UNIK

UNIVERSITY OF OSLO

UNIK4230: Mobile Communications

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Multiple Access

Multiple Access

- Introduction
- FDMA (Frequency Division Multiple Access)
- TDMA (Time Division Multiple Access)
- CDMA (Code Division Multiple Access)
- Spread Spectrum
  - Direct Sequence
  - Frequency Hopping
- Rake Receiver
- OFDMA (Orthogonal Frequency Division Multiple Access)
- Summary

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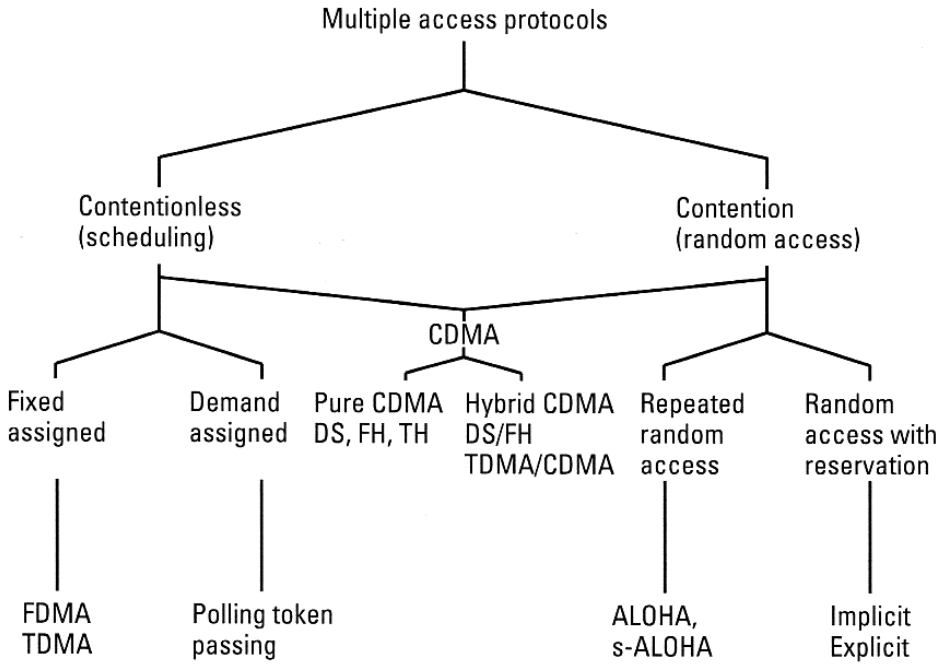
Introduction

Multiple Access is divided in two main types:

- **Contentionless:** "conflict-free" protocol based on scheduling
  - Ensuring a transmission, whenever made is a successful one and not interfered by another transmission.
  - Used in Mobile systems such as GSM, UMTS and LTE



- **Contention:** "Random access" with various means to resolve conflict for simultaneous transmission
  - In principal, transmission is not guaranteed to be successful
  - Used in WLAN/Wi-Fi systems
  - Also used in mobile system for initial connection set-up

Multiple Access in Mobile Systems

When multiple users share same bandwidth, there are four main techniques:

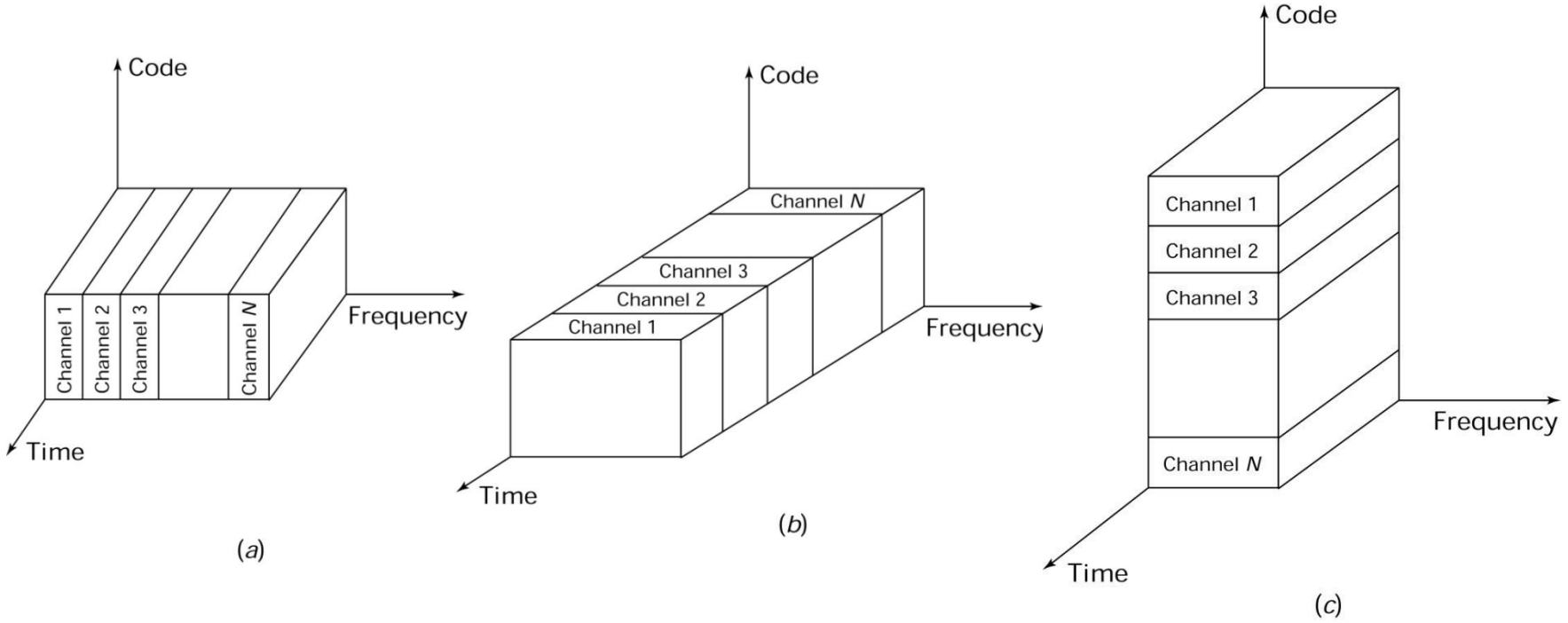
FDMA (Frequency Division Multiple Access)
- Each user is assigned a separate frequency range

TDMA (Time Division Multiple Access)
- Multiple users share the allocated frequency bands, and each user use an allocated time

CDMA (Code Division Multiple Access)
- The bandwidth used by all users simultaneously, which is separated by means of code

OFDMA (Orthogonal Frequency Division Multiple Access)
- The bandwidth is divided to the different users as needed

(O) FDMA, TDMA and CDMA



Duplex Transmission

Communication needs to be in both directions- to and from mobile

- Forward Channel (Downlink- DL): from Base Station to Mobile
- Reserve Channel (Uplink- UL): from Mobile to Base Station

Two types of Duplex systems:

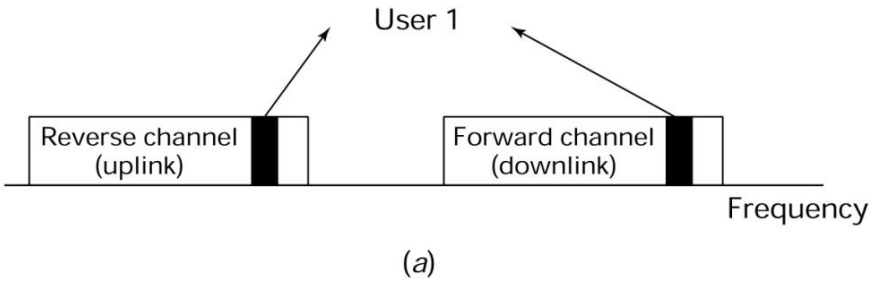
- FDD (Frequency Division Duplex)
  - Two distinct band of frequencies for each user- one for uplink and one for downlink. These bands are separated by a guard band

- TDD (Time Division Duplex)
  - Time is used to separate forward and reverse channels
  - Almost continuous transmission is possible since time split between channels are very small.

Duplex Transmission

FDD: A duplexer is needed since same antenna is used for both way transmissions

TDD: No duplexer is needed



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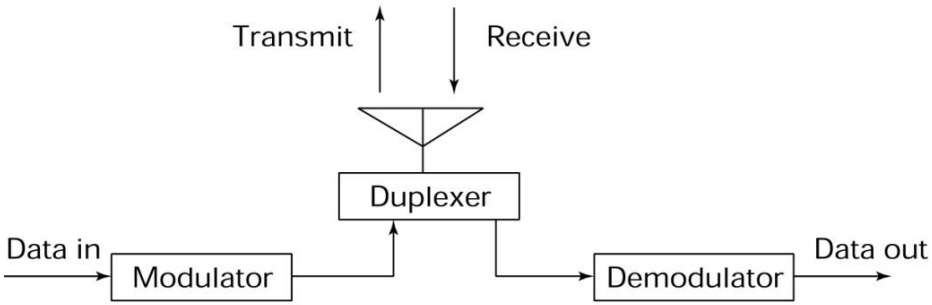

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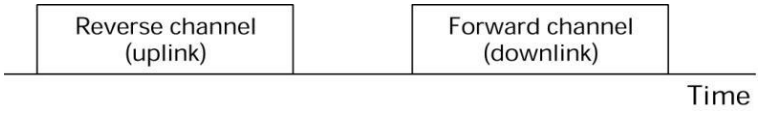

Duplex Techniques and Systems

Systems are characterized both by its method of multiple access and duplex

For example

- FDMA/FDD (e.g. NMT)
- TDMA/FDD (e.g. GSM)
- TDMA/TDD (e.g. DECT)
- CDMA/TDD (e.g. UMTS TDD)
- CDMA/FDD (e.g. UMTS FDD)
- OFDMA/TDD (e.g. WiMAX)
- OFDMA/FDD (e.g. LTE)

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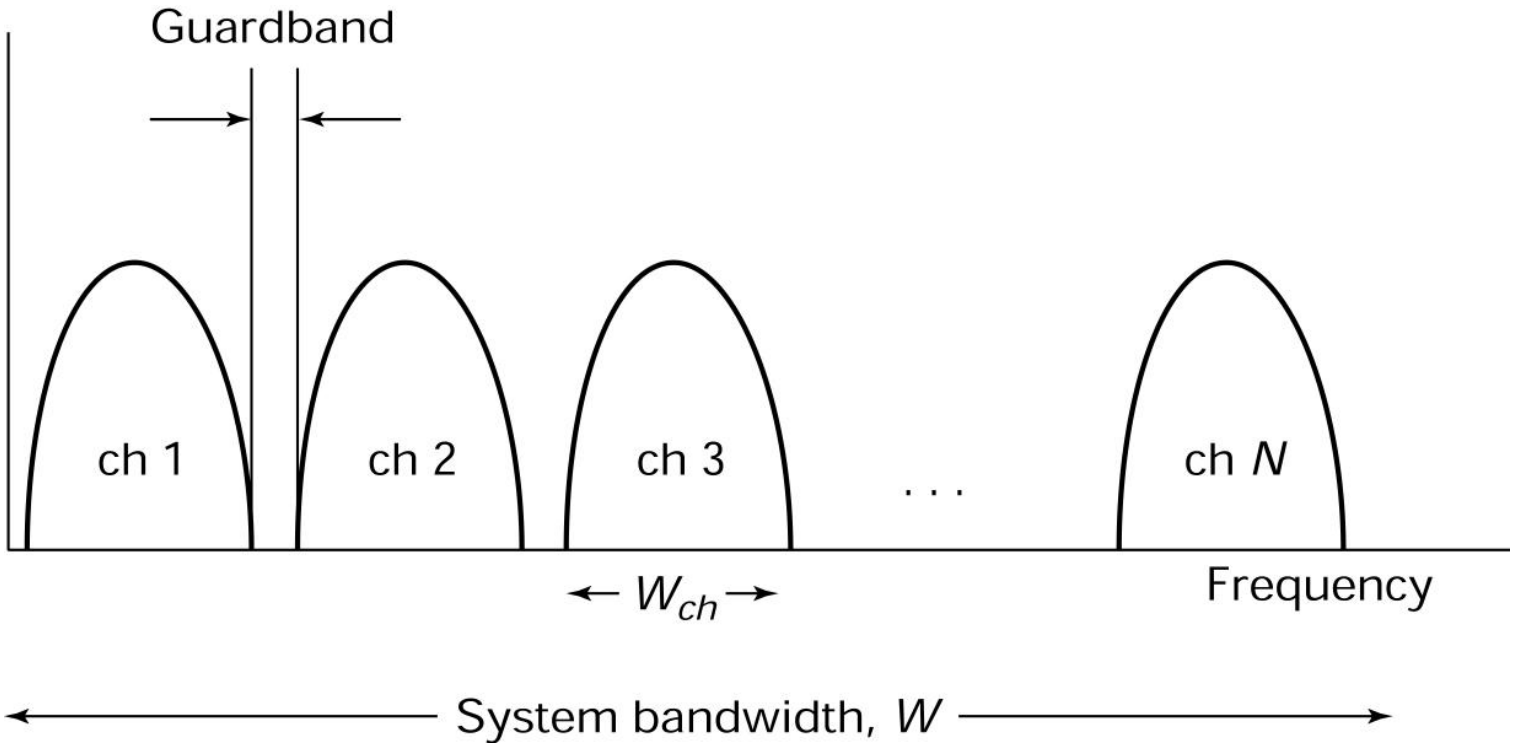
FDMA

- The available bandwidth W is divided into N non-overlapping bands, each with width *Wch*
- A small gurad band is provided to reduce interference



FDMA

- During call set-up user is given an unused channel by Base Station exclusively
- After termination of call, the channel may be reassigned to another user
- If during the call, the caller moves into another cell, then it will be assigned an unused channel from new cell
- If FDD is used with FDMA, then available band is divided in two; one half for downlink and another half for uplink. The caller has one frequency for the uplink and another for downlink.

Advantages of FDMA

- The major advantage of FDMA is the “hardware simplicity” since discrimination between users is done by simple bandpass filters.
- No timing information or synchronization is required
- Little problem of frequency-selective fading and Intersymbol Interference (ISI) since bandwidth assigned to each user is relatively small

Disadvantages of FDMA

- Little flexibility in resource allocation
  - Available channels may not be granted to existing users and enhance capacity of the system
  - Dynamic channel assignment may overcome this limitation by assigning unused channels to other cells which needs more capacity
- Inability to be used as variable rate transmission which is common in digital systems. This eliminates FDMA as the choice for combined voice and data transmission
- Filter with excellent cut-off characteristics necessary since FDMA depends on bandpass filters.
- Crosstalk due to interference from neighboring channels produced by nonlinear effects.

Crosstalk in FDMA

For example, a composite signal c(t) at the receiver with 3 channels can be expressed as:

$$c(t) = a_1(t)\cos(2\pi f_1 t) + a_2(t)\cos(2\pi f_2 t) + a_3(t)\cos(2\pi f_3 t)$$

where f1, f2, f3 are carrier freq. and a1, a2, a3 are information bearing signal.

The output of a nonlinear amplifier will be:

$$c_{out}(t) = b_0 + b_1[c(t)] + b_2[c(t)]^2 + b_3[c(t)]^3 + \ldots$$

where bi are the scaling factor. Depending on the ratio of carrier freq. the nonlinear terms can be:

$$f_1 = 2f_2 - f_3$$

Or any other combination, which will lead to interchannel interference (ACI).

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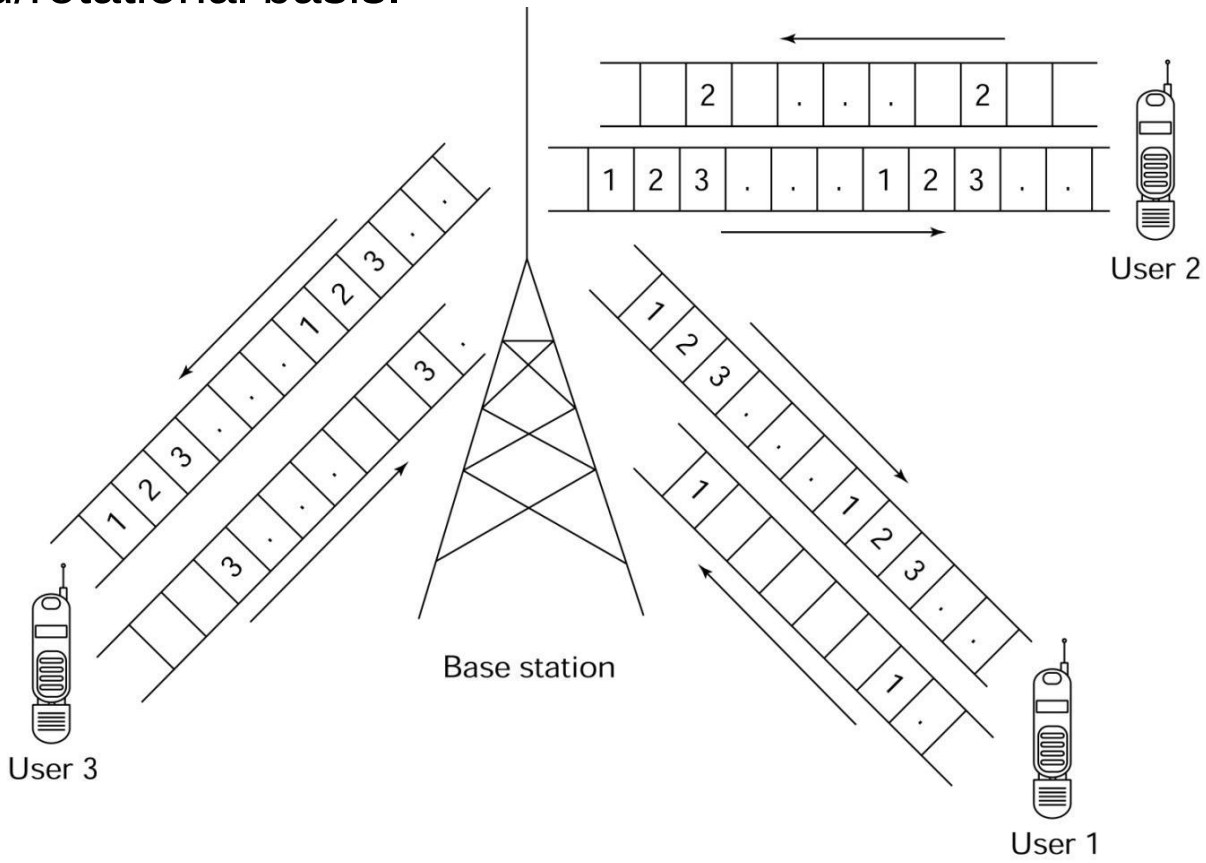
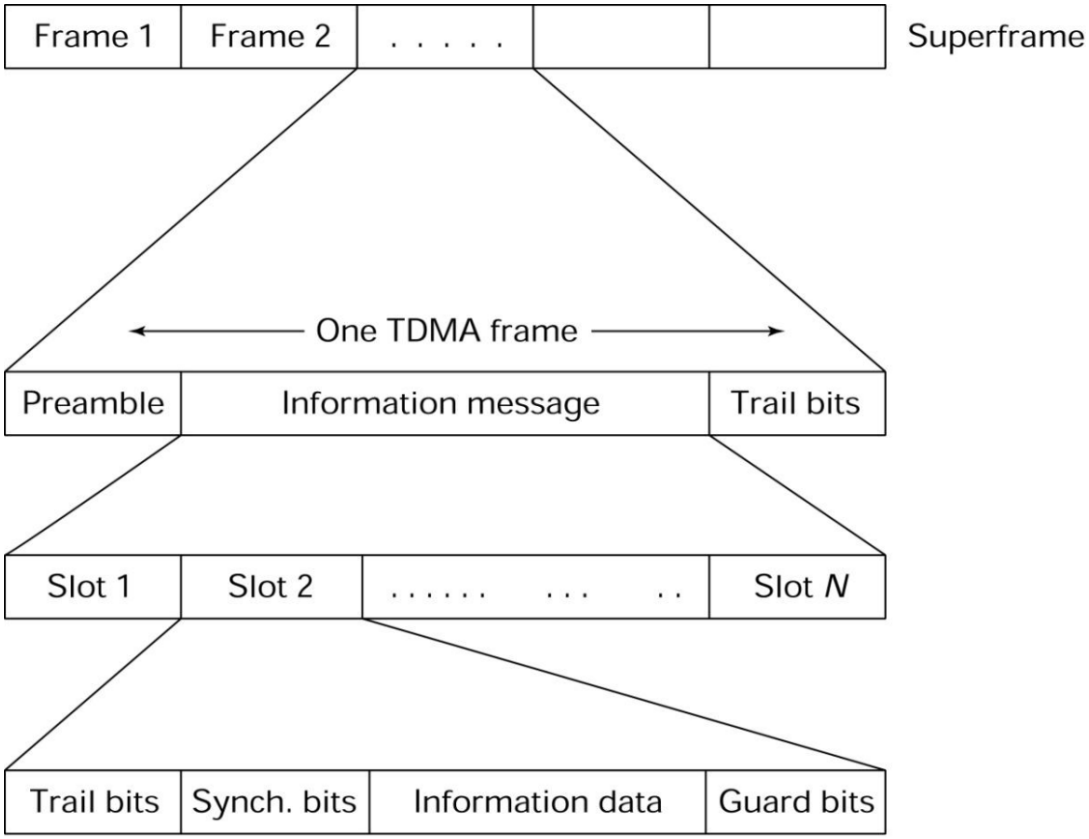
TDMA

Each user occupies the whole bandwidth for a fraction of a time, called a time slot (per frame) and continues to have access to the bandwidth on a period/rotational basis.



TDMA: Timeslot and Frame



Preamble:

- Address and synchronization information

Guardbits:

- Necessary to allow non-ideal time synchronization between the mobile?

TDMA and Duplex

TDMA/TDD

- Half of timeslots in the frame will corresponds uplink and other half downlink within same carrier

TDMA/FDD

- Uplink and downlink will be separate frames in different carrier frequencies

Resource Allocation

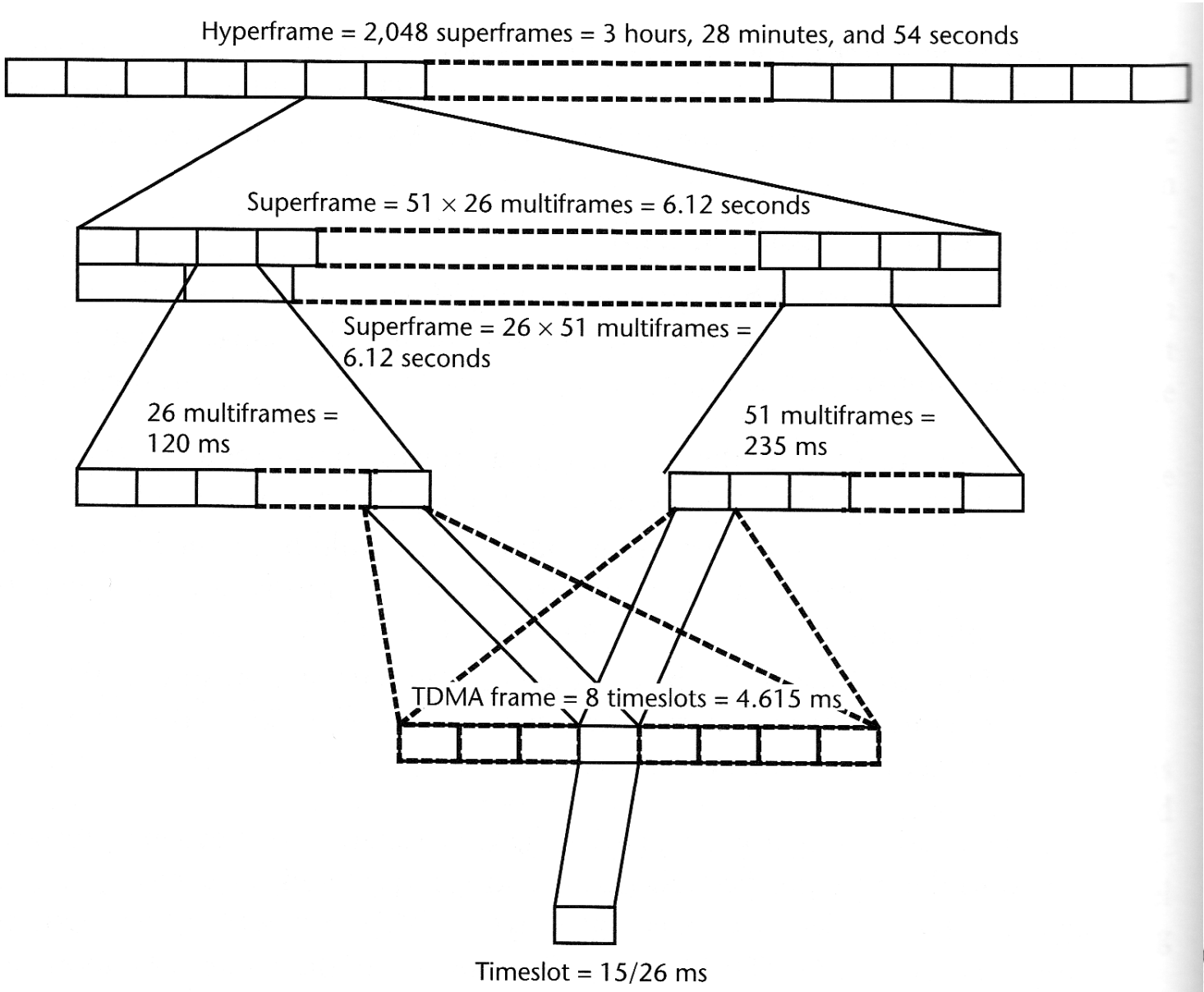
- During call set-up, user is assigned a free time slot, and use it in each frame
- When moving to the new cell, the user is assigned an available slot in the new cell
- For data transmission with higher data rate, a user may receive more than one time slot per. frame

TDMA in GSM

GSM is a combined FDMA / TDMA system

- The frequency band is divided into the carrier (carriers) of 200 kHz
  - Different carrier used in different cells
  - For larger capacity requirements, multiple carrier used in a cell
- Each carrier is divided into eight TDMA timeslots, which together is called a TDMA frame.
- Each frame is 4.615 ms (= 120/26 ms) and each time slot is 0577 ms (= 15/26 ms). A time slot is the smallest unit in GSM
- Each channel uses one time slot per TDMA frame
- Bit-rate on the physical layer in GSM is 270.833 kHz

TDMA in GSM


Hyperframe = 2,048 superframes = 3 hours, 28 minutes, and 54 seconds
Superframe = 51 × 26 multiframes = 6.12 seconds
Superframe = 26 × 51 multiframes = 6.12 seconds
26 multiframes = 120 ms
51 multiframes = 235 ms
TDMA frame = 8 timeslots = 4.615 ms
Timeslot = 15/26 ms

Advantages of TDMA (compare to FDMA)

Flexibility in resource allocation

- Based on availability, more time slots can be assigned to the same user. Allows for variable data rate.
- Not so strong cut-off filters requirement, or problems with crosstalk.
- Better utilization of resources. Overhead in the form of Guardbits between the time slots and Synchronization bit requires less resources than the resulting Guardband between the carrier channels in FDMA

Disadvantages of TDMA (compare to FDMA)

- The need for synchronization, both the frames and time slots
- Greater bandwidth allows more frequency selective fading and ISI

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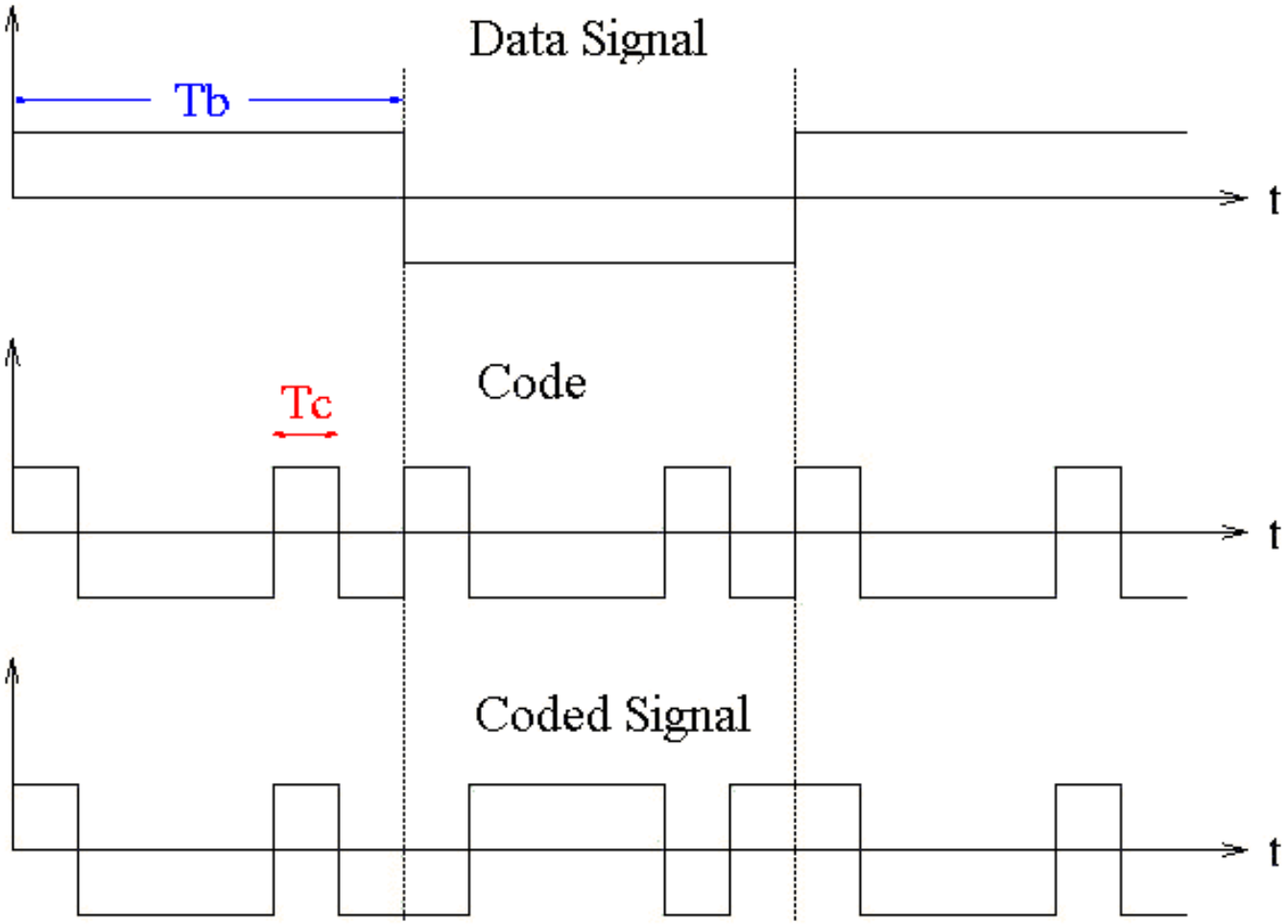
CDMA

- Multiple users can share the same carrier at the same time with each user multiplies the data stream with a unique “spreading code “ before sending.
- The data stream can be recreated in the receiver by multiplying by the same spreading code.
- Interference from other users is suppressed because of orthogonality of spreading code each user uses.
- Spreading code is a pseudo-random (or pseudo-noise-PN) periodic sequence, each bit in the spreading sequences is called a chip.
- The relationship between bit period T and chip period Tc: T/ Tc = K and called spread factor (SF).
- The bandwidth of the new signal is higher than the original by a factor of K because of higher data rate

CDMA Signal Generation

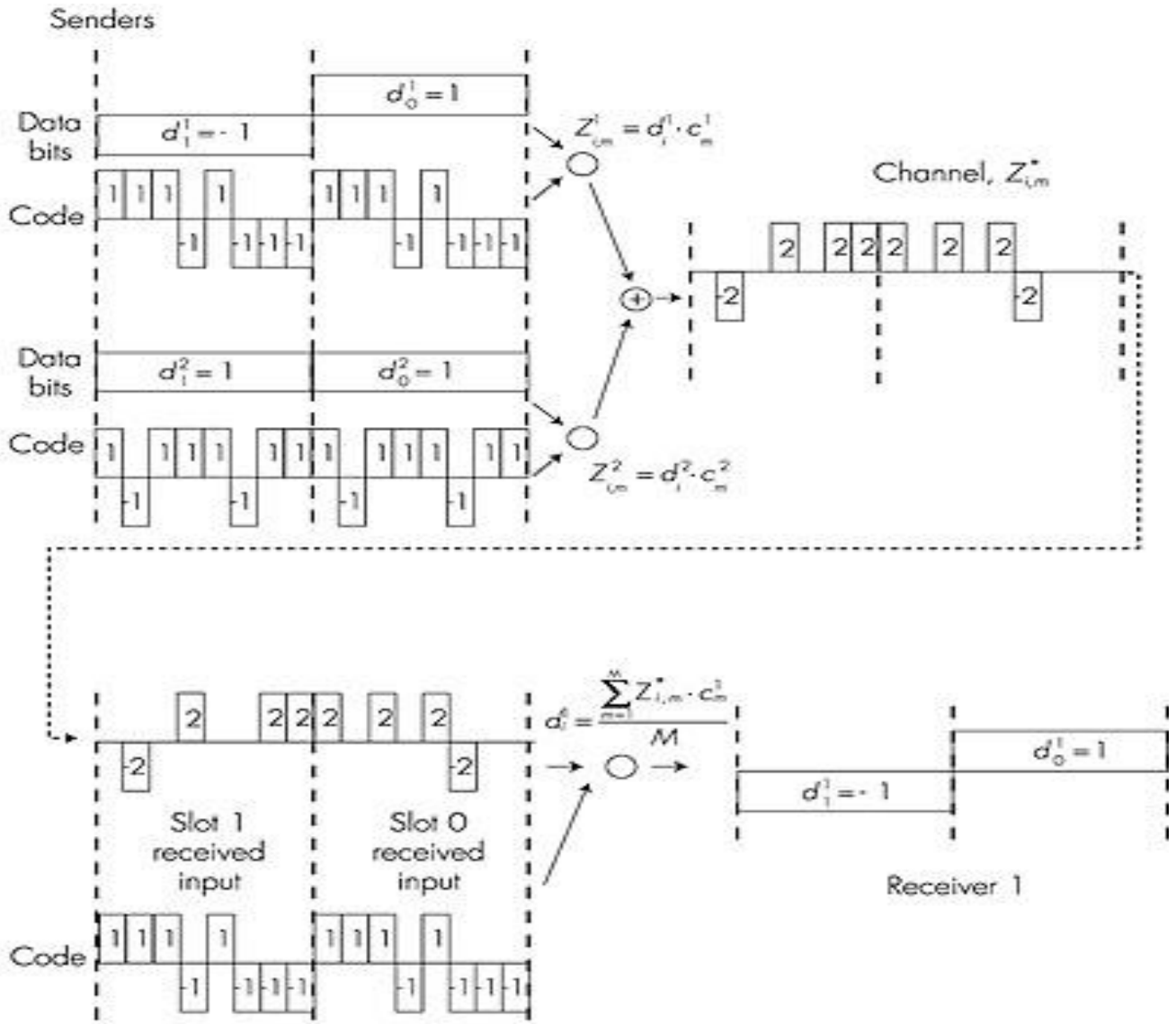


Information signal

PN Code

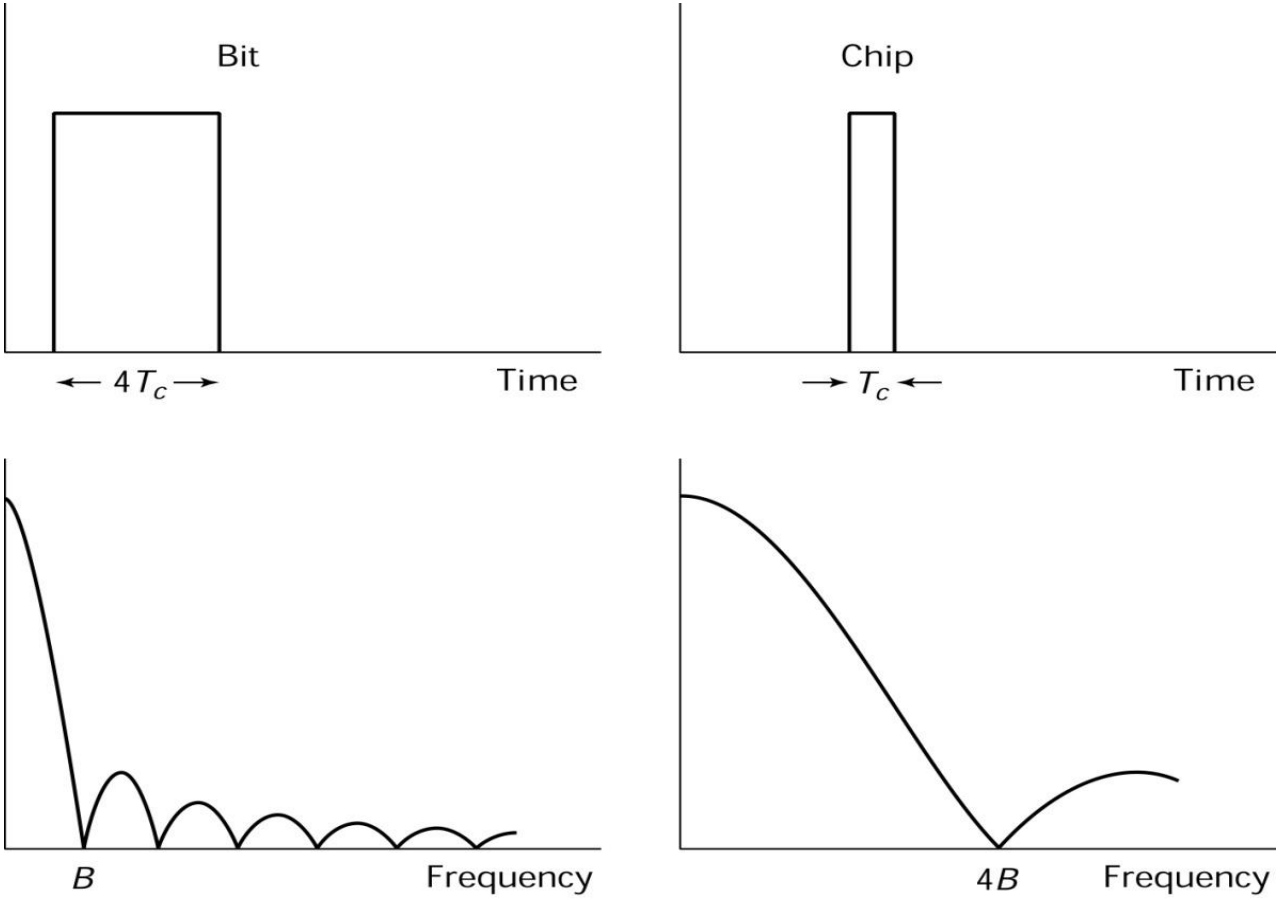
Encoded signal

CDMA Signal Generation (II)

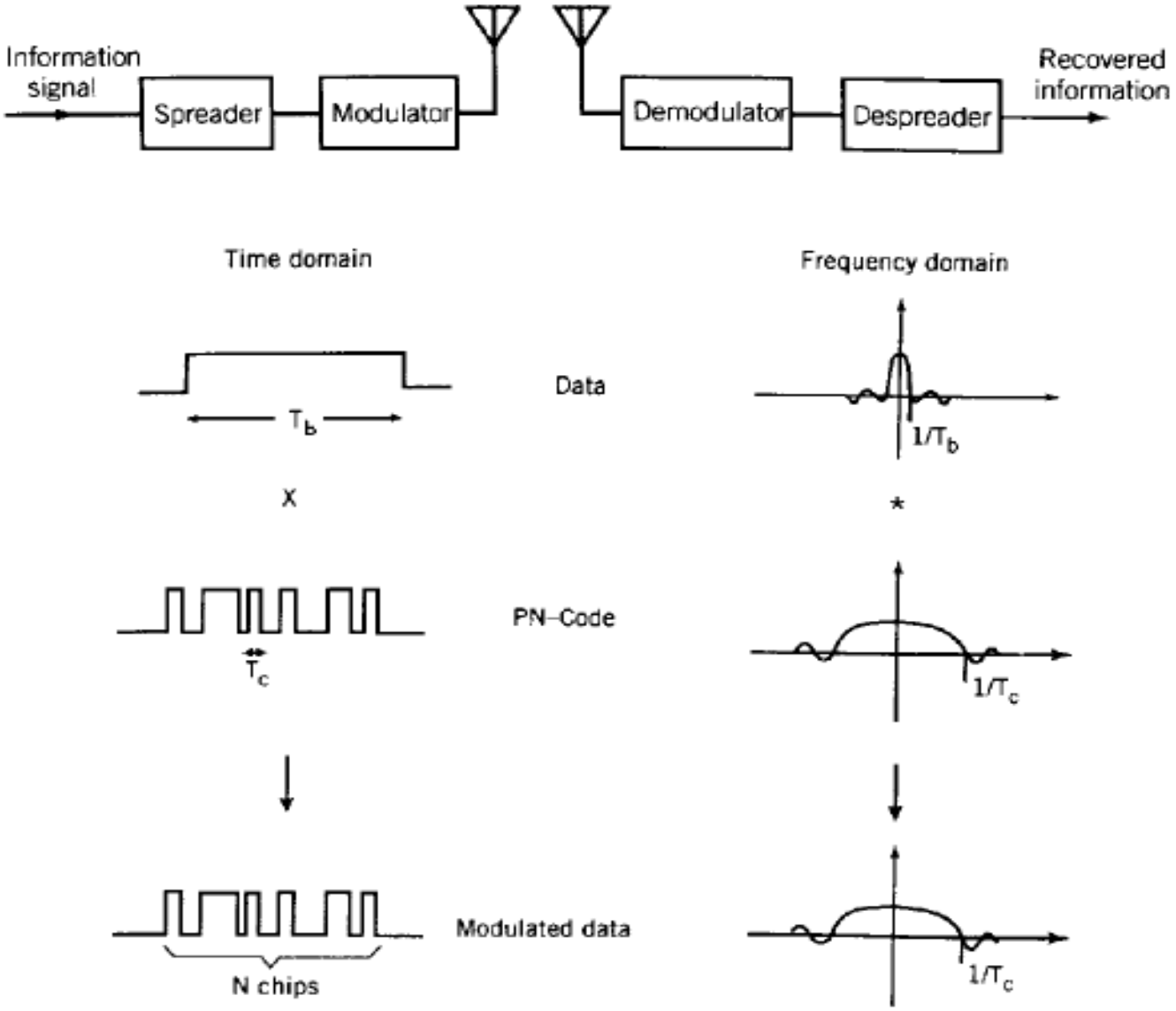


CDMA- Spread-Spectrum

Spreading of the spectrum (in freq. domain). Here for example K=4



CDMA Transmitter and Receiver



Orthogonality

- Two functions Xq(t) and Xk(t) are orthogonal over an interval [a, b] if the integral is 0 for all q and k, except when q = k:

$$\left\langle x_q, x_t \right\rangle = \int_a^b x_q(t) \cdot x_k(t) dt = \begin{cases} 1, & k = q \\ 0, & k \neq q \end{cases}$$

- Examples of orthogonal function are Spreading code used in CDMA and Sine functions used in OFDMA

Interference in CDMA

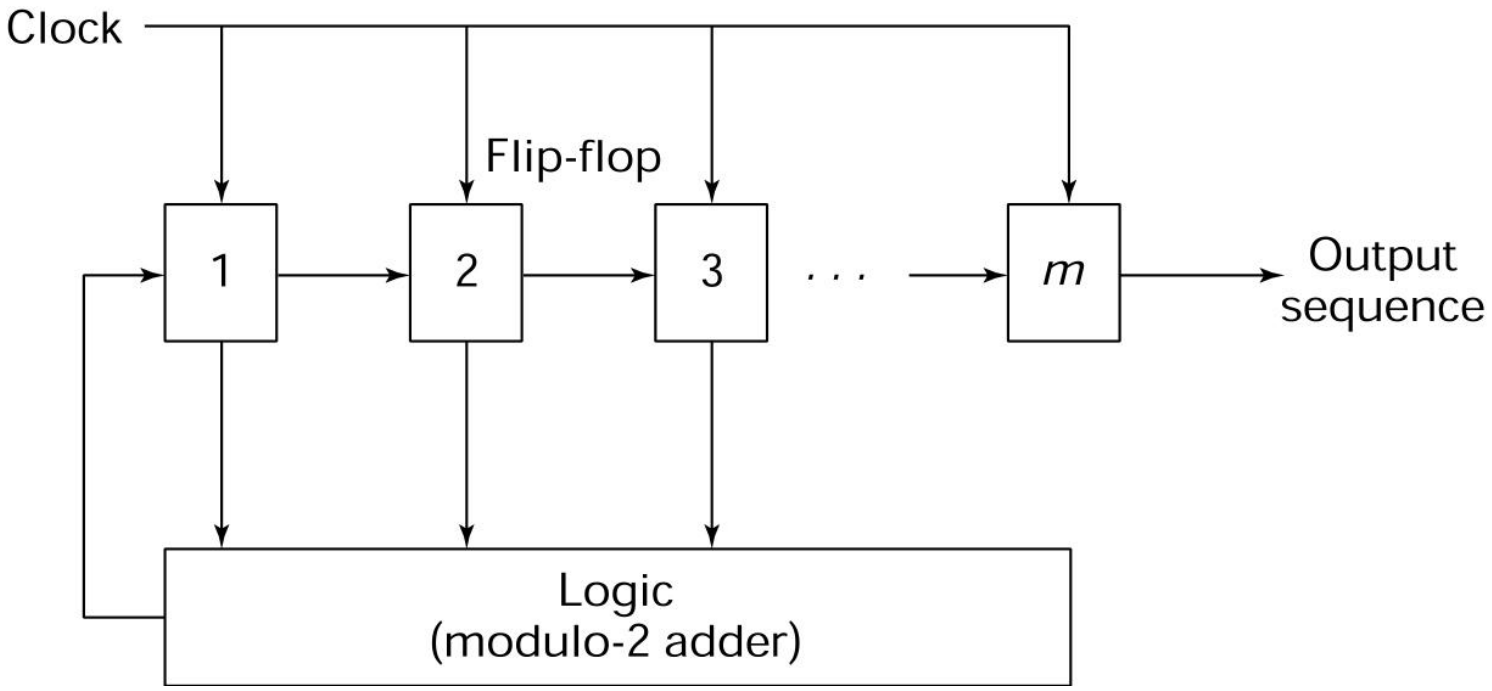
- Different users have different spreading-code, which is almost orthogonal
- If orthogonality between the codes is perfect then no interference at the receiver.
- Cross correlation between two spreading sequences Sn and Sm is:

$$R_{nm}(\tau) = \frac{1}{T_b} \int_0^{T_b} s_n(t) \cdot s_m(t-\tau) dt$$

- Perfect orthogonality means that cross-correlation function is zero for all (tau)
- In practice orthogonality is not perfect, thus there is some interference
- In CDMA, there is a soft capacity limit, new users degrades signal quality a little bit for everyone, but there is no absolute limit to the many users may be allowed

PN Code Generator

- Periodic sequence of PN code can be generated with period 2^m-1 with an m-stage feedback shift registers. Set-up consist of flip-flops and modulo-2 adder as shown in figure



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Spread Spectrum

- Spread spectrum is a generic term for techniques that spread the information over a wide frequency range (broadband)
- Can be various reasons for this, for example:
  - Avoid fast fading
  - Avoid jamming (especially in military applications)

- Available in two main types of spread spectrum:
  - Direct-Sequence
  - Frequency Hopping

- CDMA uses direct sequence spread spectrum to achieve multiple access

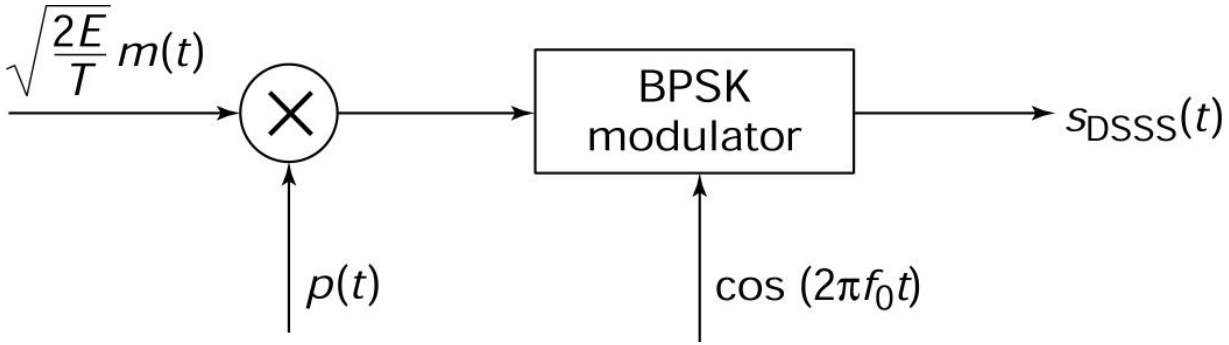
Direct Sequence Spread Spectrum (DSSS)

- A direct sequence spread-spectrum signal can be expressed as:

$$s_{DSSS}(t) = \sqrt{\frac{2E}{T}} m(t) p(t) \cos(2\pi f_0 t + \theta)$$

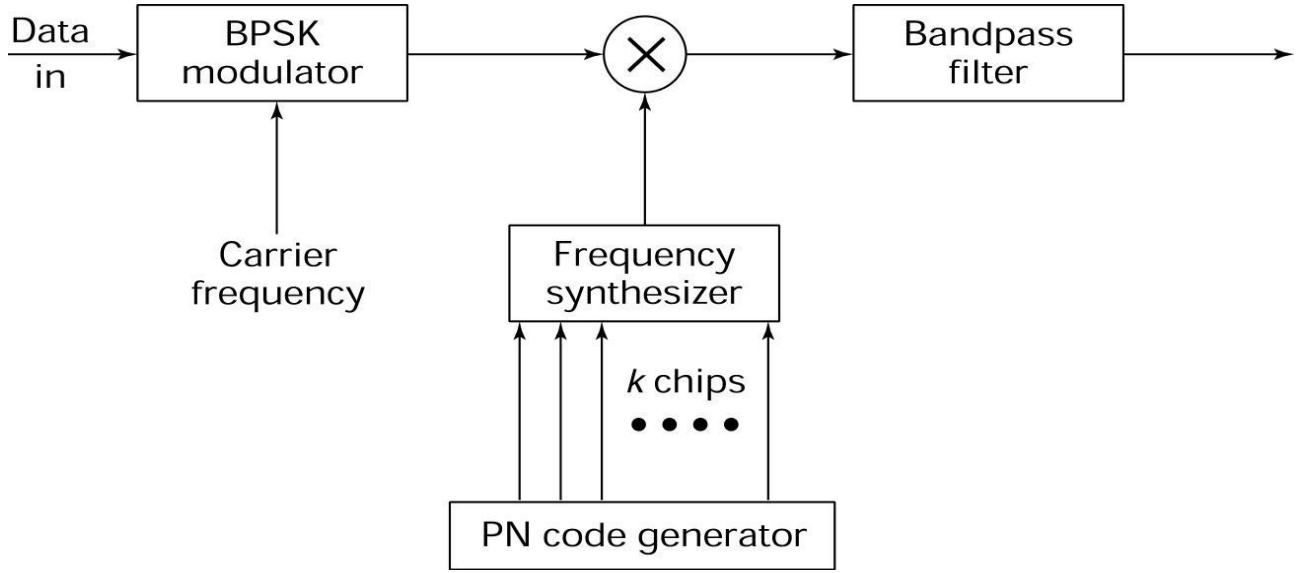
where m(t) is encoded data, p(t) is PN chip sequence and Ø is the phase at t=0

- Implementation example with BPSK modulation



Frequency Hopping Spread Spectrum (FHSS)

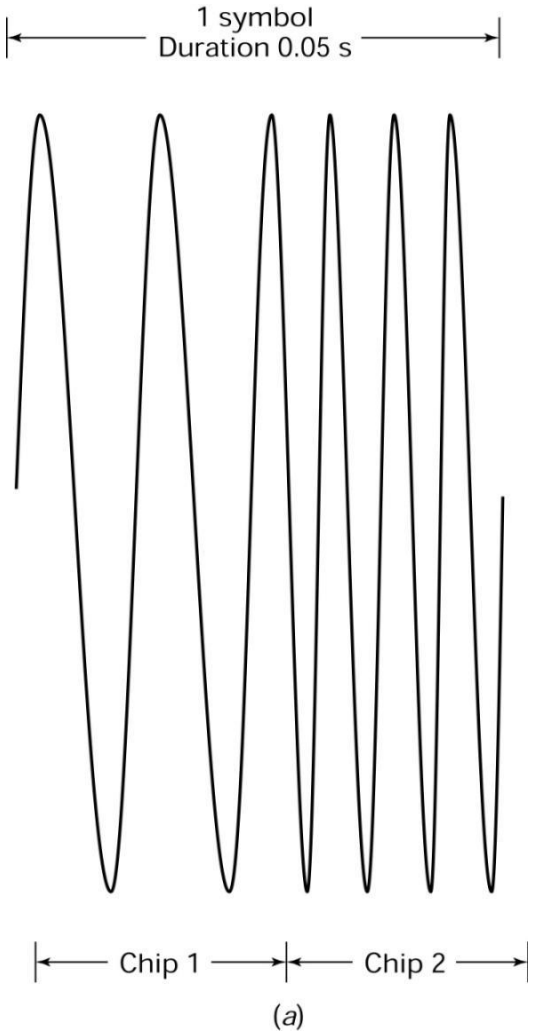
- Hopping of carrier frequency at random fashion (instead of continuous broad signal). Set of possible frequencies used is referred as *hopset*
- The output of BFSK modulator and frequency synthesizer is applied to a mixer
- The k-bit chips of PN generator enables carrier freq. to hop over 2^k distinct values.



Frequency Hopping Spread Spectrum (FHSS)

- The rate at which frequency hops determines whether it is SFH or FFH
- In *slow frequency hopping* (SFH), hopping rate, R_h is lower than the symbol ratte, R_s
- In *fast frequency hopping* (FFH), hopping rate, Rh is higher than the symbol ratte, Rs
- In FH, a “chip” refers to the shortest uninterrupted signal. The chip rate, R_c for a FH system is:

$$R_c = \max [R_h, R_s]$$



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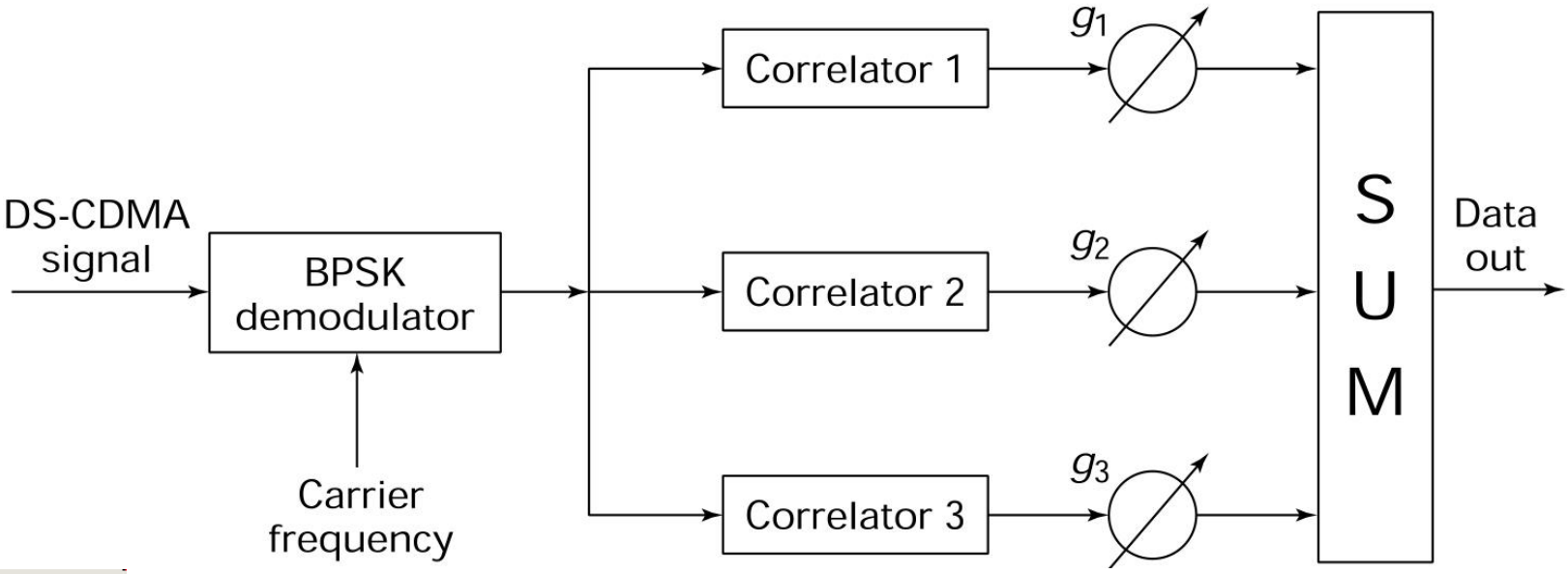
RAKE Receiver

- In DS-CDMA, the chip duration is very narrow and under the assumption that multipath delays is larger than chip duration, those delayed version of chips are resolvable
- Figure shows a conceptual RAKE receiver. The different correlators is synchronized to various paths with different delays and programmed to captured the strongest signal



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OFDMA-Orthogonal Frequency Division Multiple Access

- OFDMA is based on OFDM, where the carrying waves are distributed on multiple users
- By dividing the data stream many parallel narrowband signals we get long symbols, which reduces inter-symbol interference (ISI)
- Frequency selective fading can be suppressed by the fact that data is spread over several sub-carriers
- Interference from other users is suppressed due to the orthogonality between the carrying waves
- There is a fixed relationship between symbol length and separation between the carrying waves: $T \cdot \Delta f = 1$

OFDMA- Advantages and Disadvantages

Advantages

- Robust against frequency selective fading and interference
- Scalable bandwidth

Disadvantages

- High amplitude variation which gives high *peak to average power ratio* (PAPR). This increases in-band noise and BER (bit error rate)
- Tight synchronization between users are required for FFT in receiver
- Dealing CCI is more complex in OFDMA than CDMA

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Summary

- Multiple access allows multiple users the opportunity to share the available bandwidth
- FDMA is a simple scheme with each channel is allocated a frequency band. The main advantage is easy implementation, and that there is no need for synchronization and timing information. The main disadvantages are less flexibility in resource allocation and the need for very sharp cut-off filters.
- In TDMA users are separated in time. The main advantage (compared to FDMA) is the flexibility in resource allocation, and the possibility of variable data rate. The biggest drawback is the need for synchronization. TDMA schemes are also susceptible to fading.
- In CDMA each user is assigned a unique PN code. Each code consists of K chips, each with duration of Tc, and KTc=T, the bit duration. Thus, CDMA uses a much larger bandwidth than TDMA or FDMA. All user share the same bandwidth all the time
- In CDMA, PN sequences are almost orthogonal to each other

Summary

- Spread spectrum is a generic term for techniques that spread the information over a wide frequency range. There are two main types of spread spectrum:
  - Direct Sequence (used in CDMA)
  - Frequency Hopping

- In OFDMA orthogonal carrying waves are distributed on multiple users
  - This technique provides high robustness against frequency selective fading
  - Scalable OFDMA, which is used in LTE, provides the opportunity for flexible bandwidth utilization