Integrated Technical Education Cluster
At AlAmeeria

E-716-A
Mobile Communications Systems

Lecture #4
Basic Concepts of Cellular Transmission (p1)

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Agenda

- Spread Spectrum
- Frequency hopping & Direct Sequence
- CDMA & OFDMA
- MIMO Technique
- Speech Compression

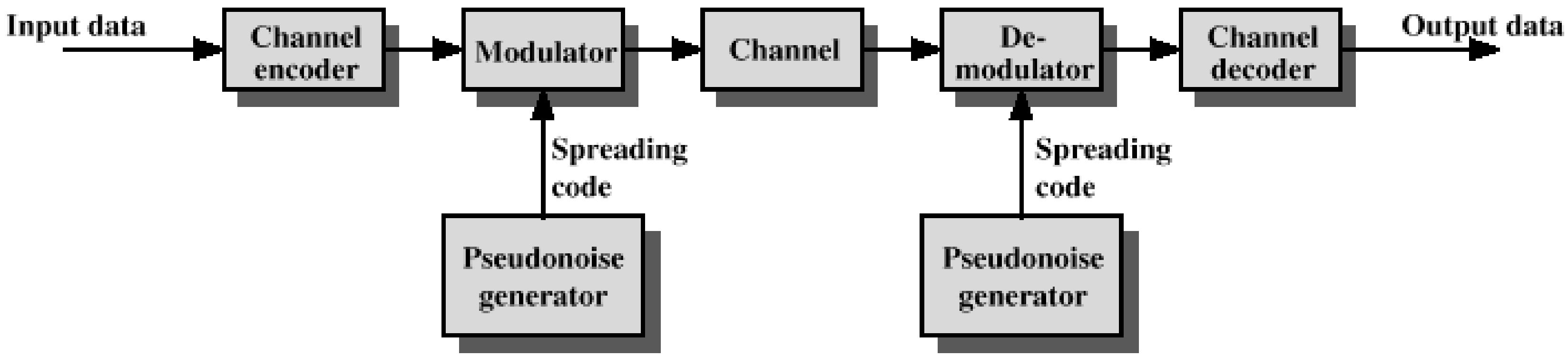
SPREAD SPECTRUM

Spread Spectrum

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - Spreading code or spreading sequence
  - Generated by pseudonoise*, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted
- On receiving end, digit sequence is used to demodulate the spread spectrum signal
- Signal is fed into a channel decoder to recover data

* PN generator produces periodic sequence that appears to be random and is generated by an algorithm using initial seed

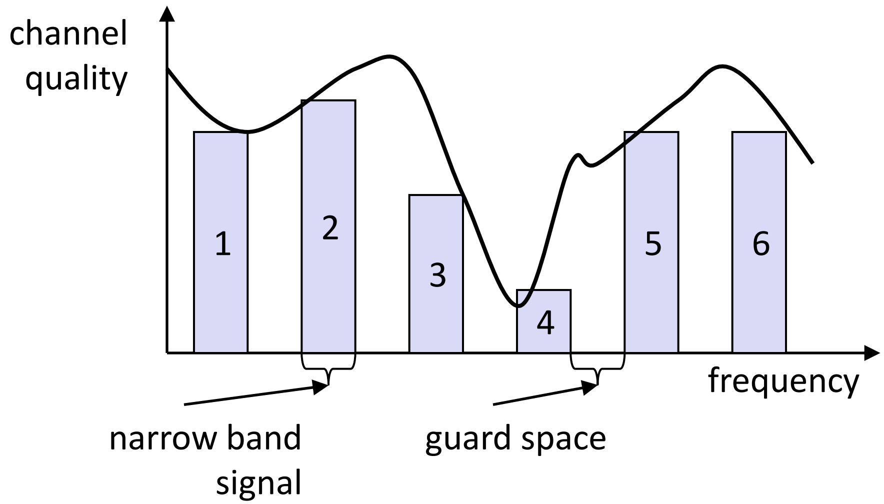
Spread Spectrum ..



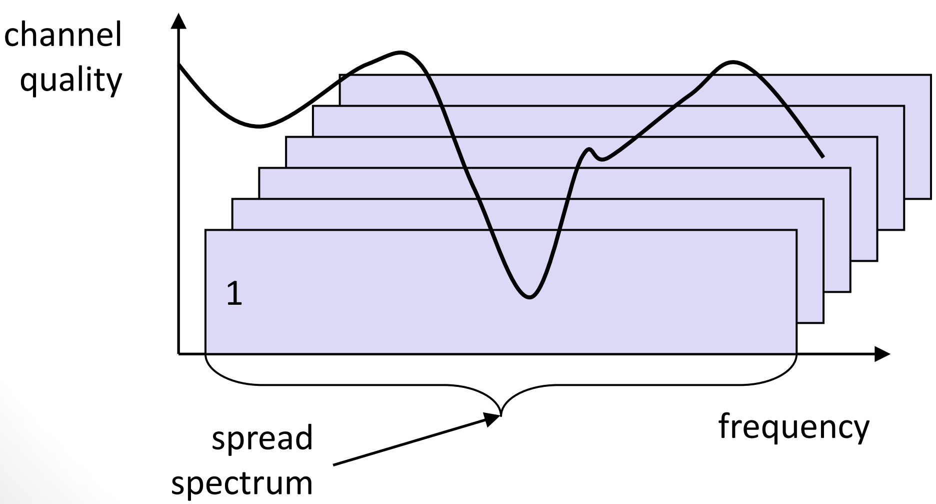
General Model of Spread Spectrum Digital Communication System

- What can be gained from apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion.
  - Can be used for hiding and encrypting signals.
  - Several users can independently use the same higher bandwidth with very little interference (Example: CDMA)

Spreading and Frequency Selective Fading



narrowband channels

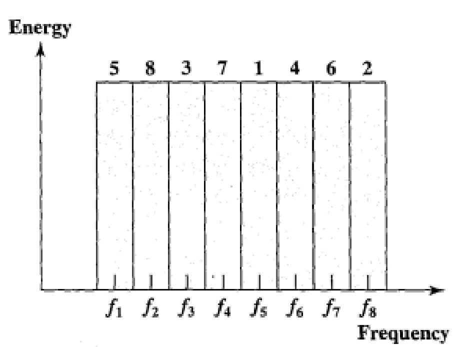


spread spectrum channels

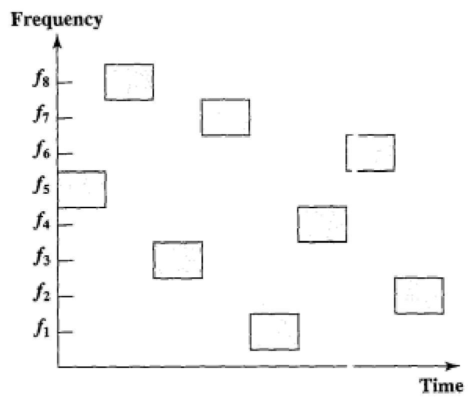
FREQUENCY HOPPING & DIRECT SEQUENCE

Frequency Hoping Spread Spectrum (FHSS)

- Signal is broadcast over random series of radio frequencies
- Signal hops from frequency to frequency at fixed intervals
- Channel sequence dictated by spreading code
- Receiver, hopping between frequencies in synchronization with transmitter, picks up message



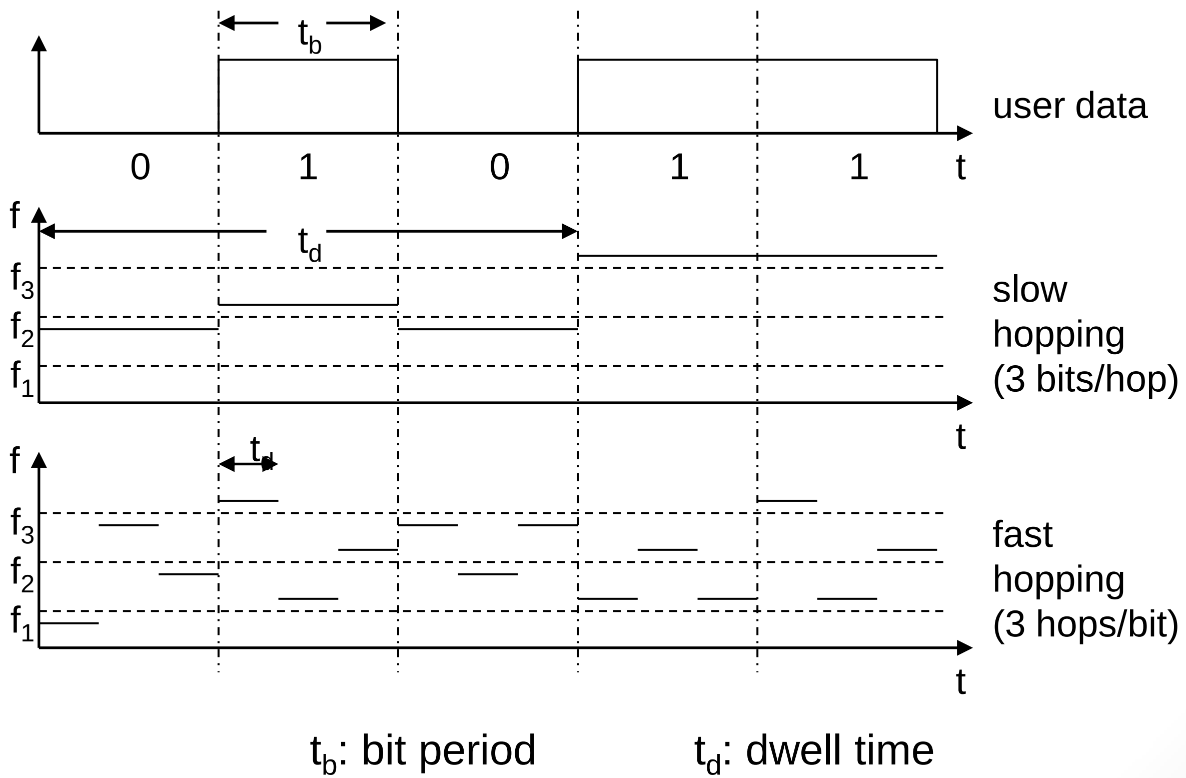
(a) Channel assignment



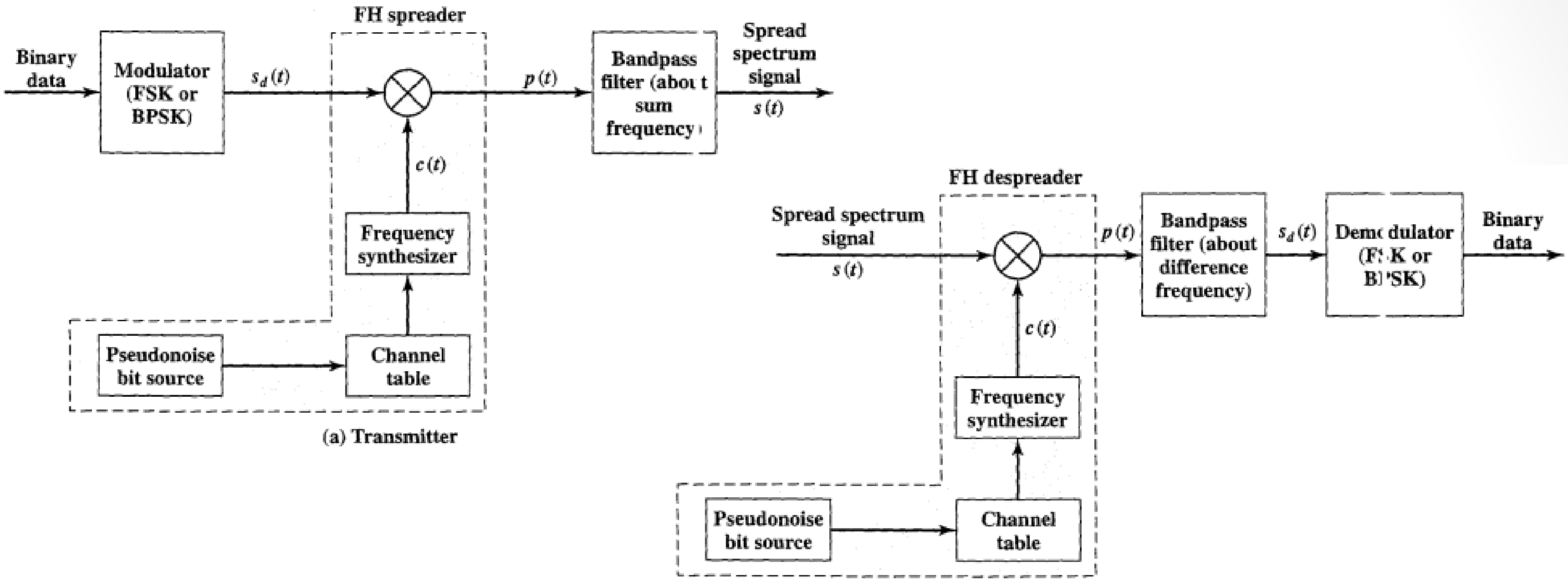
(b) Channel use

FHSS..

- Two versions
  - Fast Hopping: several frequencies per user bit
  - Slow Hopping: several user bits per frequency



FHSS…

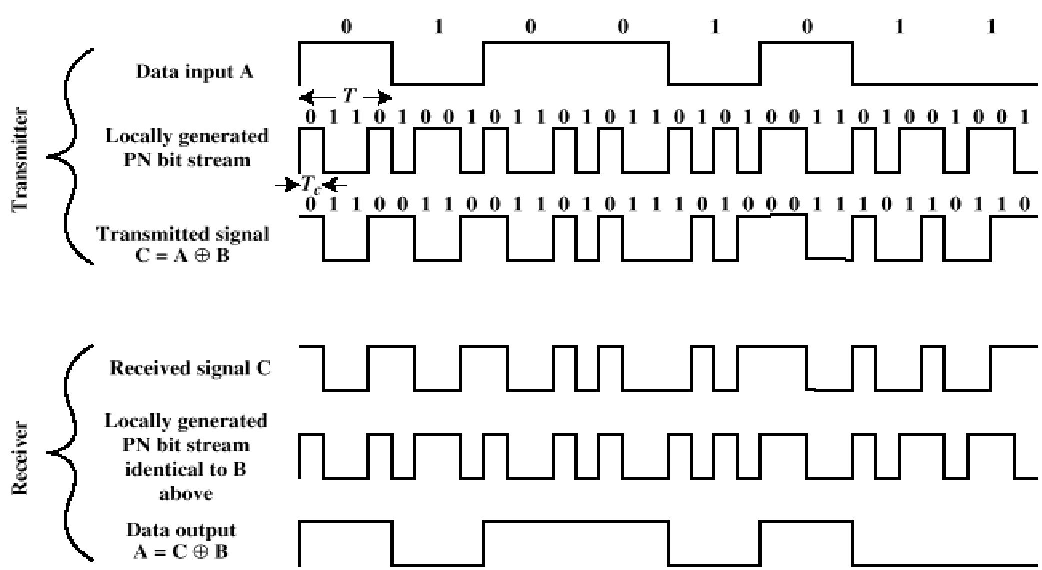


(b) Receiver

- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
  - Resistant to jamming
- Disadvantages
  - simpler to detect
  - not as robust as DSSS

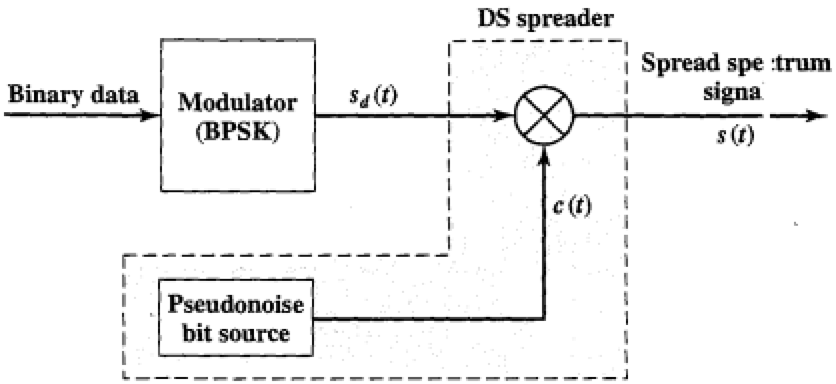
Direct Sequence Spread Spectrum (DSSS)

- Each bit in original signal is represented by multiple bits in the transmitted signal
- The spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used.
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR

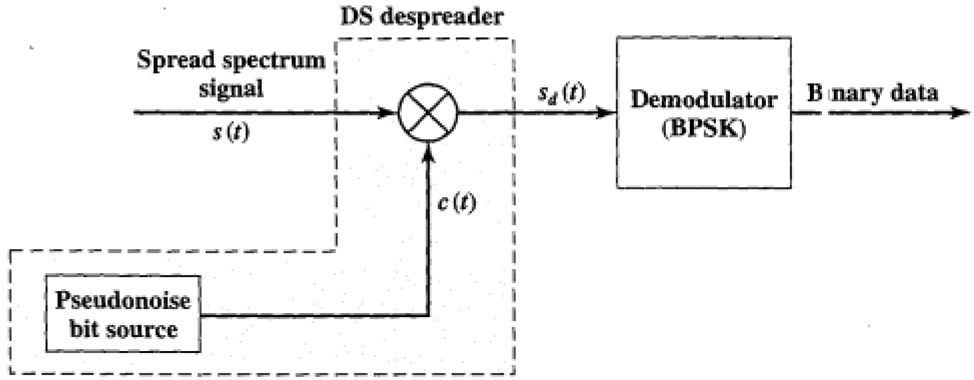


Example of Direct Sequence Spread Spectrum

DSSS..



(a) Transmitter



(b) Receiver

- 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

CDMA & OFDMA

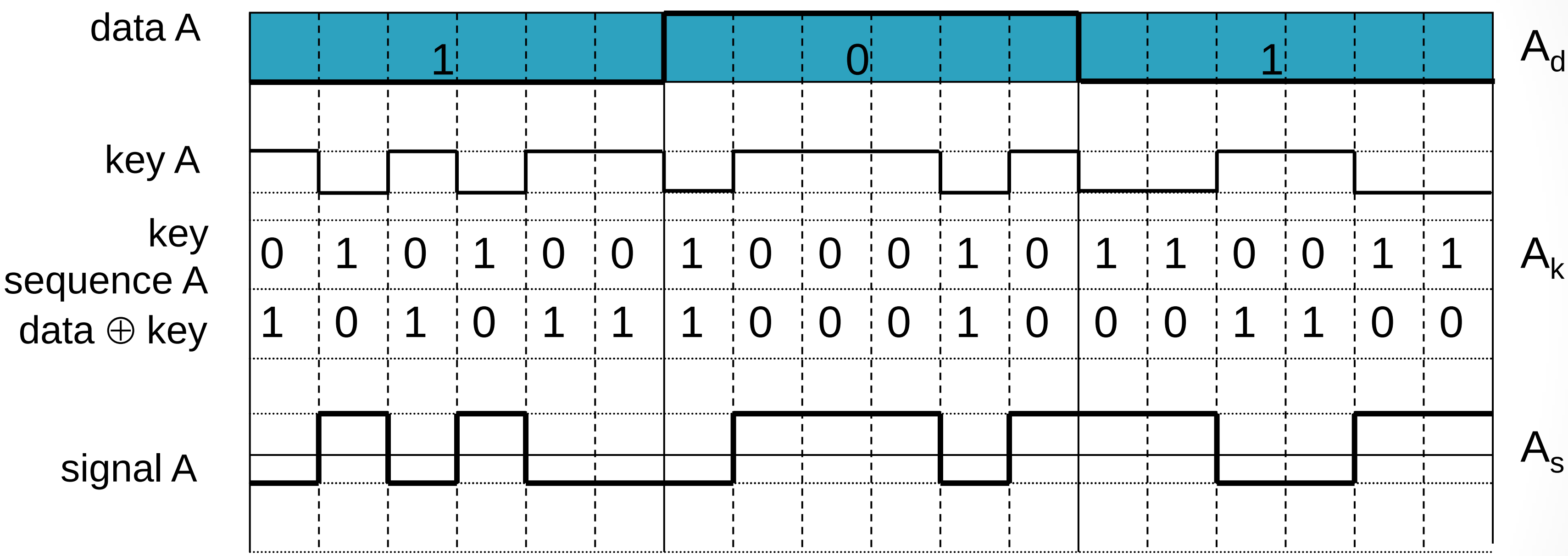
CDMA

- CDMA (Code Division Multiple Access)
  - all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
  - each sender has a unique random number, the sender XORs the signal with this random number
  - the receiver can "tune" into this signal if it knows the pseudo random number
- Disadvantages:
  - higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - all signals should have the same strength at a receiver
- Advantages:
  - all terminals can use the same frequency, no planning needed
  - huge code space (e.g. 2^{32}) compared to frequency space
  - interferences (e.g. white noise) is not coded
  - forward error correction and encryption can be easily integrated

CDMA in theory

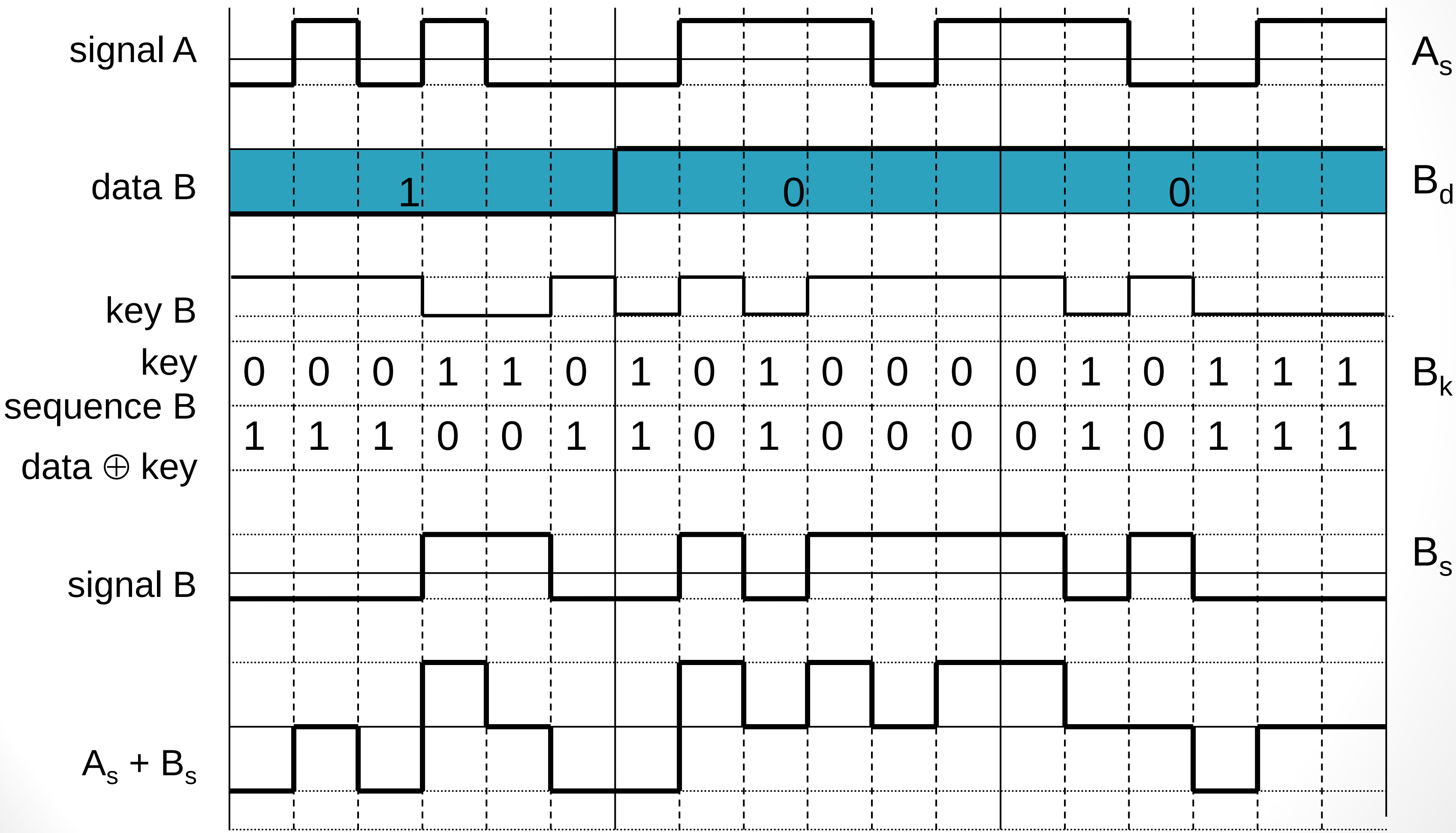
- Sender A
  - sends A_d = 1, key A_k = 010011 (assign: "0"= -1, "1"= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends B_d = 0, key B_k = 110101 (assign: "0"= -1, "1"= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
  - interference neglected (noise etc.)
  - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
  - apply key A_k bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was "1"
  - receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. "0"

CDMA in Signal level

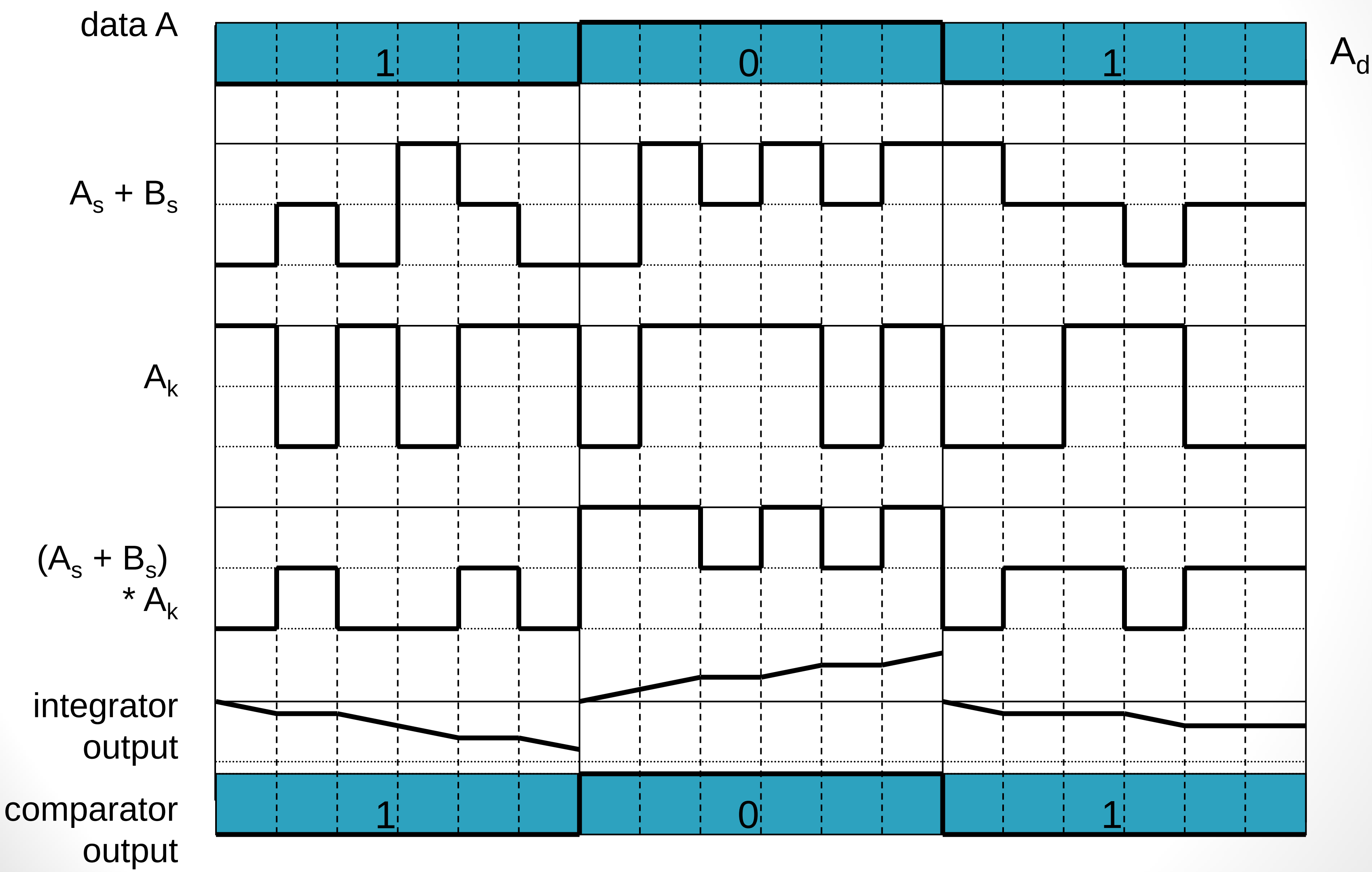


Real systems use much longer keys resulting in a larger distance between single code words in code space.

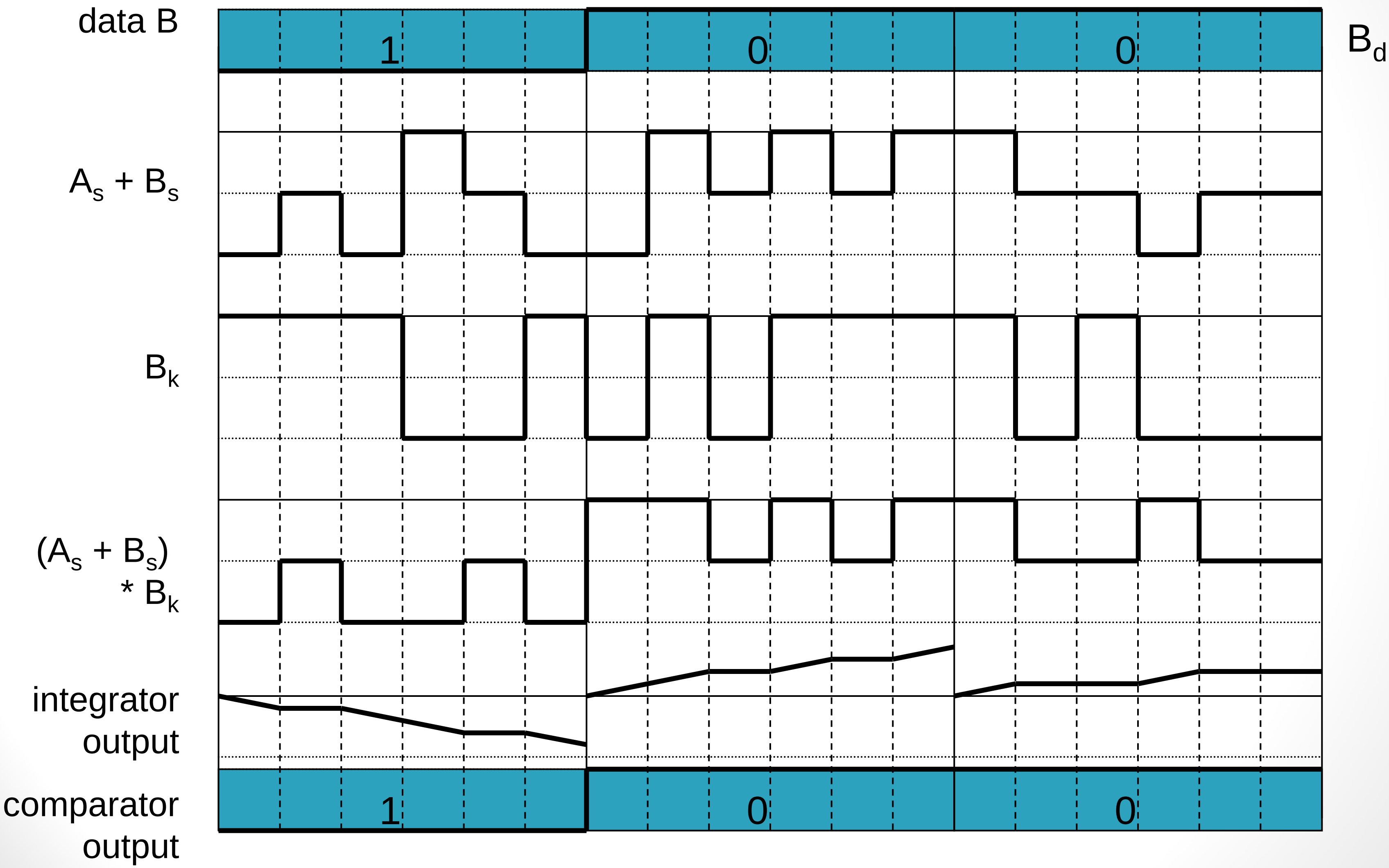
CDMA in Signal level..



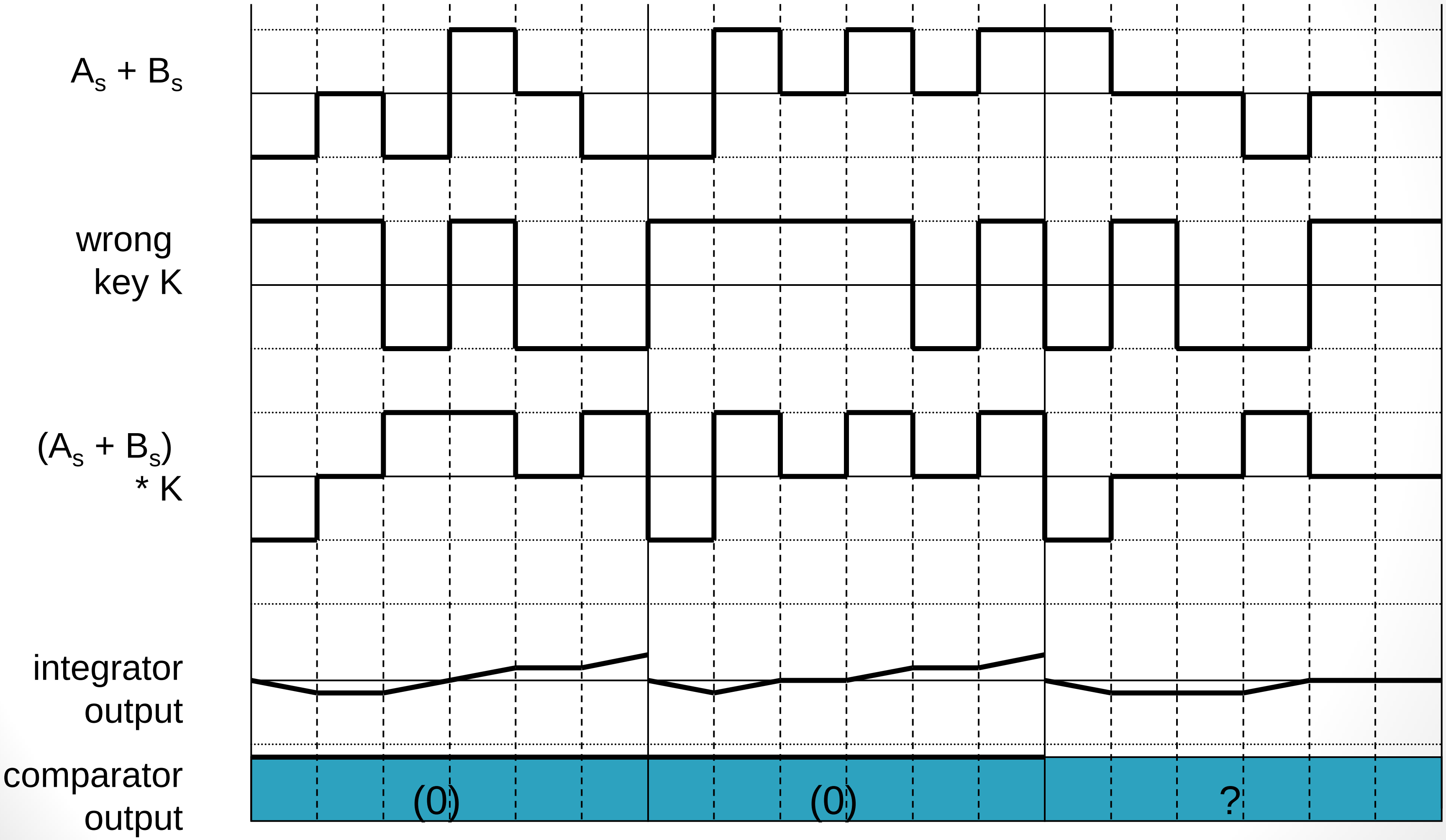
CDMA in Signal level…



CDMA in Signal level....



CDMA in Signal level.....

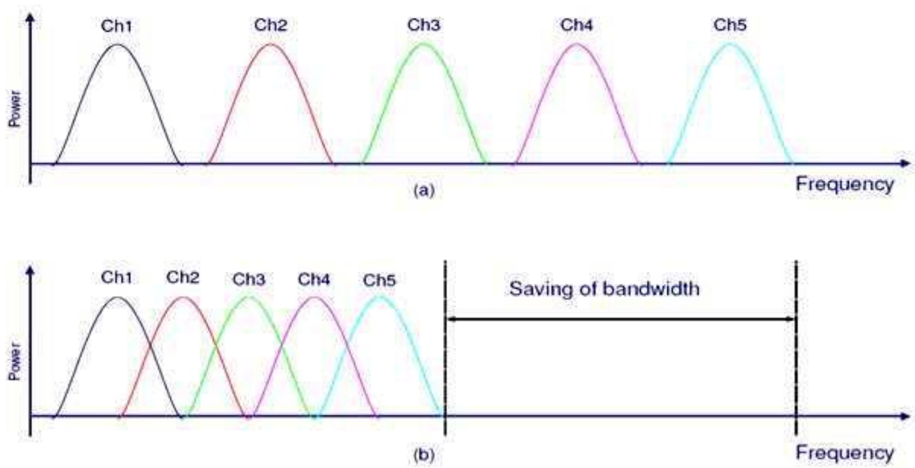


Comparison of S/T/F/C DMA

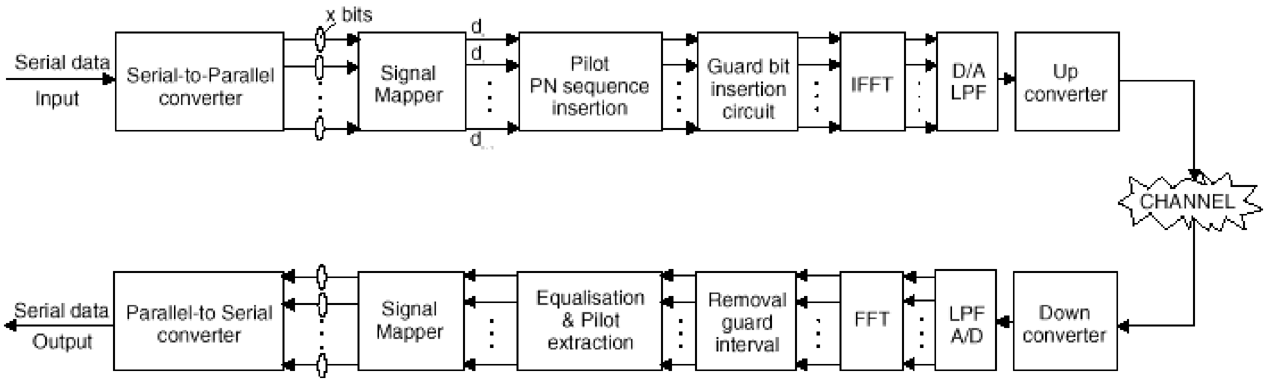
Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

OFDM

- OFDM, Orthogonal Frequency Division Multiplexing, is a special kind of FDM.
- The spacing between carriers are such that they are orthogonal to one another meaning the peak of one sub-carrier coincides with the null of an adjacent sub-carrier.
- Therefore no need of guard band between carriers and the result is saving of bandwidth.



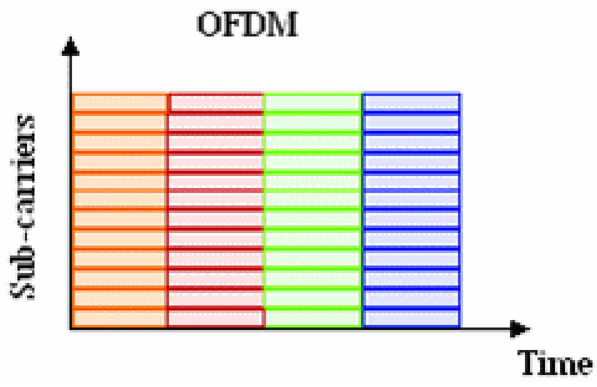
OFDM..

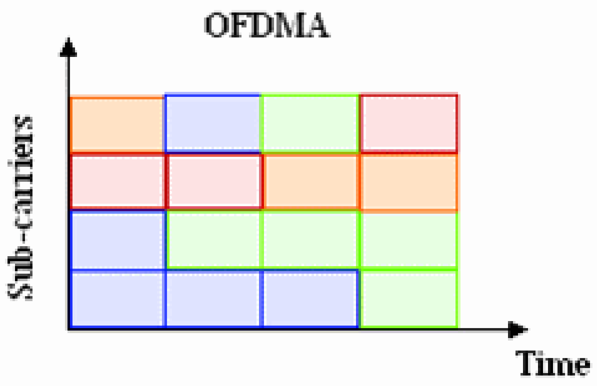


- In an OFDM system, a very high rate data stream is divided into multiple parallel low rate data streams.
- Each smaller data stream is then mapped to individual data sub-carrier and modulated using some PSK/QAM Modulation (QPSK, 16-QAM, 64-QAM).
- OFDM needs less bandwidth than FDM to carry the same amount of information which results in higher spectral efficiency.
- The effect of ISI (Inter Symbol Interference) is suppressed by virtue of a longer symbol period of the parallel OFDM subcarriers than a single carrier system and the use of a cyclic prefix (CP).

OFDMA

- Like OFDM, OFDMA, Orthogonal Frequency Division Multiple Access, employs multiple closely spaced sub-carriers, but the sub-carriers are divided into groups of sub-carriers.
- Each group is named a sub-channel.
- The sub-carriers that form a sub-channel do not need to be adjacent.
- In OFDM, only one MU transmits in one slot.
- In OFDMA, several MUs can transmit at the same time slot over several sub-channels.

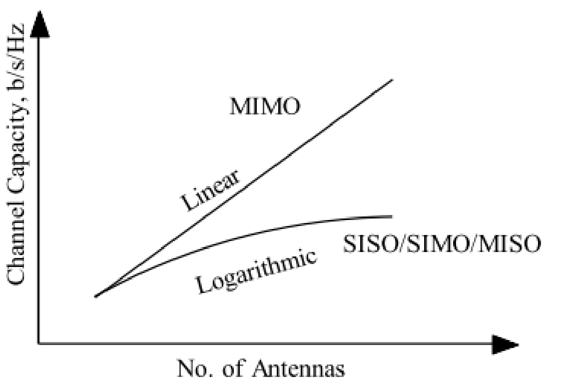




MIMO TECHNIQUE

What is MIMO?

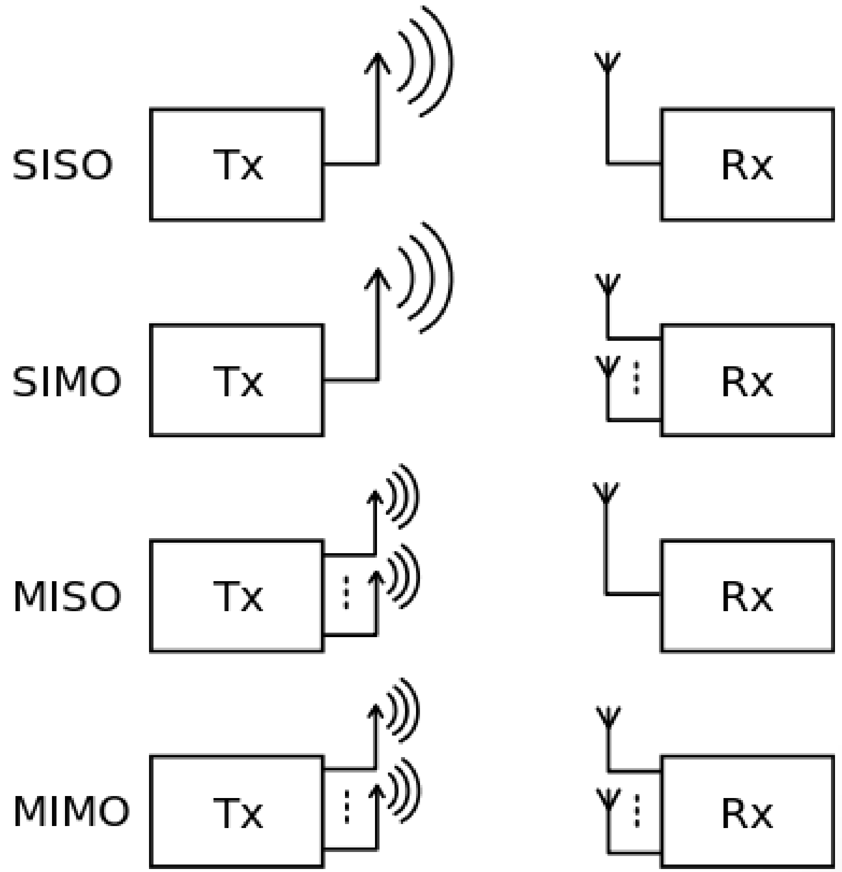
- A traditional communications link, which we call a single-in-single-out (SISO) channel, has one transmitter and one receiver.
- But instead of a single transmitter and a single receiver we can use several of each.
- The SISO channel then becomes a multiple-in-multiple-out, or a MIMO channel; i.e. a channel that has multiple transmitters and multiple receivers.
- MIMO offers a way to increase capacity without increasing power.



MIMO Forms/Topologies

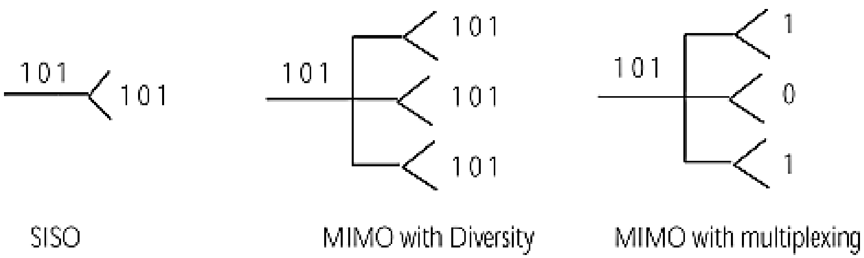
- SISO
- SIMO
- MISO
- MIMO

S : Single
M: Multiple
I : Input
O: Output



MIMO Techniques

- The MIMO design of a communications link can be classified in two main ways.
  - MIMO using diversity techniques
  - MIMO using spatial-multiplexing techniques

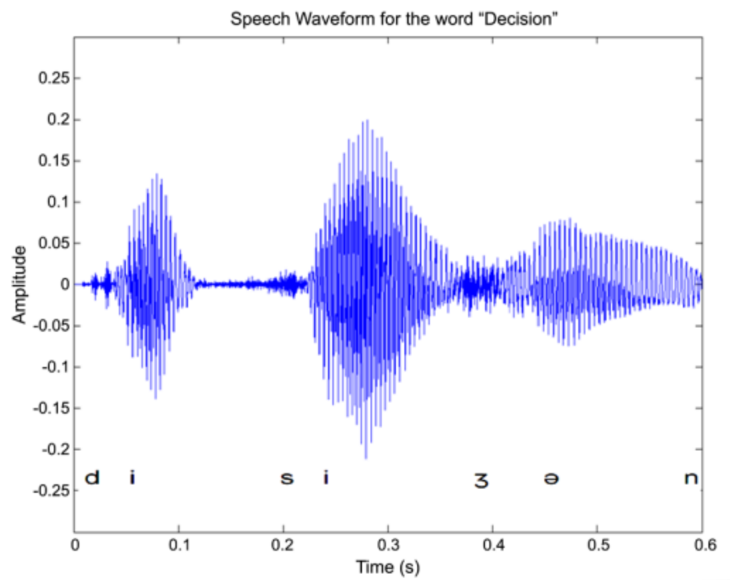


- Diversity means that the same data has traveled through diverse paths to get to the receiver.
- Diversity increases the reliability of communications. If one path is weak, then a copy of the data received on another path maybe just fine.
- In spatial-multiplexing, we multiplex the data on the multiple channels.
- It increases the data throughput or the capacity of the channel

SPEECH COMPRESSION

Purpose and Examples

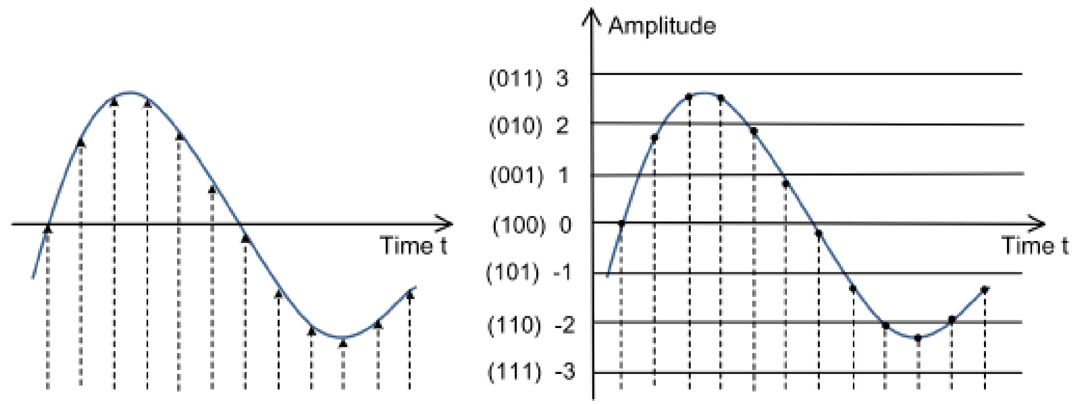
- The purpose of speech compression is to reduce the number of bits required to represent speech signals (by reducing redundancy) in order to minimize the requirement for transmission bandwidth



- The compression of speech signals has many practical applications.
- One example is in digital cellular technology where many users share the same frequency bandwidth.
  - Compression allows more users to share the system than otherwise possible.
- Another example is in digital voice storage (e.g. answering machines).
  - For a given memory size, compression allows longer messages to be stored than otherwise.

Speech Signal Digitization

- A) Sampling
- B) Quantization
- C) Coding



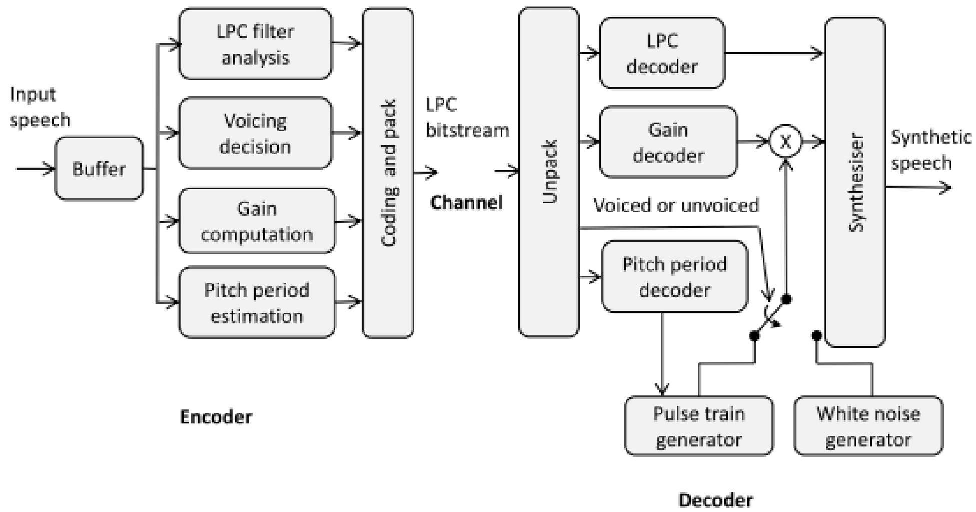
(a) Sampling

(b) Quantisation and Coding

- Digital speech signals are sampled at a rate of 8000 samples/sec.
- Typically, each sample is represented by 8 bits.
- Speech coders are of two types:
  - Waveform Coders
    - Time Domain: (PCM, ADPCM)
    - Frequency Domain: Sub-band coders, Adaptive transform coders
  - Vocoders
    - Linear Predictive Coders
    - Formant Coders

Compression

- The 8 bit sample to an uncompressed rate of 64 kbps (kbits/sec).
  - 8000(sample/sec) x 8(bit) = 64 kbps
- With current compression techniques (all of which are lossy), it is possible to reduce the rate to 8 kbps with almost no perceptible loss in quality.
- Further compression is possible at a cost of lower quality.
- All of the current low-rate speech coders are based on the principle of *linear predictive coding (LPC)*.



- For more details, refer to:
  - Chapter 2&3, J. Chiller, Mobile Communications, 2003.
  - Chapter 7, W. Stallings, Wireless Communications and Networks, 2005.
- The lecture is available onlin e at:
  - https://speakerdeck.com/ahmad_elbanna
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