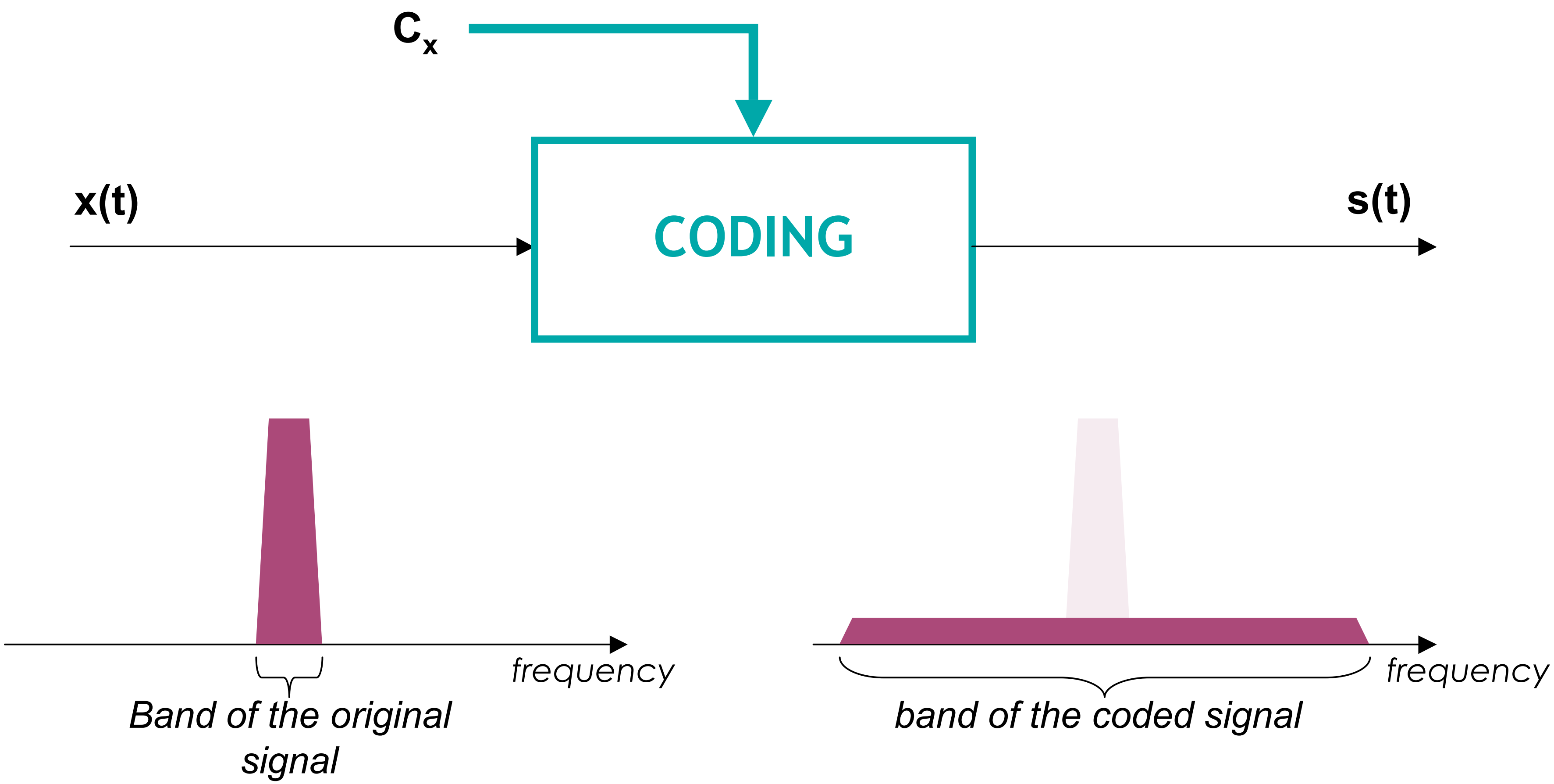
CDMA: basic principles

- In CDMA each user is assigned a unique code sequence (spreading code), which it uses to encode its data signal.
- The receiver, knowing the code sequence of the user, decodes the received signal and recovers the original data.
- The bandwidth of the coded data signal is chosen to be much larger than the bandwidth of the original data signal, that is, the encoding process enlarges (spreads) the spectrum of the data signal.
  - CDMA is based on spread-spectrum modulation.
- If multiple users transmit a spread-spectrum signal at the same time, the receiver will still be able to distinguish between users, provided that each user has a unique code that has a sufficiently low cross-correlation with the other codes.

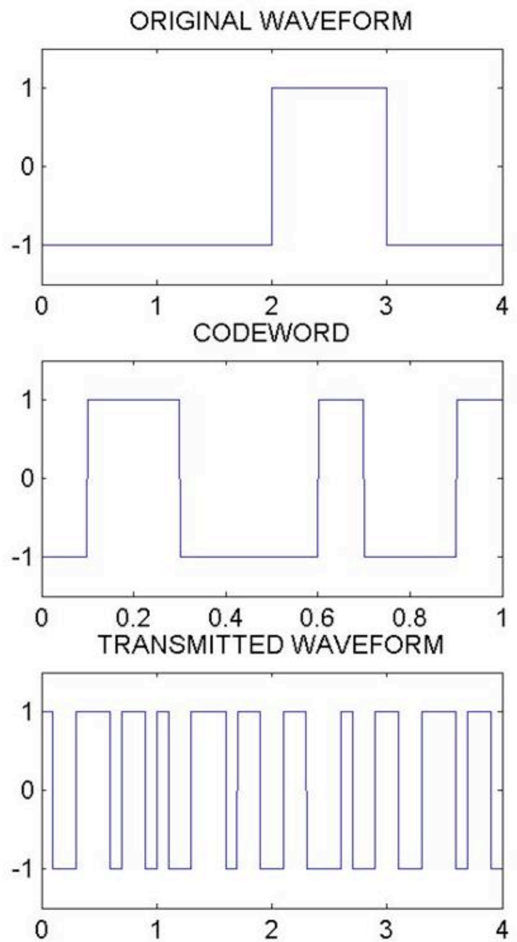
CDMA schemes

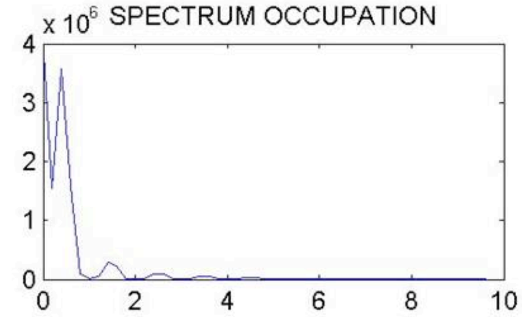
- Direct Sequence CDMA (DS-CDMA)
  - The original data signal is multiplied directly by the high chip rate spreading code.
- Frequency Hopping CDMA (FH-CDMA)
  - The carrier frequency at which the original data signal is transmitted is rapidly changed according to the spreading code.
- Time Hopping CDMA (TH-CDMA)
  - The original data signal is not transmitted continuously. Instead, the signal is transmitted in short bursts where the times of the bursts are decided by the spreading code.

Direct Sequence Spread Spectrum



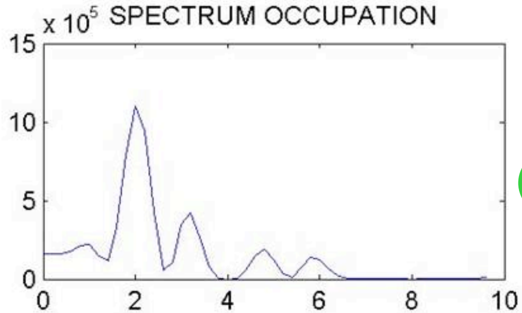
Direct Sequence Spread Spectrum





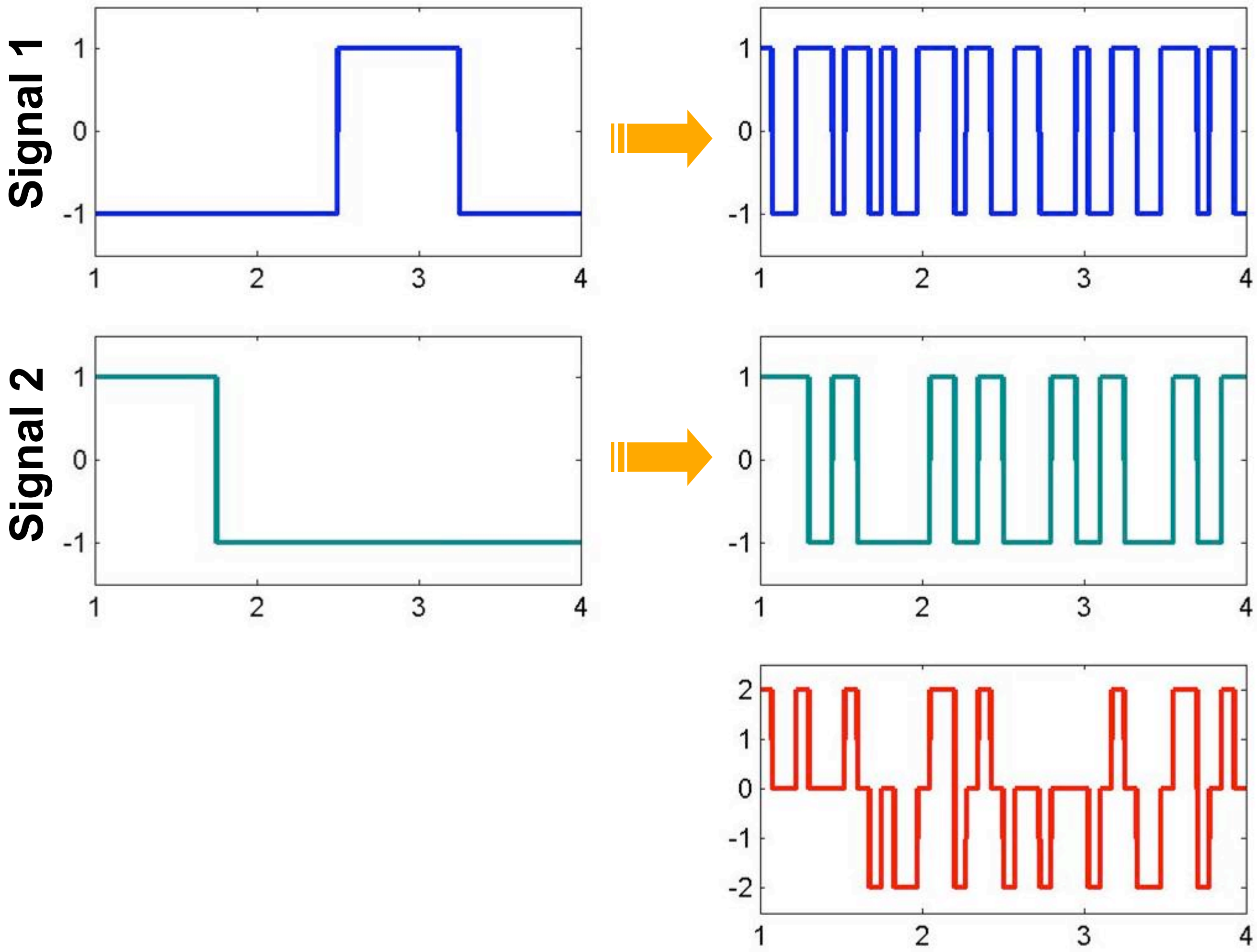
Original signal
(band related to the **bit** rate)

Spreading sequence composed by **chips**, with **chip** rate >> **bit** rate



Coded signal
(band related to the **chip** rate)

Direct Sequence Spread Spectrum

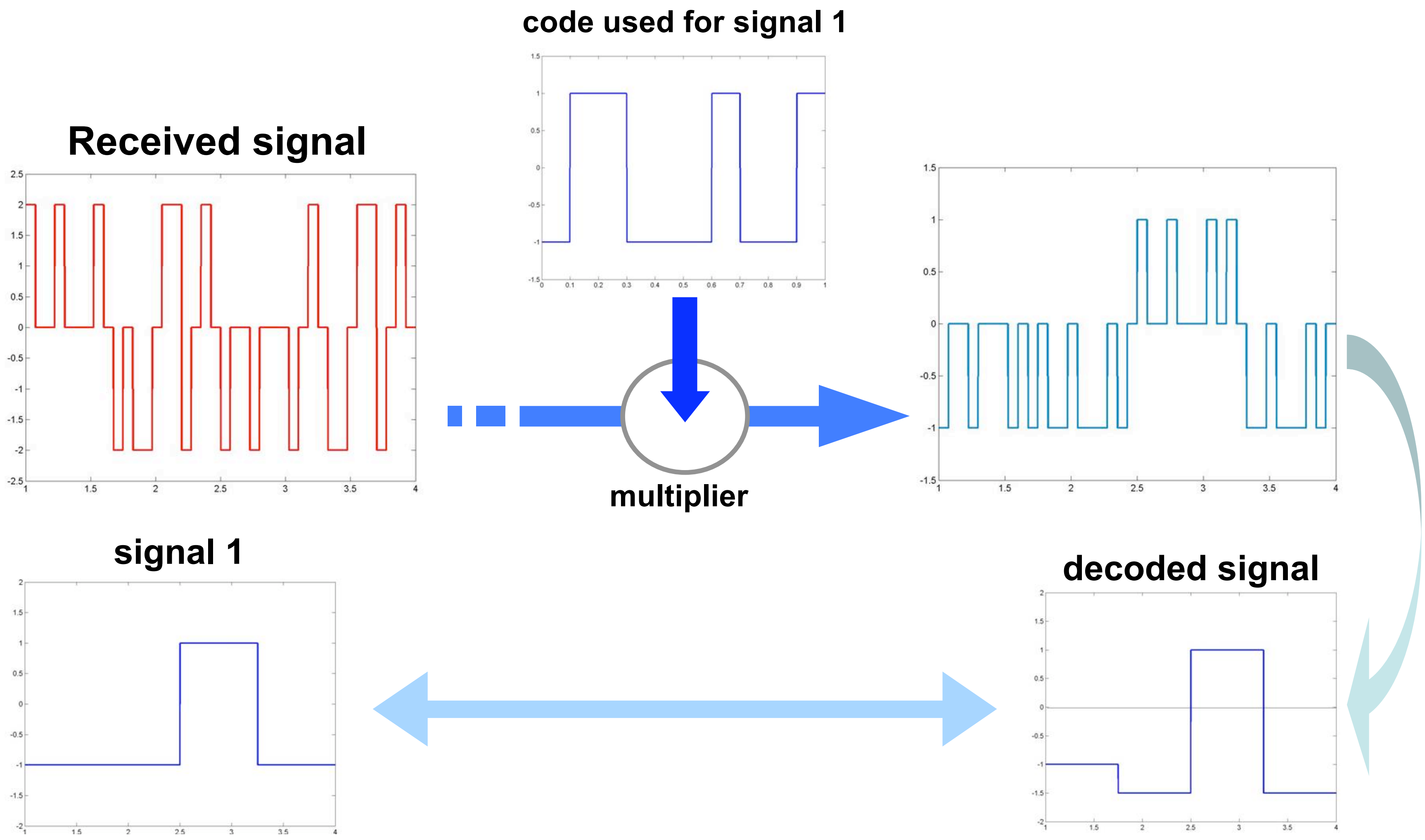


Coded signal 1

Coded signal 2

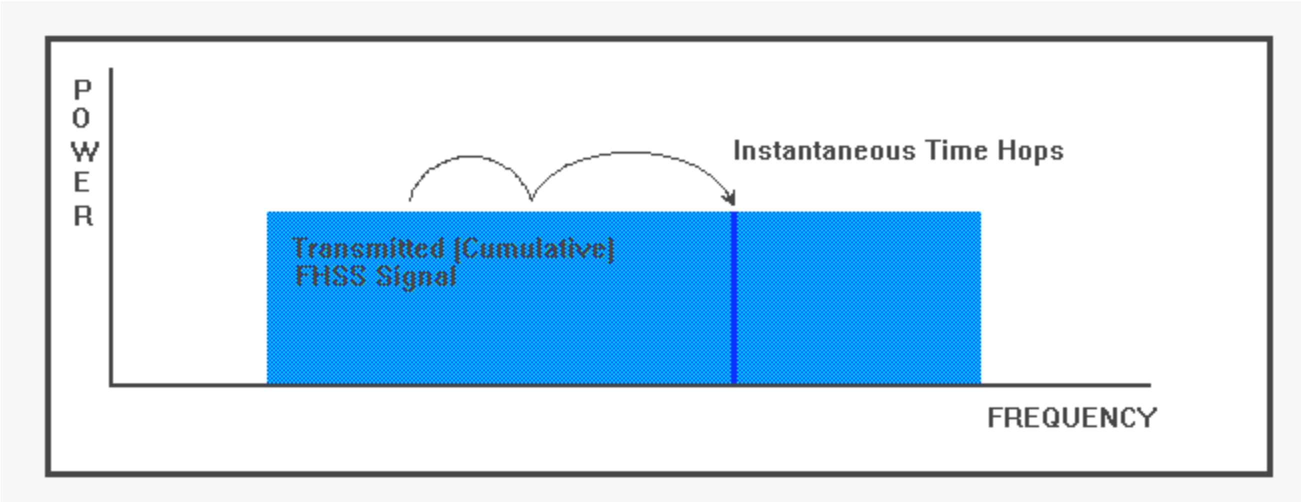
Sum of coded signals 1 and 2

Direct Sequence Spread Spectrum



Frequency Hopping Spread Spectrum

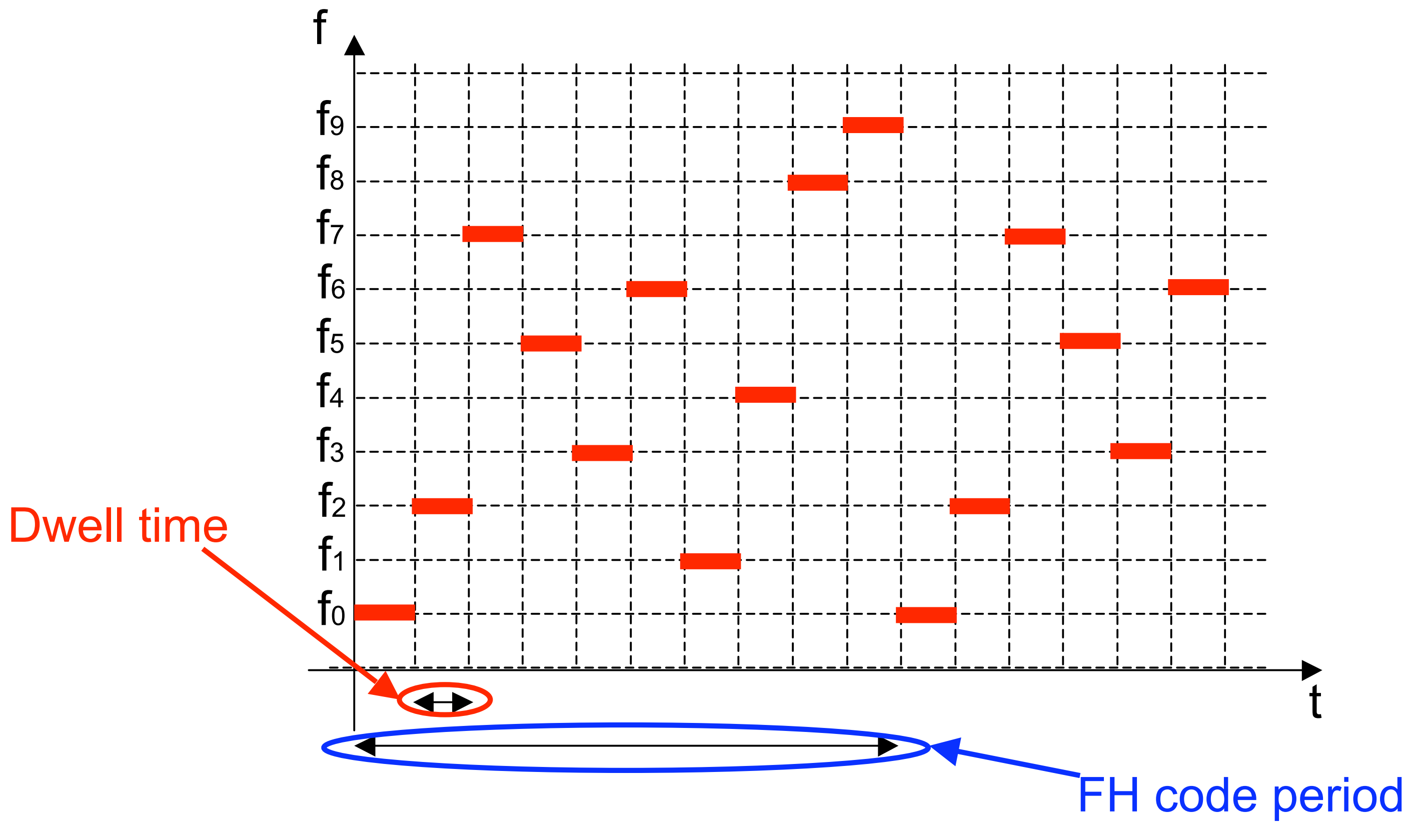
- In FH-SS, the transmitter spreads the spectrum by continuously jumping from one frequency channel to another



- A larger number of intervals leads to a better spreading
- Each user selectees the next frequency hop according to a code (*FH code*)

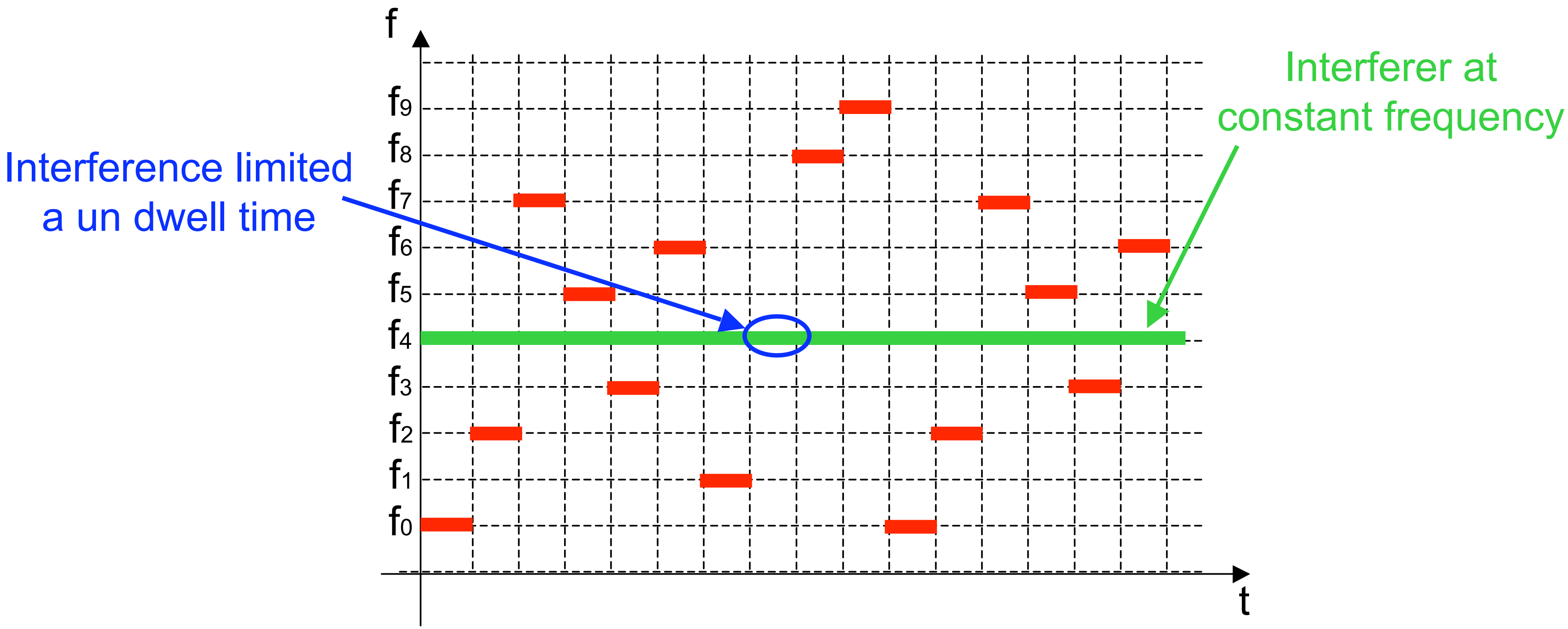
Frequency Hopping Spread Spectrum

- Time-frequency occupation for a FH-SS signal



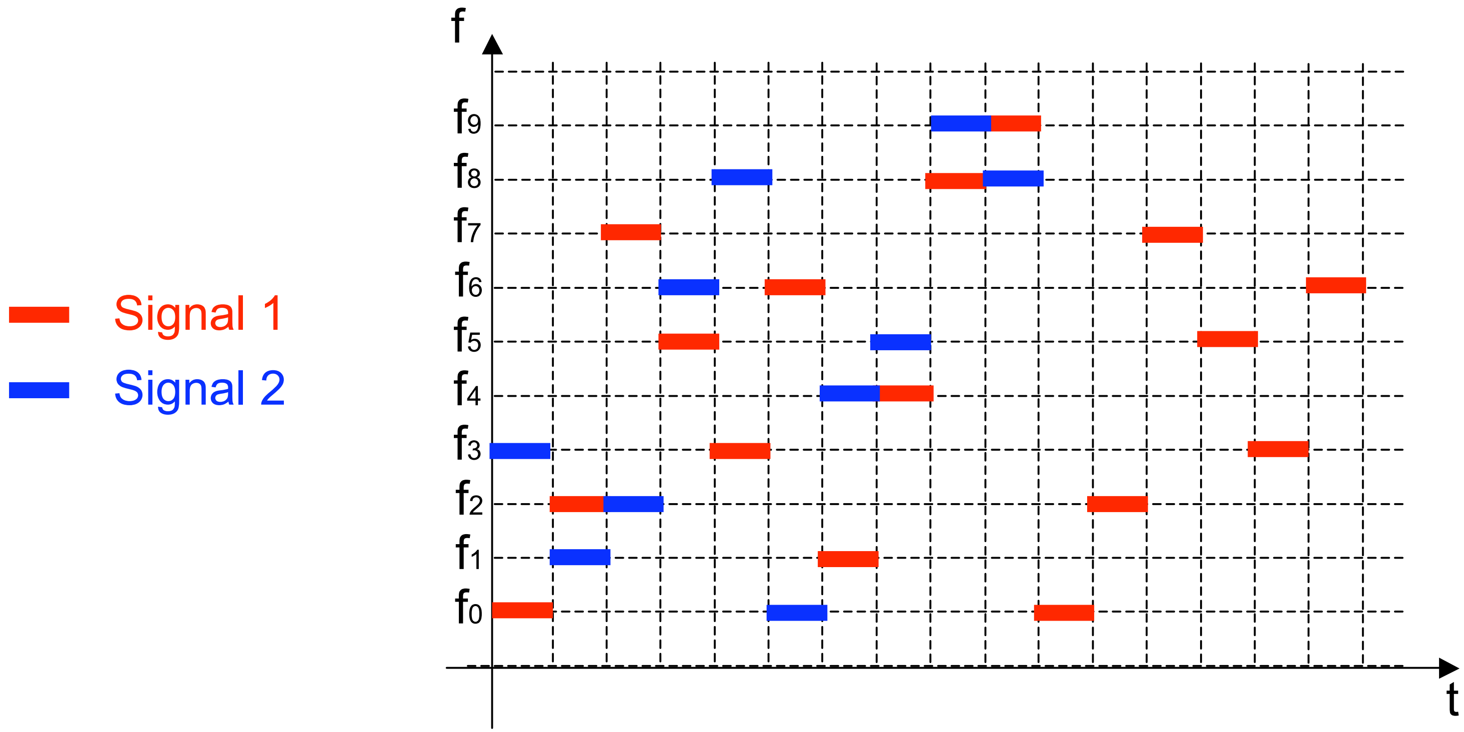
Frequency Hopping Spread Spectrum

- FH-SS signal robustness to a interferers at constant frequency



Frequency Hopping Spread Spectrum

- Coexistence of different FH-SS signals



If codes are well chosen (*orthogonal*) ⟹ **No interference!!**

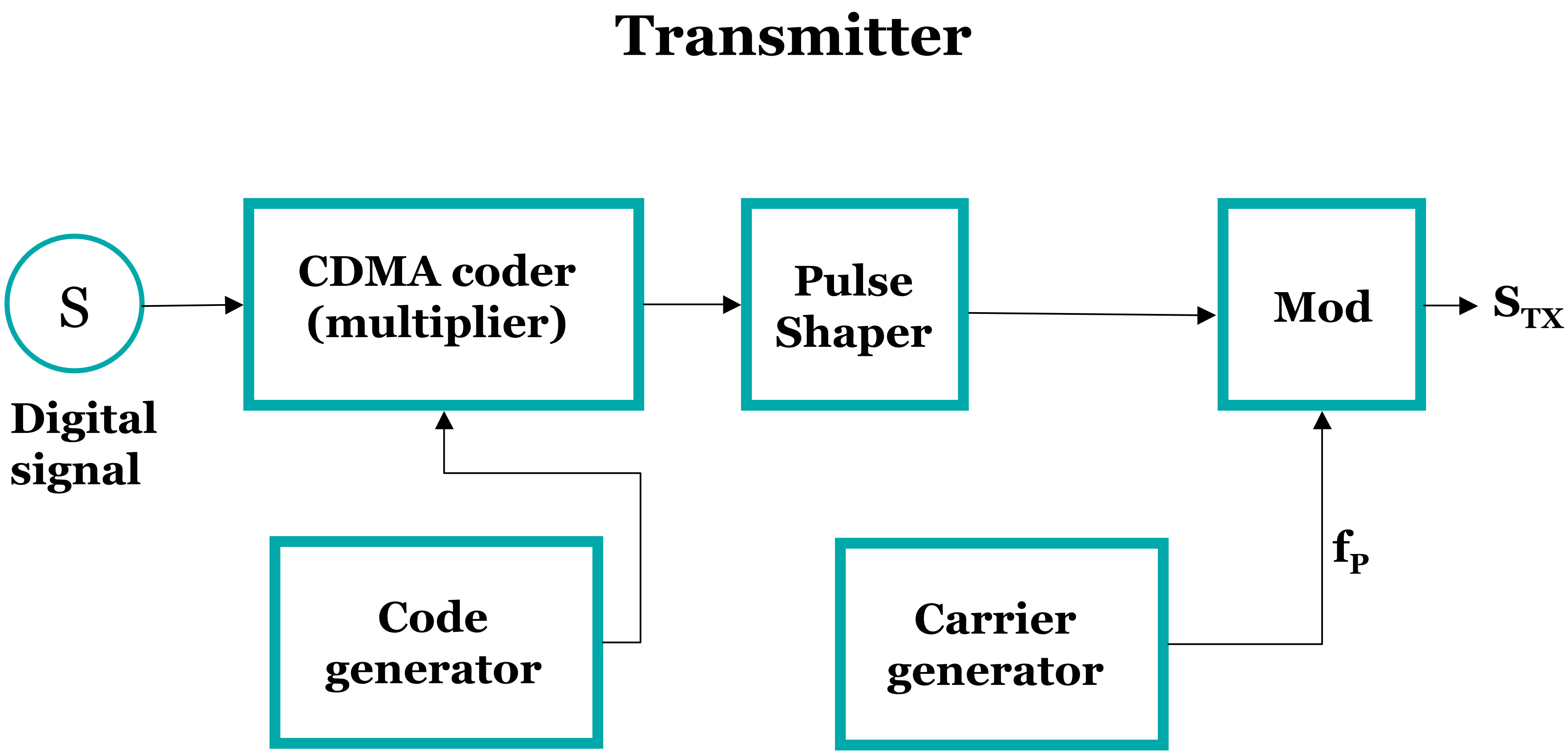
CDMA : the partial correlation problem

- **Partial correlations** among encoded signals arise when no attempt is made to synchronize the transmitters sharing the channel, or when propagation delays cause misalignment even when transmitters are synchronized.
- Partial correlations impede the receiver to totally cancel the contributions of other users even in the presence of spreading codes having low cross-correlation.
- In presence of partial correlations, the received signal is therefore affected by Multi User Interference.
- The partial correlations can be reduced by proper choice of the spreading codes, but cannot be totally eliminated.
- **CDMA system capacity is thus tipically limited by the interference from other users, rather than by thermal noise**.

CDMA : the near-far problem

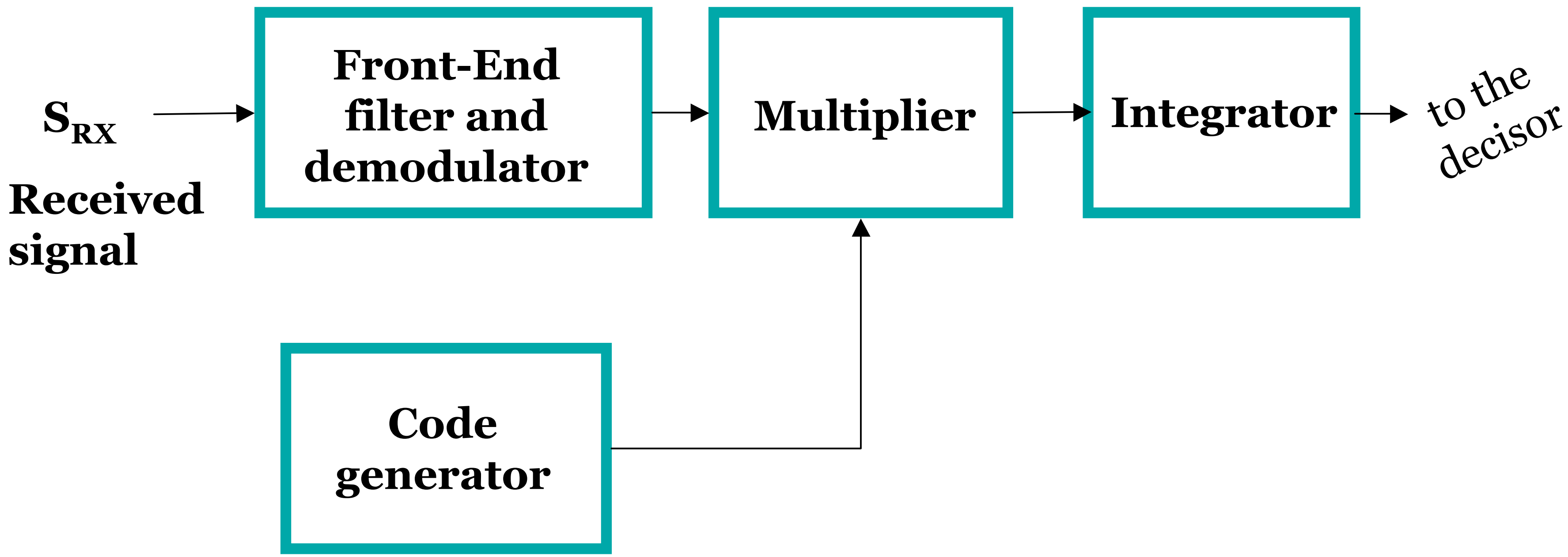
- If all the users transmit at the same power level, then the received power is higher for transmitters closer to the receiving antenna.
- Thus, transmitters that are far from the receiving antenna are at a disadvantage with respect to interference from other users.
- This inequity can be compensated by using **power control**.
- Each transmitter can accept central control of its transmitted power, such that the power arriving at the common receiving antenna is the same for all transmitters.
- In other words, the nearby transmitters are assigned a lower transmit power level than the far away transmitters.
- Power control can be easily achieved in centralized access schemes (e.g. third generation cellular networks), but is a challenging issue in distributed systems.

DS-CDMA: reference scheme



DS-CDMA: reference scheme

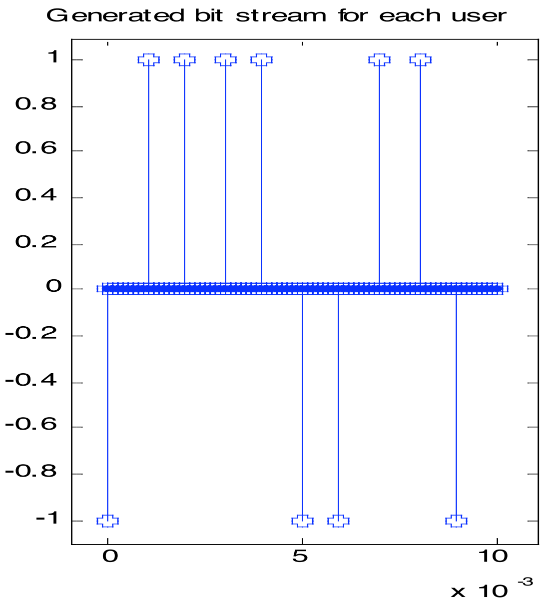
Receiver



DS-CDMA: a case study

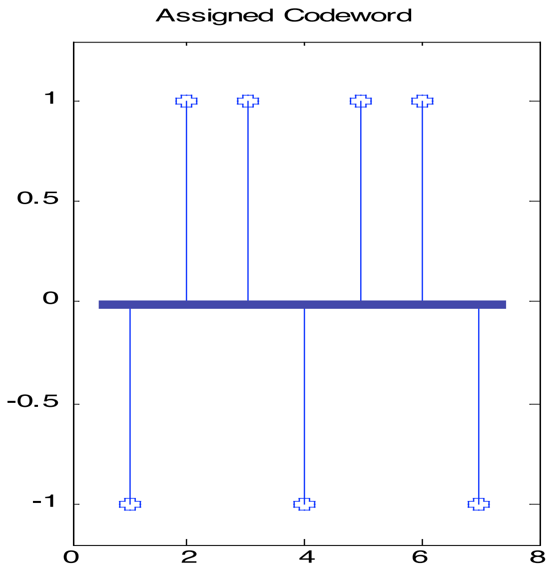
binary data signal

$$s^{(j)}(t)$$



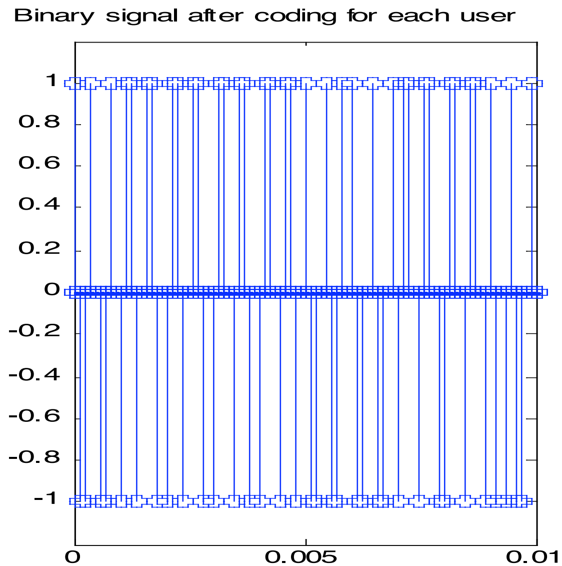
Codeword

$$c^{(j)}[k]$$



DS-CDMA-coded signal

$$s^{(j)}_{DSCDMA}(t)$$



DS-CDMA: a case study

Digital binary signal

$$s^{(j)}(t)=\sum_k a_k^{(j)}\delta(t-kT)$$

DS-CDMA-coded signal

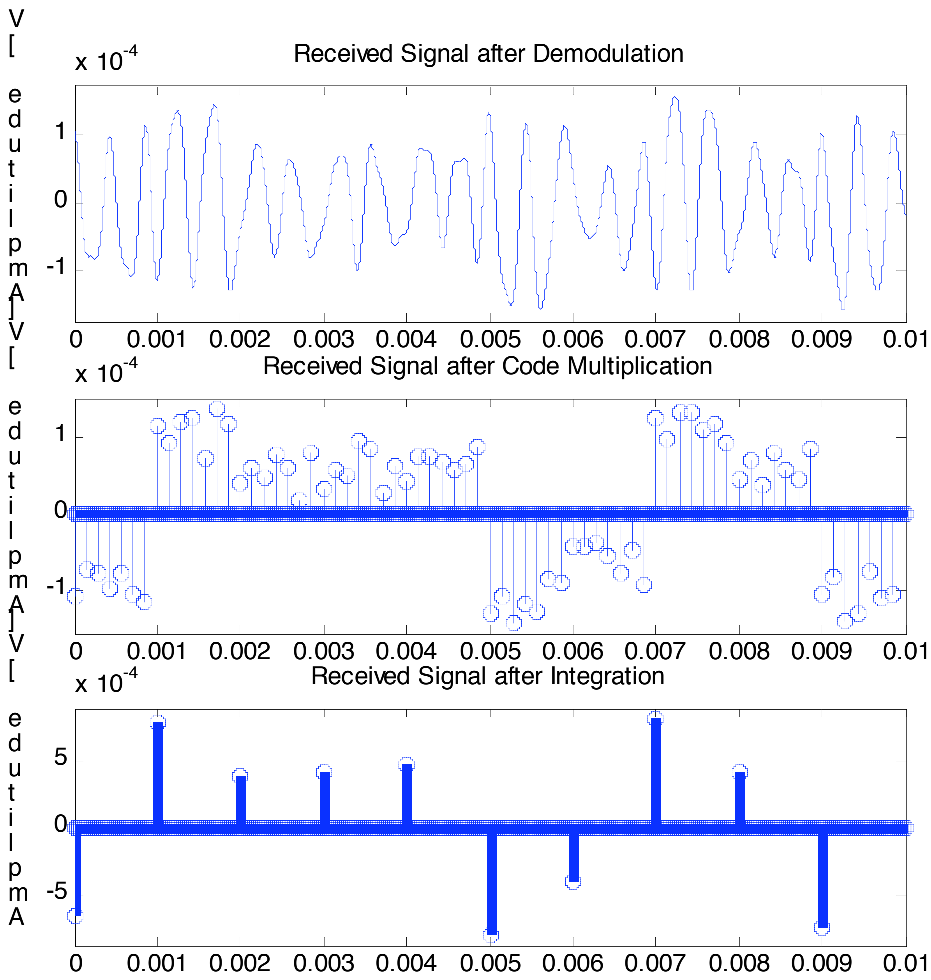
$$s_{DSCDMA}^{(j)}(t)=\sum_k a_k^{(j)}\underbrace{\sum_{m=1}^{N_{DS}} c^{(j)}[m]\delta(t-mT_C-kT)}_{\text{Spreading Signal}}$$

N_{DS} : length of the codeword
T_C : chip time

$$s_{TX}^{(j)}(t)=\sqrt{2P_{TX}}\left(s_{DSCDMA}^{(j)}(t)*g_o(t)\right)\sin\left(2\pi f_P t+\varphi^{(j)}\right)$$ **Transmitted signal**

$$s_{RX}^{(j)}(t)=s_{TX}^{(j)}(t)*h^{(j)}(t)=\sum_{l=1}^{L}\alpha_l^{(j)}s_{TX}^{(j)}\left(t-\tau_l^{(j)}\right)$$ **Signal after propagation over a multipath channel**

DS-CDMA: a case study



Received signal after Front-End filtering and demodulation

Signal obtained by direct multiplication of the base-band signal with the spreading signal

Received sequence after integration of the above samples