Multiple Access Schemes

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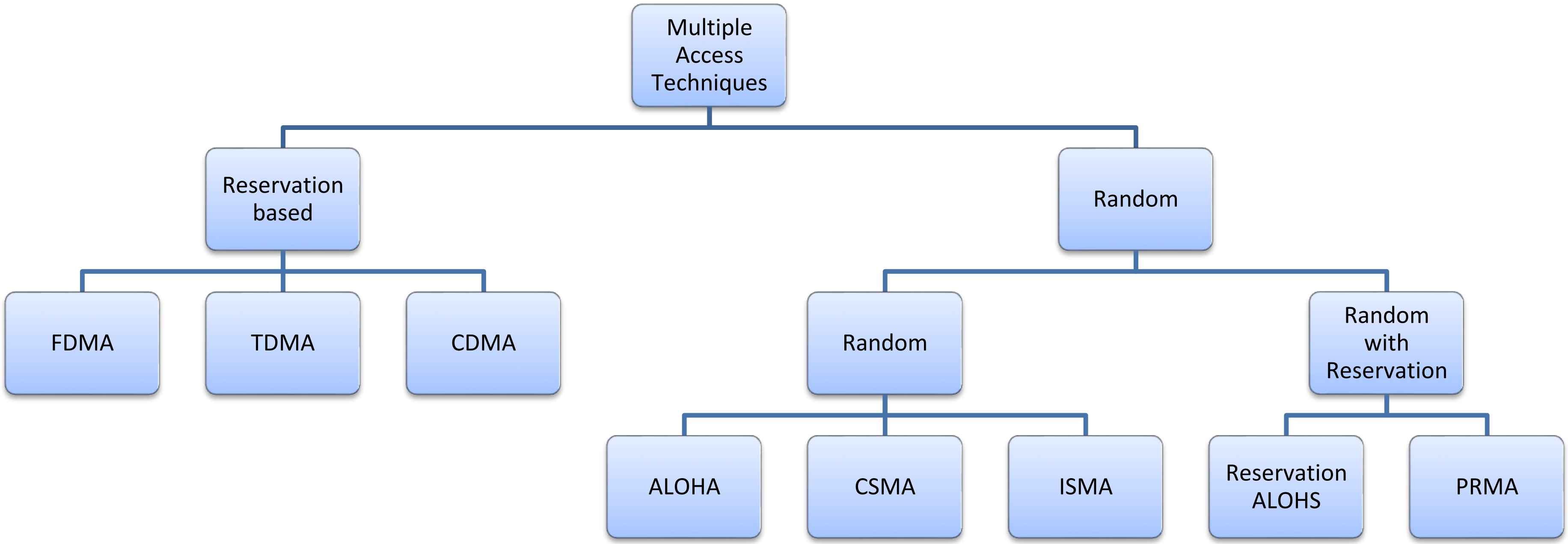
Why Multiple access schemes

- Multiple access schemes are used to allow many users to share simultaneously a finite amount of radio spectrum
- Sharing of spectrum is required to increase capacity
- For high quality communication this sharing of spectrum should not degrade performance of the system

- Defines how or when the sharing is to take place and the means for identifying individual messages. Process is known as **multiplexing** in wired networks and **multiple access** in wireless digital communications.

Multiple access schemes classification



CSMA: carrier sense multiple access
ISMA : Idle Signal Casting Multiple Access
PRMA : Packet Reservation Multiple Access

Multiplexing/Multiple Access

There four possible ways to divide the frequency spectrum among many channels:

- Space-division multiplexing (SDM)
- Frequency-division multiplexing (FDM) / Frequency Division Multiple Access (FDMA)
- Time-division multiplexing (TDM) / Time Division Multiple Access (TDMA)
- Code-division multiplexing (CDM) / Code Division Multiple Access (CDMA)

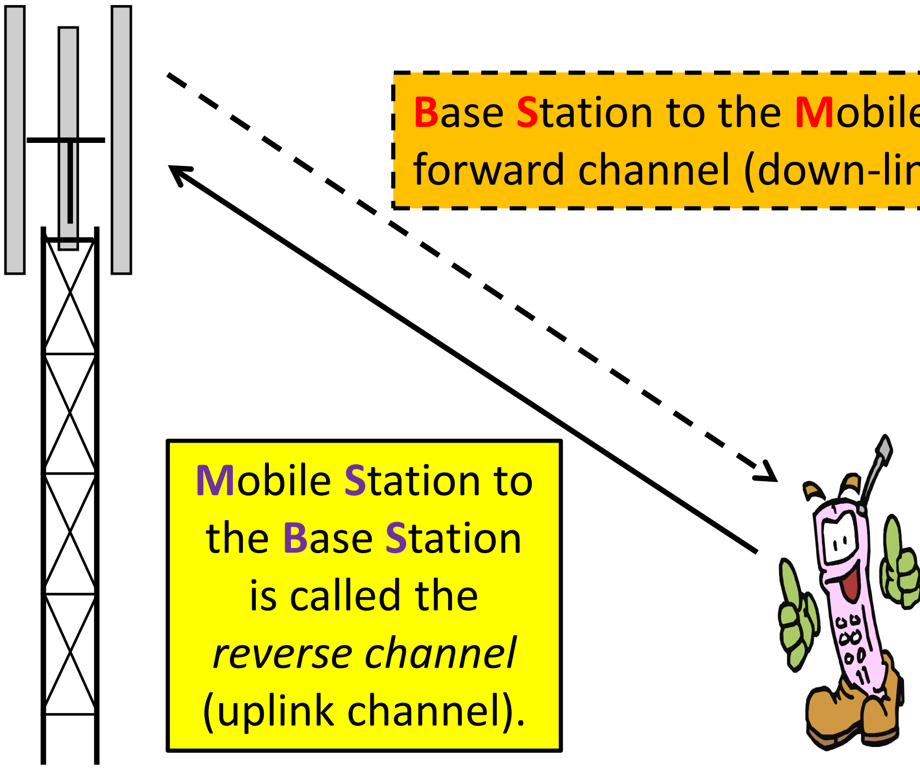
- Grouped as:
  - Narrowband systems
  - Wideband systems

Narrowband Channelized Systems

- In a channelized system, the total spectrum is divided into a large number of relatively narrow radio channels that are defined by carrier frequency.
- Each radio channel consists of a pair of frequencies.
- The forward and reverse channels are assigned widely separated frequencies to keep the interference between transmission and reception to a minimum
- A narrowband channelized system demands precise control of output frequencies for an individual transmitter.
- The transmission by a given mobile station occurs within the specified narrow bandwidth to avoid interference with adjacent channels.
- The tightness of bandwidth limitations plays a dominant role in the evaluation and selection of modulation technique.
- It also influences the design of transmitter and receiver elements, particularly the filters which can greatly affect the cost of a mobile station.

Channelized Systems

Each radio channel consists of a pair of frequencies



Base Station to the Mobile Station is called the forward channel (down-link channel)

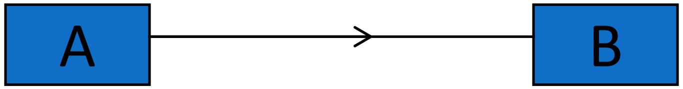
Mobile Station to the Base Station is called the *reverse channel* (uplink channel).

- A user is assigned both frequencies for the duration of the call.
- The forward and reverse channels are assigned widely separated frequencies to keep the interference between transmission and reception to a minimum

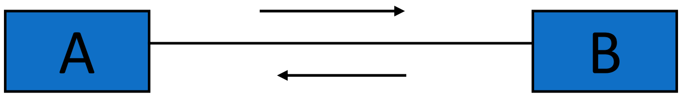
Duplexing

- What is Duplexing?
- Allow the subscriber to send “concurrently” information to the base station while receiving information from the base station.
  - ❖ to talk and listen concurrently is called duplexing
- Classification of communication systems according to their connectivity

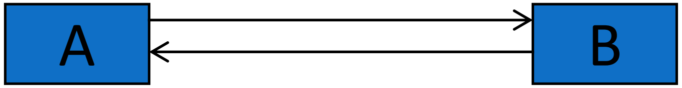
  – Simplex



  – Half-duplex

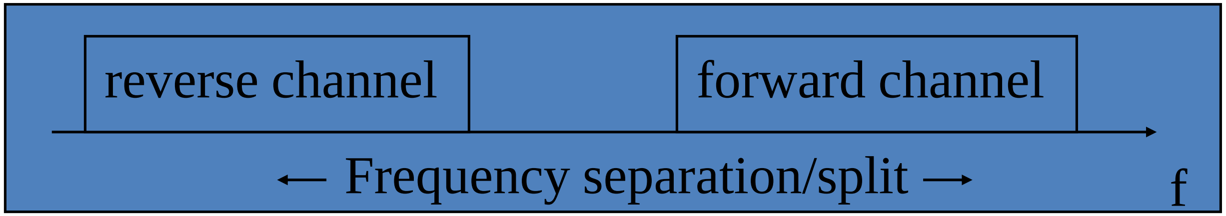


  – Duplex

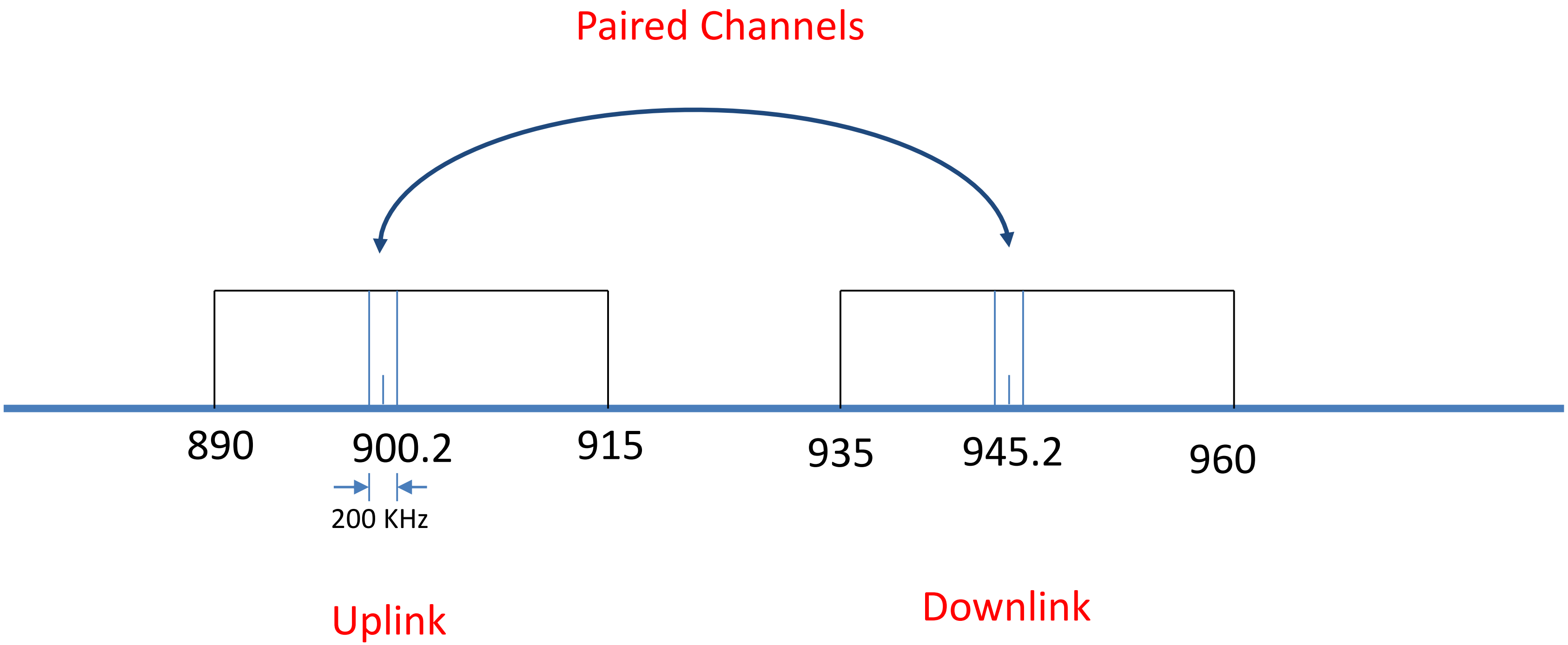


Frequency division duplexing (FDD)

- Provide ***two distinct bands*** of frequencies (simplex channels) for every user.
- Forward band, i.e. Downlink (for traffic from Base station to mobile unit)
- Reverse band, i.e. Uplink (for traffic from mobile unit to Base station)
- Frequency separation between forward band and reverse band is constant throughout the system
- Any duplex channel actually consists of two simplex channels (a forward and reverse).
- Most commercial cellular systems are based on FDD.



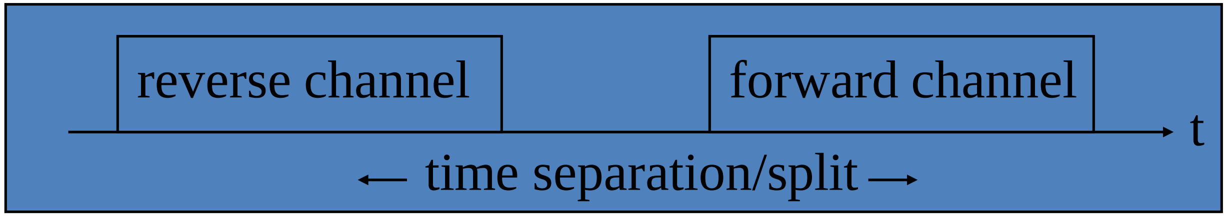
FDD Example



Paired Channels
890
900.2
915
935
945.2
960
200 KHz
Uplink
Downlink

Time division duplexing (TDD)

- The UL and DL data are transmitted on the **same carrier frequency** at different times. (Taking turns)
- Use time instead of frequency to provide both **forward and reverse links.**
- Each *duplex* channel has both a **forward time slot** and a **reverse time slot.**
- If the *time separation* between the forward and reverse time slot is *small*, then the transmission and reception of data *appears* concurrent to the users at both the subscriber unit and on the base station side.



Problems of FDD

- Each transceiver concurrently transmits and receives radio signals
  - The signals transmitted and received can vary by more than 100 dB.
  - The signals in each direction need to occupy bands that are ***separated far apart*** (tens of MHz)
- A device called a **duplexer** is required to filter out any interference between the two bands.

Advantages of FDD

- TDD frames need to incorporate guard periods **equal to the max round trip propagation delay** to avoid interference between uplink and downlink under worst-case conditions.
- There is a **time latency** created by TDD due to the fact that communications is not full duplex in the truest sense.
  - This latency creates inherent sensitivities to propagation delays of individual users.

Advantages of TDD

- Duplexer is not required.
- Enable *adjustment* of the downlink/uplink ratio to efficiently support *asymmetric* DL/UL traffic.
    - With FDD, DL and UL have fixed and generally, equal DL and UL *bandwidths*.
- Ability to implement in ***nonpaired spectrum***
    - FDD requires a pair of channels
    - TDD only requires a single channel for both DL and UL providing
- NOTE: **The amount of spectrum required for both FDD and TDD is the same.**

Narrowband systems

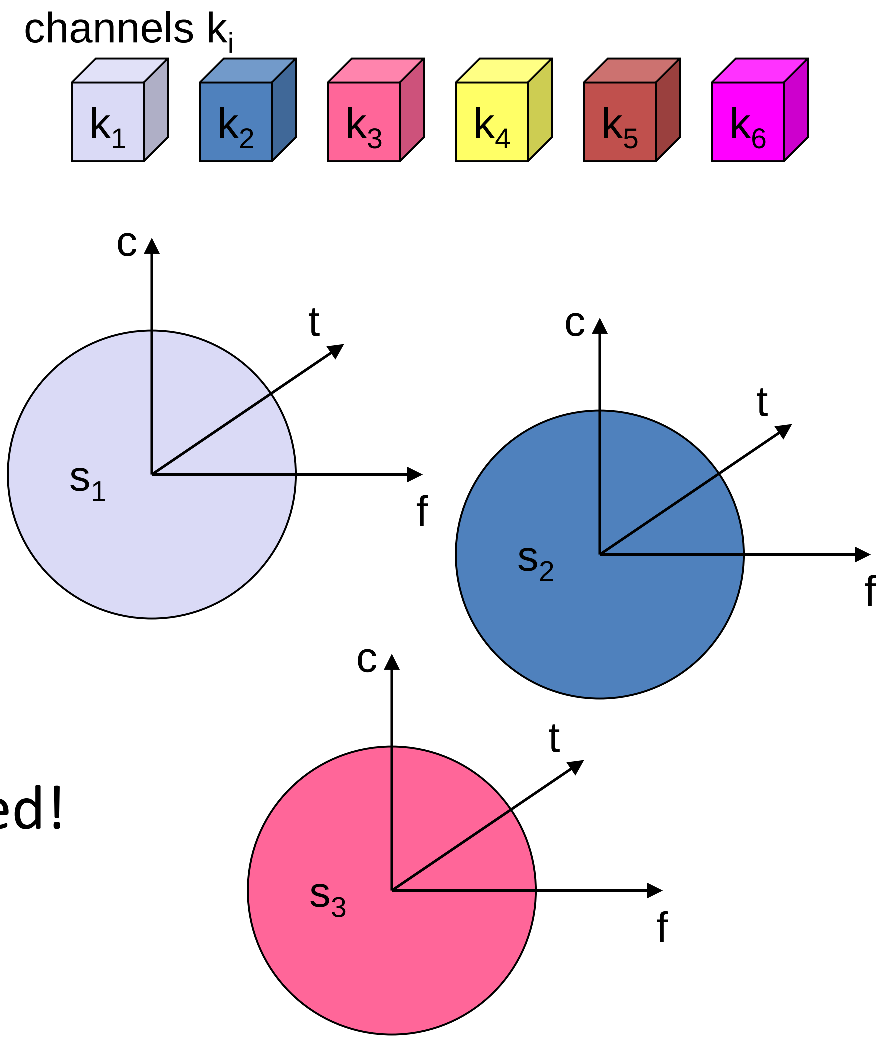
- Bandwidth of the signal is narrow compared with the coherence bandwidth of the channel.
- In Narrowband systems available radio spectrum is divided into large number of narrowband channels usually FDD (large frequency split)
- Narrowband FDMA
  - a user is assigned a particular channel which is not shared by other users
  - if FDD is used then each channel has a forward and reverse link (called FDMA/FDD)
- Narrowband TDMA
  - Allows users to share the same channel but allocates a unique time slot to each user
- FDMA/FDD
- FDMA/TDD
- TDMA/FDD
- TDMA/TDD

Wideband systems

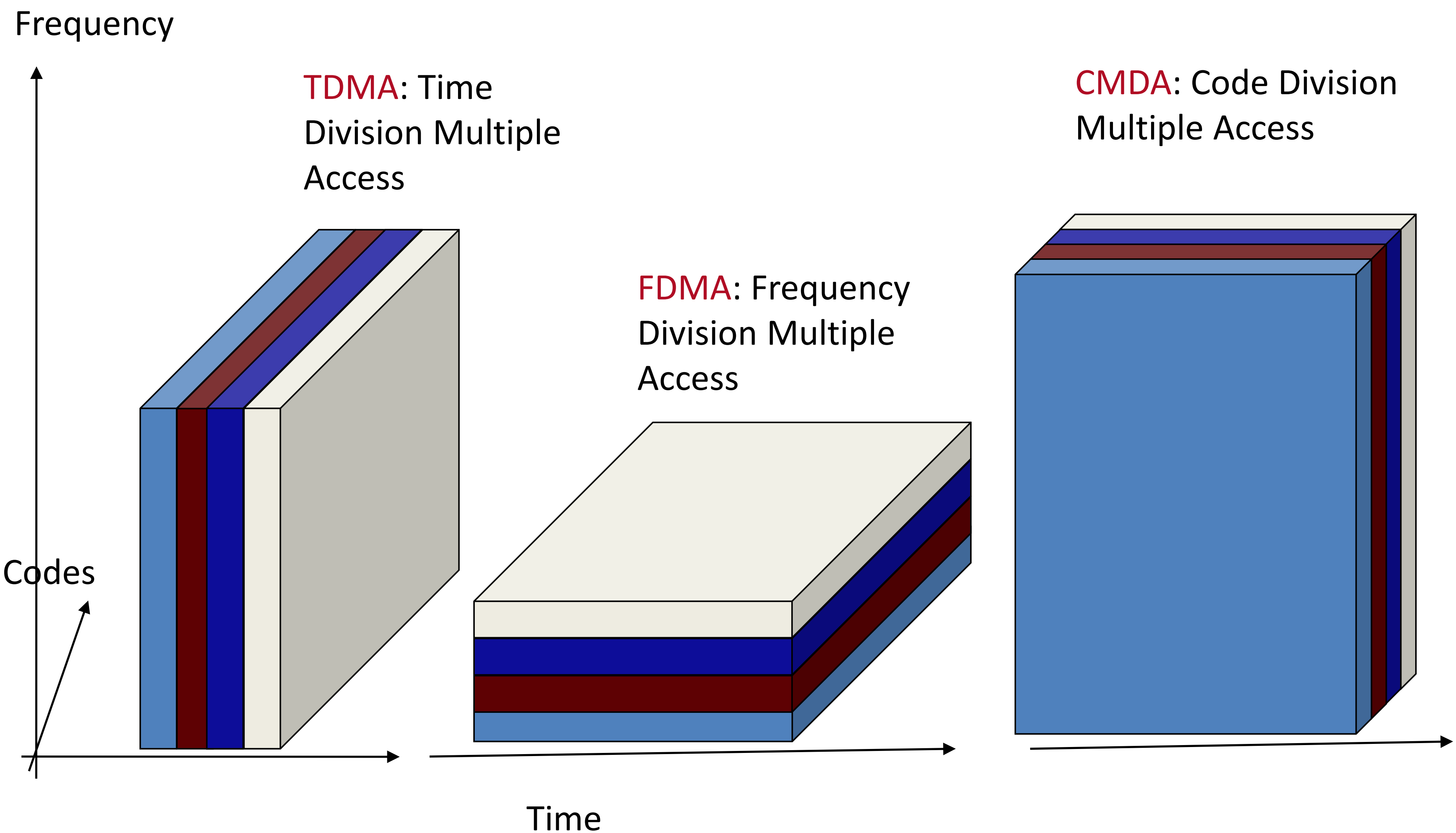
- The transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel
- Users are allowed to transmit in a large part of the spectrum
- Large number of transmitters on one channel
- TDMA techniques allocates time slots to different transmitters

Multiplexing

- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)
- Goal: multiple use of a shared medium
- Important: guard spaces needed!



Basics: Multiple Access Methods



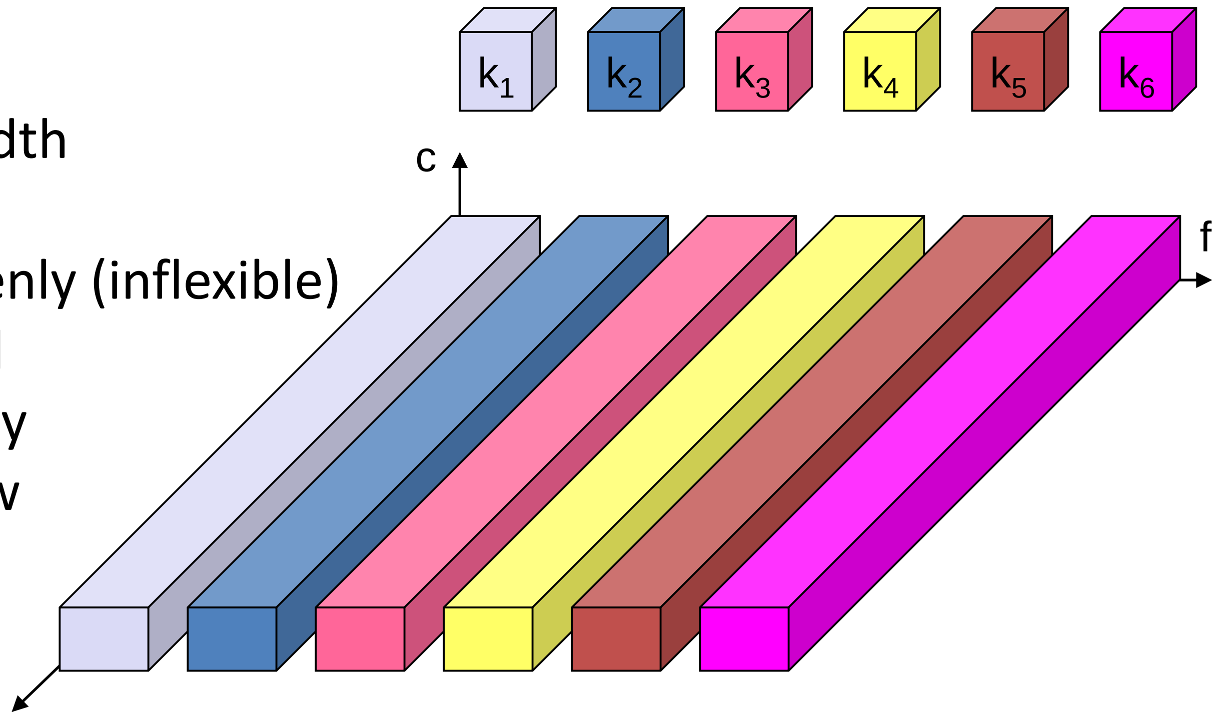
Frequency division multiple access (FDMA)

- The *oldest* multiple access scheme for wireless communications.
- Assign individual channels to individual users.
  - Different carrier frequency is assigned to each user so that the resulting spectra do not overlap.
  - During the period of the call, no other user can share the same channel.
- **Band-pass filtering** (or heterodyning) enables separate demodulation of each channel.

- If an FDMA channel is not in use, then it sits idle and can**not** be used by other users to increase or share capacity.
  - It is essentially a wasted resource.
- In FDD systems, the users are assigned a channel as a pair of frequencies (FDMA/FDD)

Frequency multiplex

Separation of the whole spectrum into smaller frequency bands
A channel gets a certain band of the spectrum for the whole time



Disadvantages:

- Waste of bandwidth if the traffic is distributed unevenly (inflexible)
- Guard bands lead to a waste of Capacity
- The maximum flow rate per channel is fixed and small
- Hardware implies narrowband filters, which cannot be realized

Number of channels in a FDMA system

$$\boxed{N = \frac{B_{sys} - B_{guard}}{B_{chan}}}$$

N:number of channels
B_{sys}: system allocated bandwidth
B_{guard}: guard band
B_{chan}: channel bandwidth

Example: Advanced Mobile Phone System

- 12.5 MHz per simplex band - B_{sys}
- B_{guard} = 2 kHz ; B_{chan} = 30 kHz

$$\boxed{N = \frac{12.5 \times 10^6 - 2 \times 10^3}{30 \times 10^3} = 416\ channels}$$

Time division multiple access (TDMA)

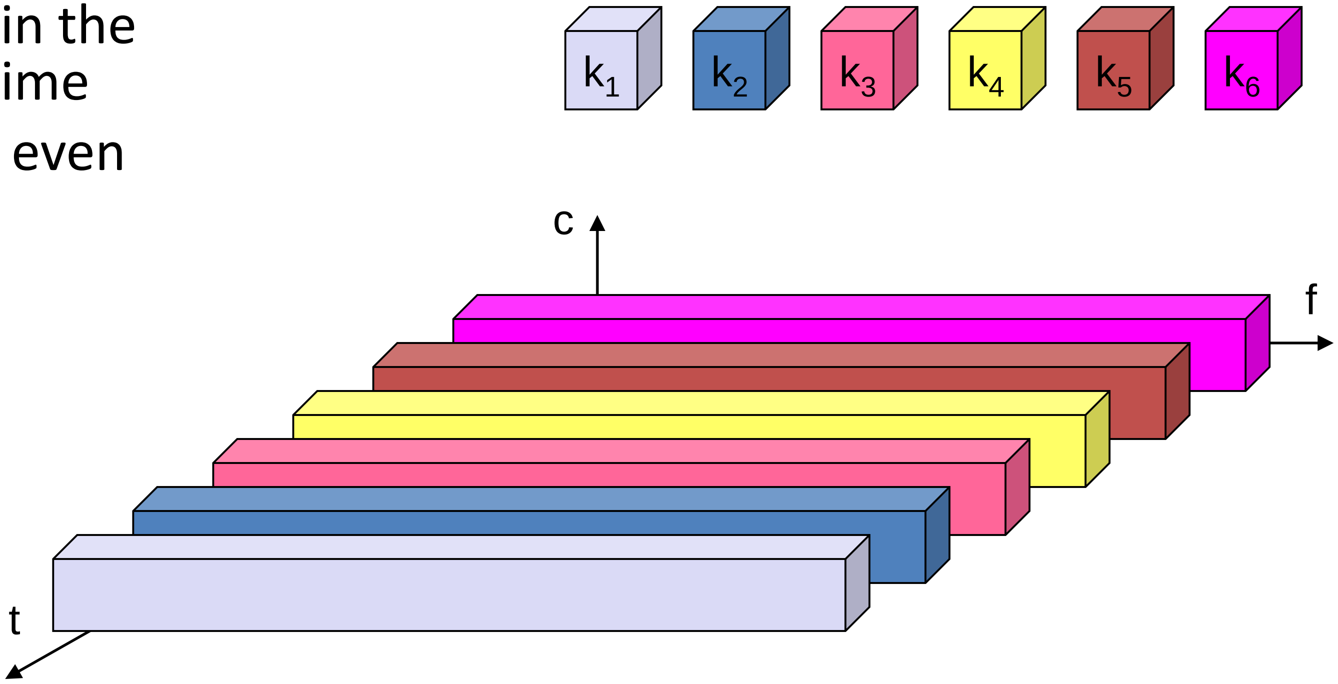
- Divide the radio spectrum into **time slots**.
- In each slot only one user is allowed to either transmit or receive.
- A channel may be thought of as a particular time slot that reoccurs every frame, where *N* time slots comprise a frame.
- Transmit data in a **buffer-and-burst method**
- The transmission for any user is non-continuous.
    - This results in low battery consumption, since the subscriber transmitter can be turned off when not in use (which is most of the time).

Time multiplex

- A channel gets the whole spectrum for a certain amount of time

- Advantages:
  - only one carrier in the medium at any time
  - throughput high even for many users

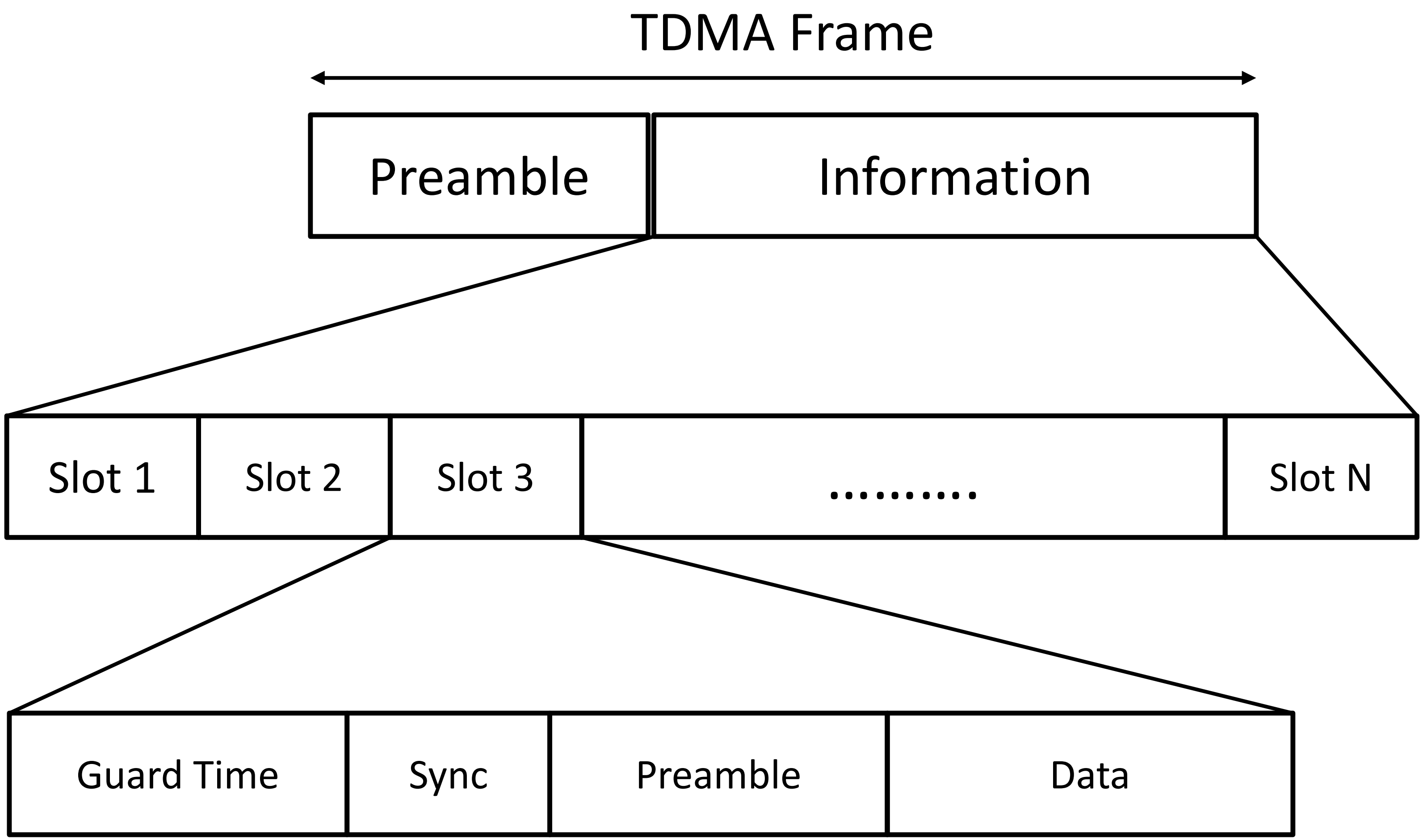
- Disadvantages:
  - precise synchronization necessary



Tradeoffs

- TDMA transmissions are slotted
- Require the receivers to be **synchronized** for each data burst.
- **Guard times** are necessary to separate users. This results in larger overheads.
- FDMA allows completely **uncoordinated transmission** in the time domain. i.e. No time synchronization among users is required.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for **overhead** purposes (such as synchronization and framing bits) as compared to TDMA.
- FDMA needs to use costly **bandpass filters**. For TDMA, no filters are required to separate individual physical channels.

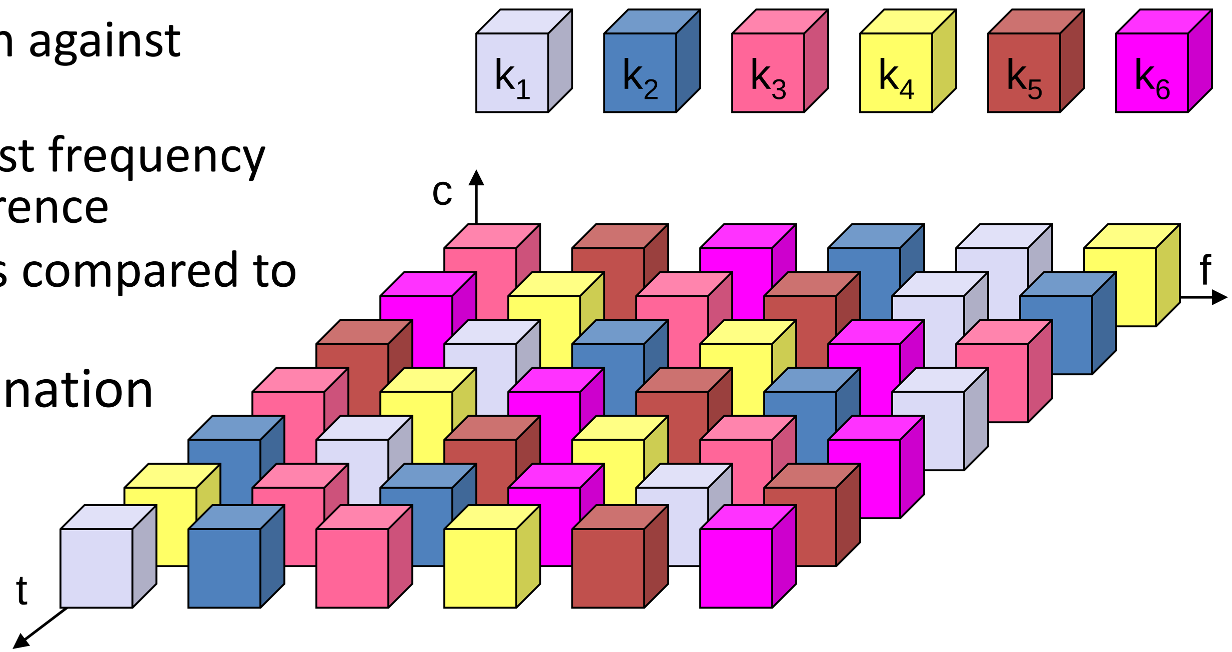
Repeating Frame Structure



Time and frequency multiplex

- Combination of both methods
- **A channel gets a certain frequency band for a certain amount of time**
- Example: GSM

- Advantages:
  - better protection against tapping
  - protection against frequency selective interference
  - higher data rates compared to code multiplex
- but: precise coordination required



Number of channels in a TDMA system

$$N = \frac{m \times \left(B_{sys} - B_{guard}\right)}{B_{chan}}$$

m:number of TDMA users per radio channel
N:number of channels
B_{sys}: system allocated bandwidth
B_{guard}: guard band
B_{chan}: channel bandwidth

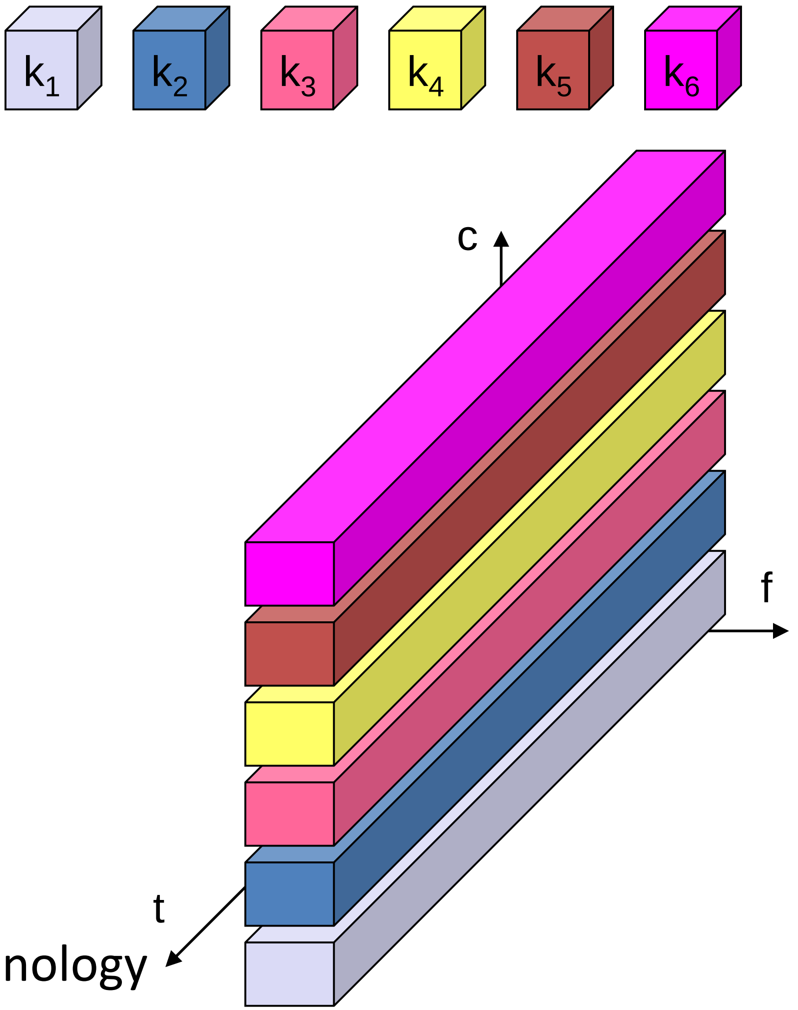
Example: Global System for Mobile (GSM)

- forward link at B_{sys} = 25 MHz
- radio channels of B_{chan} = 200 kHz
- if m = 8 speech channels supported, and
- if no guard band is assumed :

$$\boxed{N = \frac{8 \times (25 \times 10^6 - 0)}{200 \times 10^3} = 1000\ simultaneous\ users}$$

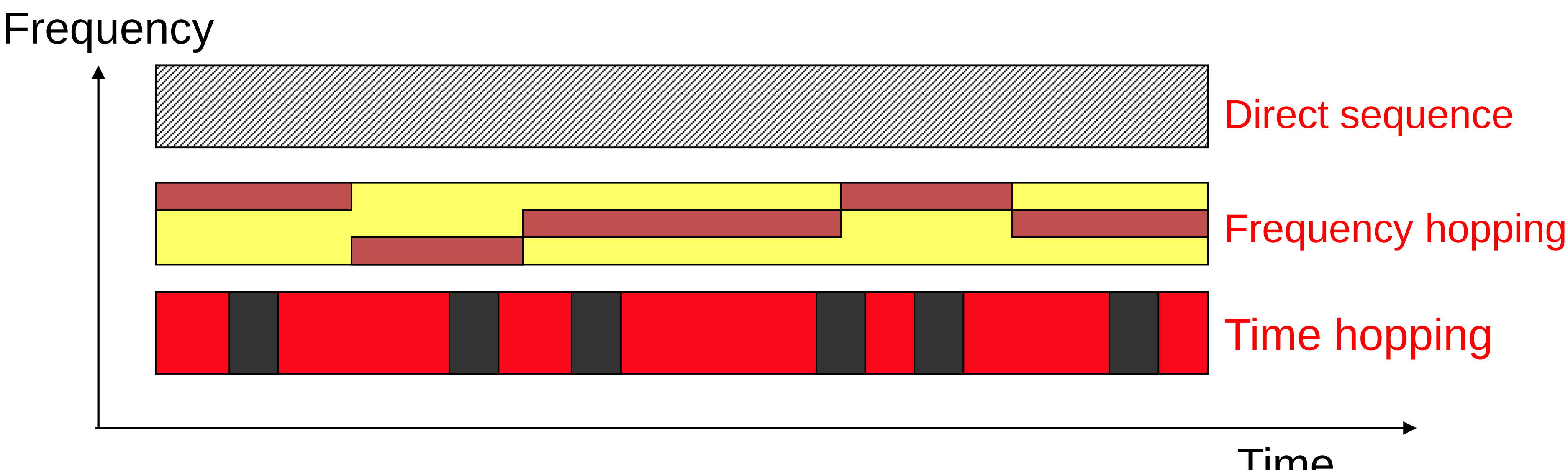
Code multiplex

- Each channel has a unique code
- All channels use the same spectrum at the same time
- Advantages:
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages:
  - more complex signal regeneration
- Implemented using spread spectrum technology



CDMA Classification

- CDMA : direct sequence (DS)
- CDMA : frequency hopping (FH)
  - Carrier frequency changes periodically, after *T* secs
  - Hopping pattern determined by spread code
- CDMA : time hopping (TH)
  - Data transmitted in rapid bursts
  - Time intervals determined by code



Wideband Systems

- In wideband systems, the entire system bandwidth is made available to each user, and is many times larger than the bandwidth required to transmit information.

- Such systems are known as *spread spectrum* (SS) systems.

- There are two fundamental types of spread spectrum systems:

(1) direct sequence spread spectrum (DSSS)

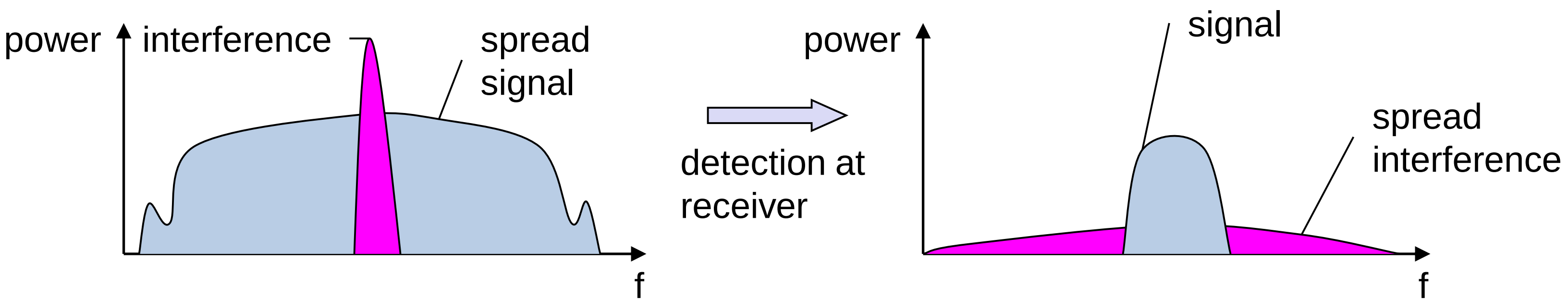
(2) frequency hopping spread spectrum (FHSS)

- In **DSSS** the bandwidth of the baseband information carrying signals from a different user is spread by different codes with a bandwidth much larger than that of the baseband signals.

- The spreading codes used for different users are orthogonal or nearly orthogonal to each other.

Spread spectrum technology

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code.



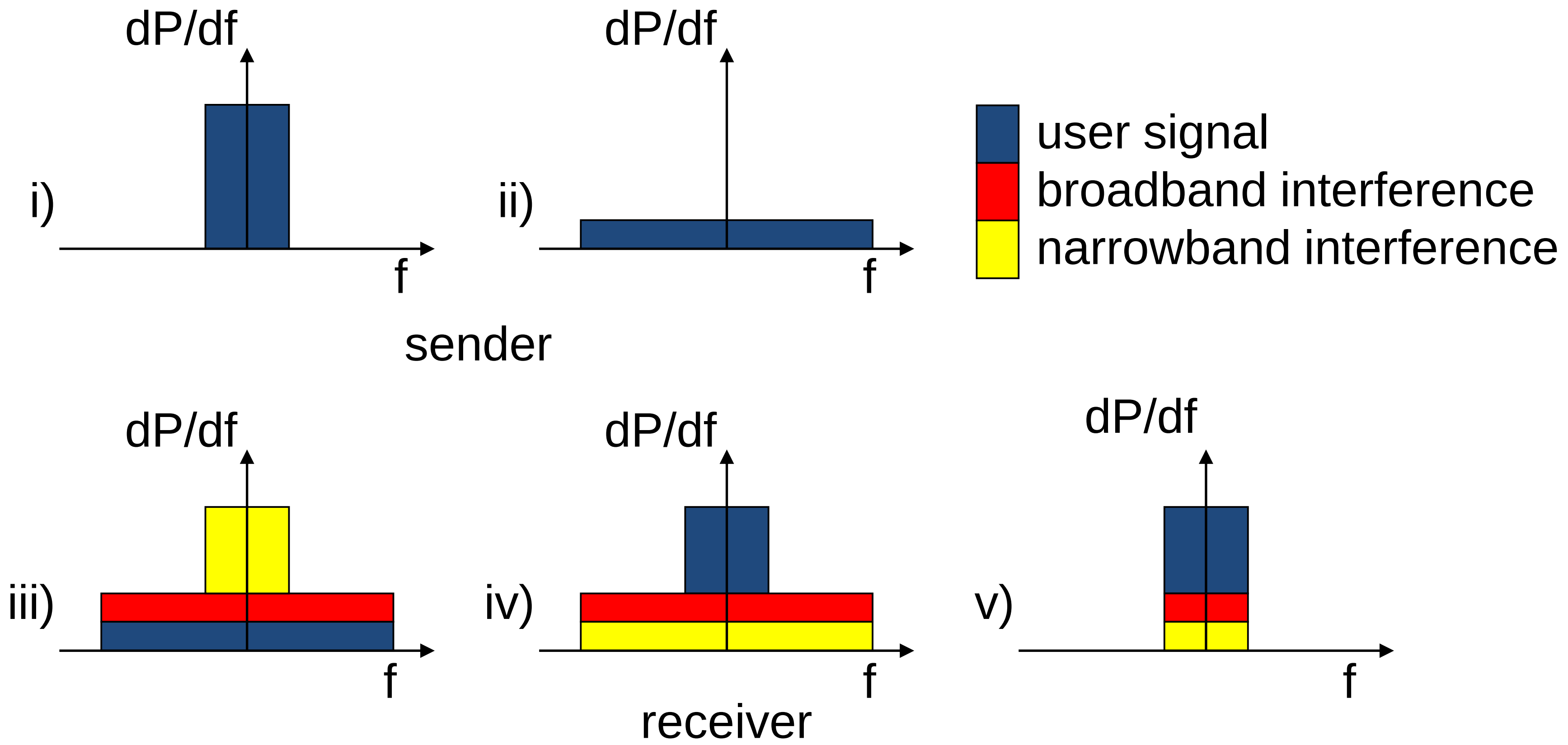
protection against narrow band interference

Side effects:

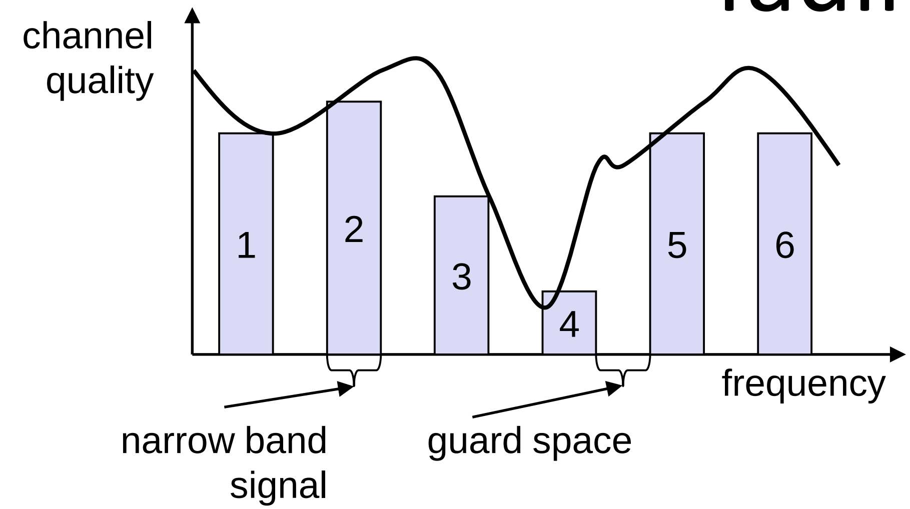
- coexistence of several signals without dynamic coordination
- tap-proof

Alternatives: Direct Sequence, Frequency Hopping

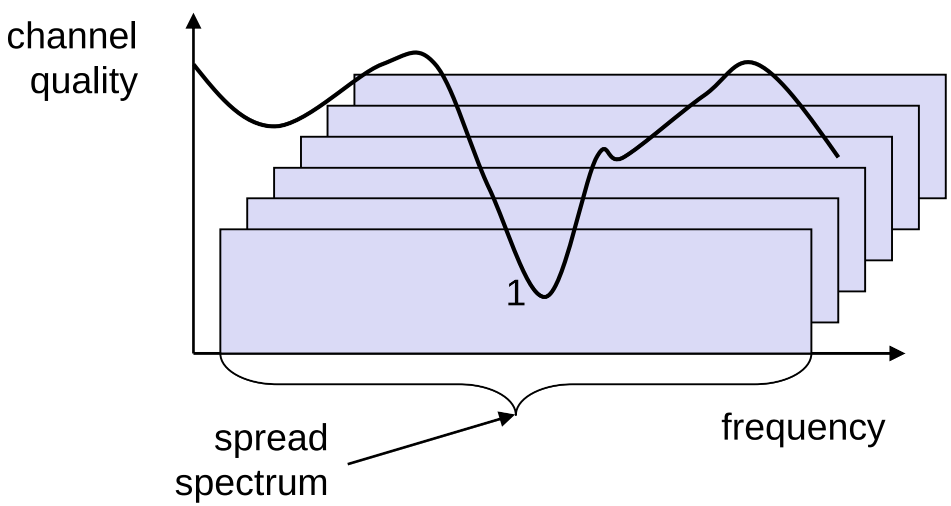
Effects of spreading and interference



Spreading and frequency selective fading



Narrowband channels



Spread spectrum channels

Spread spectrum (SS)

- Historically spread spectrum was developed for *secure* communication and *military* uses.
- **Difficult to intercept** for an unauthorized person.
- Easily **hidden**. For an unauthorized person, it is **difficult to even detect their presence** in many cases.
- **Resistant to jamming**.
- Provide a measure of immunity to distortion due to multipath propagation.
- Wide bandwidth of spread spectrum signals is useful for location and timing acquisition.
- First achieve widespread use in military applications due to
  - its inherent property of *hiding the spread signal below the noise floor* during transmission,
  - its resistance to narrowband jamming and interference, and
  - its low probability of detection and interception.

- The narrowband interference resistance has made spread spectrum common in **cordless phones**.
- The basis for both 3rd generation **cellular systems** as well as 2nd generation wireless LANs (**WLAN**).

Spread spectrum conditions

Spread spectrum refers to any system that satisfies the following conditions:

1. The spread spectrum may be viewed as a kind of modulation scheme in which **the modulated (spread spectrum) signal bandwidth is much greater than the message (baseband) signal bandwidth.**
2. The **spectral spreading** is performed by a **code** that is **independent** of the message signal.

- This same code is also used at the receiver to despread the received signal in order to recover the message signal (from the spread spectrum signal).
- In secure communication, this code is known only to the person(s) for whom the message is intended.

- Increase the bandwidth of the message signal by a factor ***N***, called the **processing gain** (or bandwidth spreading factor).
- In practice, *N* is on the order of **100-1000**.
- Although we use much higher BW for a spread spectrum signal,
    - **Multiplexing**: we can also multiplex large numbers of such signals over the same band.
    - **Multiple Access**: many users can share the same spread spectrum bandwidth without interfering with one another.
        - Achieved by assigning different code to each user.
        - Frequency bands can be reused without regard to the separation distance of the users.

Direct sequence spread spectrum

- **Direct sequence spread spectrum (DSSS)** systems take a user bit stream and perform an (XOR) with a so-called **chipping sequence**
- each user bit has a duration t_b, the chipping sequence consists of smaller pulses, called **chips**, with a duration t_c.

- If chipping sequence is generated properly it appears as random noise: pseudo-noise sequence (PN)
- The **spreading factor** (S) determines the bandwidth of the resulting signal

$$\boxed{S = \frac{t_b}{t_c}}$$

- If the original signal needs a bandwidth W, the resulting signal needs $S \cdot W$ after spreading.

DSSS (Direct Sequence Spread Spectrum) I

XOR of the signal with pseudo-random number (chipping sequence)

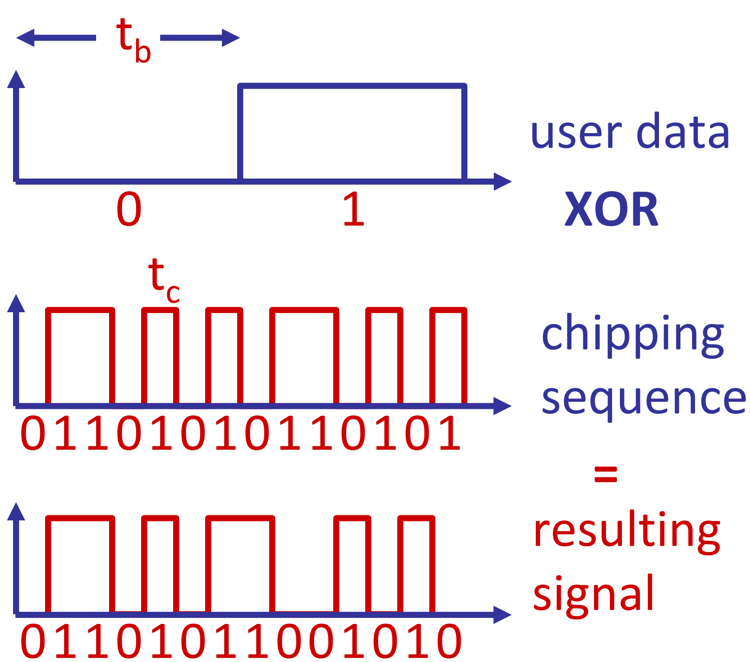
- many chips per bit (e.g., 128) result in higher bandwidth of the signal

Advantages

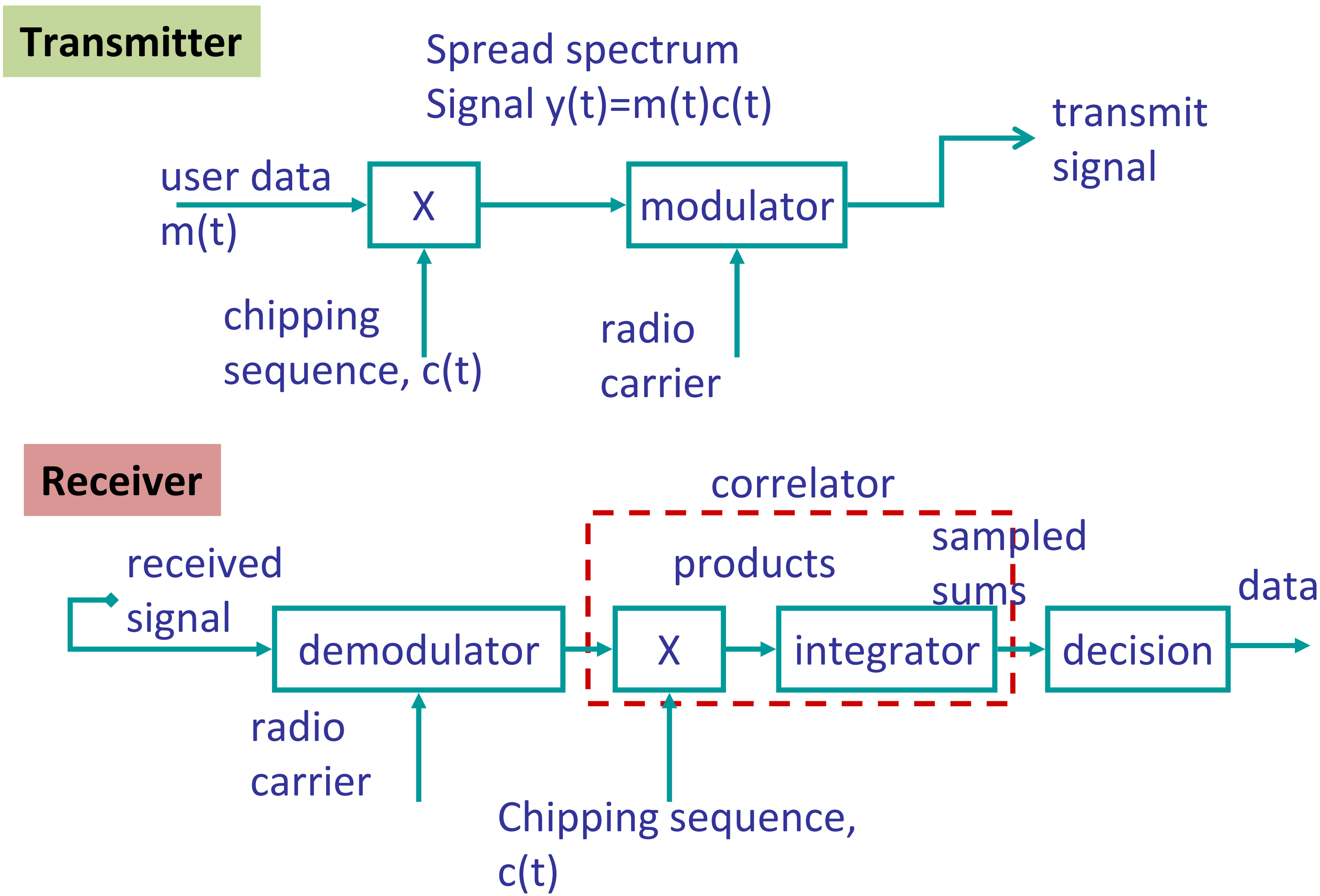
- reduces frequency selective fading.
- in cellular networks .
  - base stations can use the same frequency range
  - several base stations can detect and recover the signal
  - soft handover

Disadvantages

- precise power control necessary



DSSS (Direct Sequence Spread Spectrum) II



Frequency Hopping Spread Spectrum (FHSS) I

- The total available bandwidth is split into many channels of smaller bandwidth plus guard spaces between the channels.
- Transmitter and receiver stay on one of these channels for a certain time and then hop to another channel.
- This system implements FDM and TDM
- The pattern of channel usage is called the **hopping sequence**
- The time spend on a channel with a certain frequency is called the **dwell time**
- **It can be described as:** Discrete changes of carrier frequency where the sequence of frequency changes determined via pseudo random number sequence

Frequency Hopping Spread Spectrum (FHSS) II

Two versions

- Slow Hopping:
  - The transmitter uses one frequency for several bit periods.
- Fast Hopping:
  - the transmitter changes the frequency several times during the transmission of a single bit

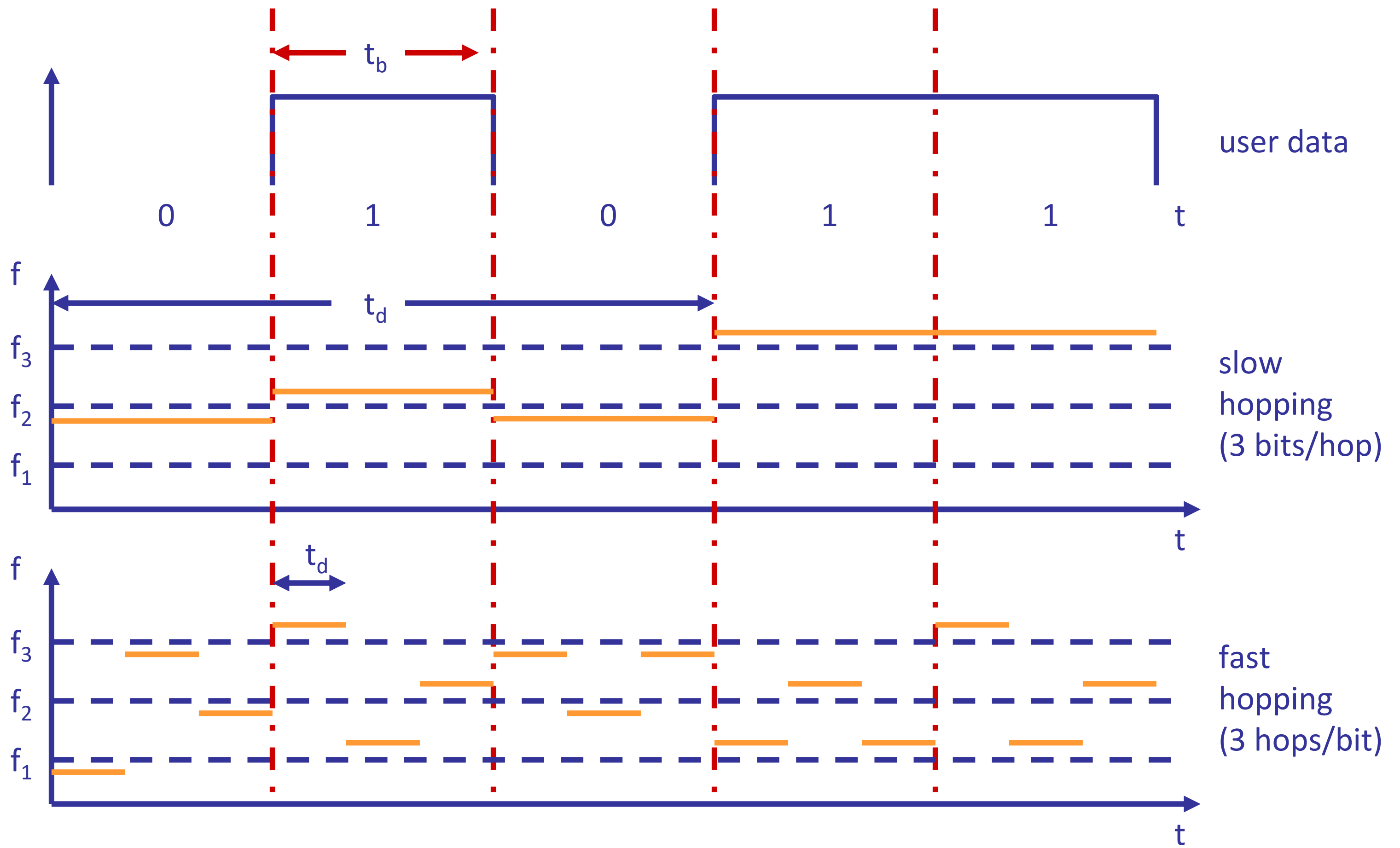
Advantages

- frequency selective fading and interference limited to short period
- simple implementation
- uses only small portion of spectrum at any time

Disadvantages

- not as robust as DSSS
- simpler to detect

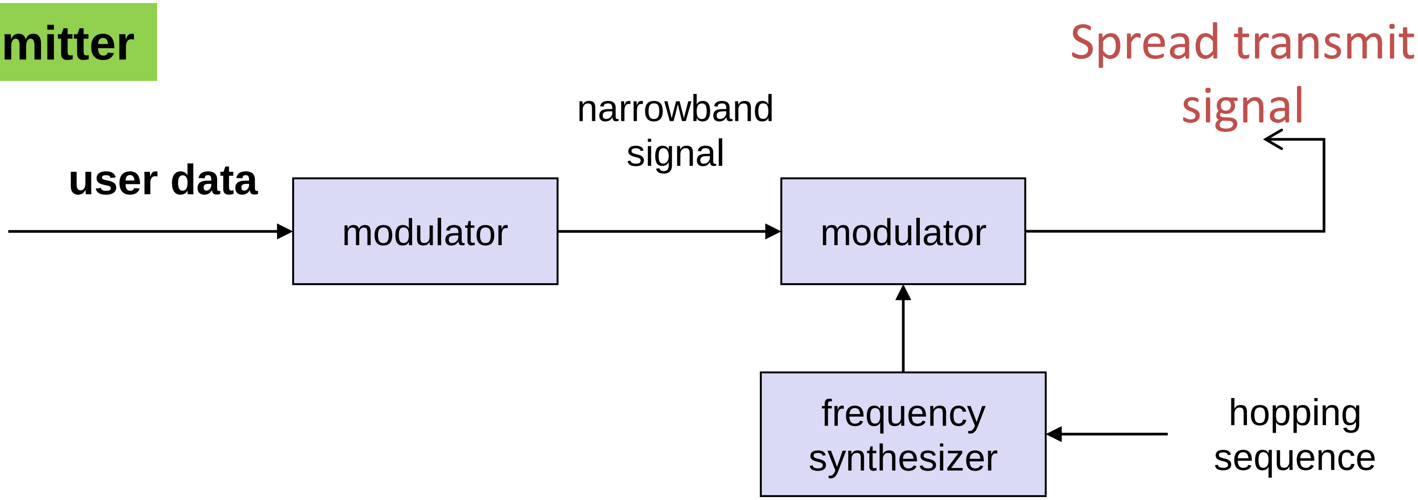
Frequency Hopping Spread Spectrum (FHSS) III



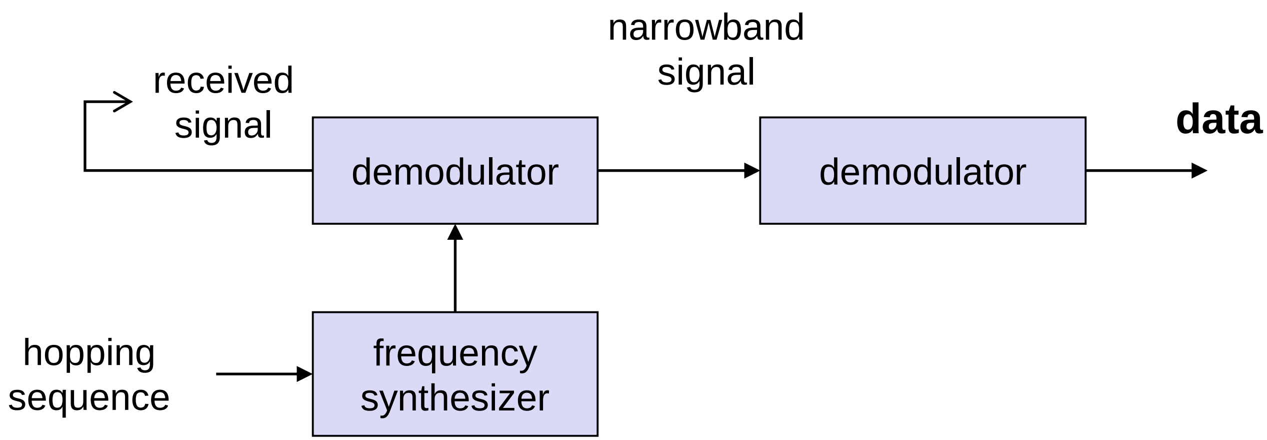
t_b: bit period t_d: dwell time

Frequency Hopping Spread Spectrum (FHSS) IV

Transmitter



Receiver



DSSS Vs. FHSS

- Spreading is simpler using FHSS systems.
- FHSS systems only use a portion of the total band at any time.
- DSSS systems always use the total bandwidth available.
- DSSS more resistant to fading and multi-path effects.
- DSSS signals are much harder to detect without knowing the spreading code.

Further reading:

John Schiller, “Mobile Communications”, section 2.5 and 2.7.