CSE 445: Mobile and Wireless Communication

Lecture 4: Multiple Access Techniques

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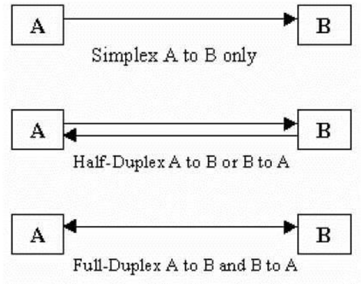
Duplexing

Duplexing

- Duplexing refers to the technique of separating the transmitting and receiving channels
- Communication system can be divided into two parts: Simplex and Duplex system.
- **Simplex** communication refers to communication that occurs in one direction only.
- **Duplex** communication system is a point-to-point system composed of two connected devices that can communicate with one another in both directions.
- There are *two types* of duplex communication systems:
  - **half-duplex**
    - provides communication in both directions, but only one direction at a time (not simultaneously).
  - **full-duplex**
    - allows communication in both directions to happen simultaneously.

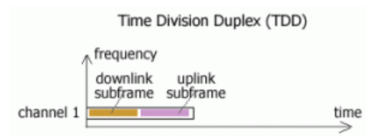
Duplexing

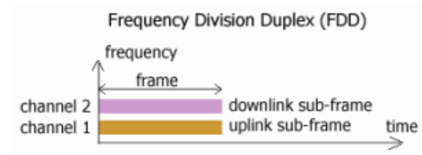


Duplexing Methods

- As channel access methods are used in point-to-multipoint networks (such as cellular networks) for dividing forward and reverse communication channels on the same physical communications medium, they are known as duplexing methods, such as time-division duplexing and frequency-division duplexing.
- **Time-division duplexing (TDD)** is the application of time-division multiplexing to separate outward and return signals.
- It emulates full duplex communication over a half duplex communication link.
- **Frequency-division duplexing (FDD)** means that the transmitter and receiver operate at different carrier frequencies.

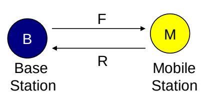
Duplexing Methods

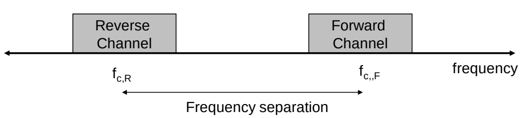




Duplexing - FDD

- A duplex channel consists of two simplex channel with different carrier frequencies
  - ***Forward band*: carries traffic from base to mobile**
  - ***Reverse band*: carries traffic from mobile to base**

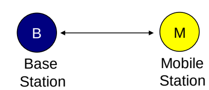


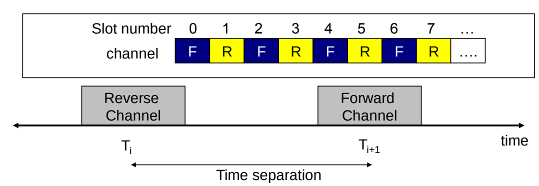


Frequency separation should be carefully decided
Frequency separation is constant

Duplexing - TDD

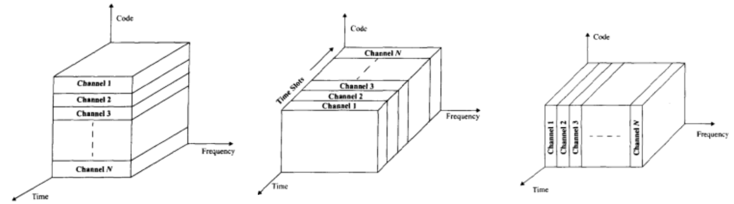
- A single radio channel (carrier frequency) is shared in time in a deterministic manner.
  - **The time is slotted with fixed slot length (sec)**
  - **Some slots are used for forward channel (traffic from base to mobile)**
  - **Some slots are used for reverse channel (traffic from mobile to base)**





Contemporary TDMA Systems

	GSM (Europa)	IS-54 (USA)	PDC (Japan)	DECT (European Cordless)
Bit Rate	270.8 Kbps	48.6 Kbps	42 Kbps	1.152 Mbps
Bandwidth	200 KHz	30 KHz	25 KHz	1.728 MHz
Time Slot	0.577 ms	6.7 ms	6.7 ms	0.417 ms
Upstream slots per frame	8	3	3	12
Duplexing	FDD	FDD	FDD	TDD
Efficiency of Time Slots	73 %	80 %	80 %	67 %
Modulation	GMSK	$\pi/4$ DQPSK	$\pi/4$ DQPSK	GMSK
Adaptive Equalized	Mandatory	Mandatory	Optional	None



Identify which is what!!!

3 types of multiplexing (Review)

Media Access

Motivation

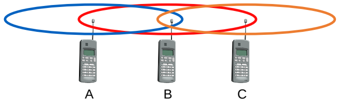
- Can we apply media access methods from fixed networks?

- Example CSMA/CD
  - **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
  - send as soon as the medium is free, listen into the medium if a collision occurs (legacy method in IEEE 802.3)

- Problems in wireless networks
  - signal strength decreases proportional to (at least) the square of the distance
  - the *sender* would apply CS and CD, but the collisions happen at the *receiver*
  - it might be the case that a sender cannot “hear” the collision, i.e., CD does not work
  - furthermore, CS might not work if, e.g., a terminal is “hidden”

Motivation - hidden and exposed terminals

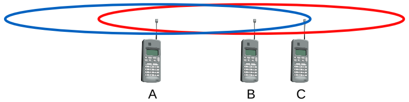
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)
  - A is “hidden” for C



- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

Motivation - near and far terminals

- Terminals A and B send, C receives
  - signal strength decreases proportional to the square of the distance
  - the signal of terminal B therefore drowns out A’s signal
  - C cannot receive A



- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks - precise power control needed!

Access methods SDMA/FDMA/TDMA

- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure

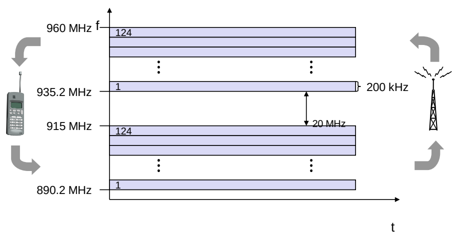
We will study further about SDMA in later topics like frequency reuse policies

- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time
- The multiplexing schemes presented in chapter 2 are now used to control medium access!
  - multiplexing scheme plus algorithm ➔ Multiple Access method

FDMA

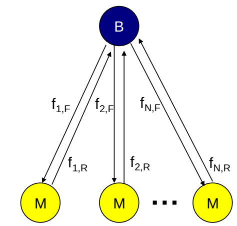
Frequency Division Multiple Access

FDD/FDMA - general scheme, example GSM



Frequency Division Multiple Access

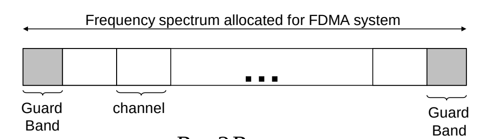
- Individual radio channels are assigned to individual users
- Each user is allocated a frequency band (channel)
  - During this time, no other user can share the channel
- Base station allocates channels to the users



Features of FDMA

- An FDMA channel carries one phone circuit at a time
- If channel allocated to a user is idle, then it is not used by someone else: waste of resource.
- Mobile and base can transmit and receive simultaneously
- Bandwidth of FDMA channels are relatively low.
- Symbol time is usually larger (low data rate) than the delay spread of the multipath channel (implies that inter-symbol interference is low)
- Lower complexity systems that TDMA systems.

Capacity of FDMA Systems



$$N = \frac{B_t - 2B_{guard}}{B_c}$$

B_t : Total spectrum allocation
B_{guard}: Guard band allocated at the edge of the spectrum band
B_c : Bandwidth of a channel

AMPS has 12.MHz simplex spectrum band, 10Khz guard band, 30kHz channel bandwidth (simplex): Number of channels is 416.

TDMA

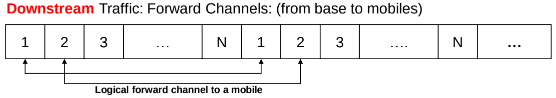
Time Division Multiple Access

Time Division Multiple Access

- The allocated radio spectrum for the system is divided into time slots
  - In each slot a user can transmit or receive
  - A user occupiess a cyclically repeating slots.
  - A channel is logically defined as a particular time slot that repeats with some period.
- TDMA systems buffer the data, until its turn (time slot) comes to transmit.
  - This is called *buffer-and-burst* method.
- Requires digital modulation

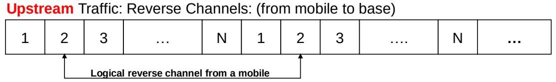
TDMA Concept

Downstream Traffic: Forward Channels: (from base to mobiles)



Base station broadcasts to mobiles on each slot

Upstream Traffic: Reverse Channels: (from mobile to base)



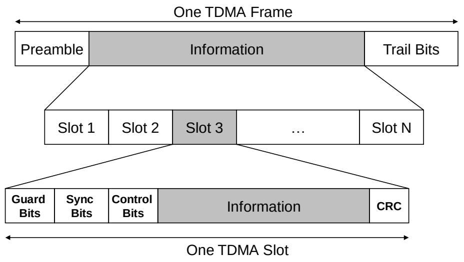
A mobile transmits to the base station in its allocated slot

Upstream and downstream traffic uses of the two different carrier frequencies.

TDMA Frames

- Multiple, fixed number of slots are put together into a frame.
- A frame repeats.
- In TDMA/TDD: half of the slots in the frame is used for forward channels, the other is used for reverse channels.
- In TDMA/FDD: a different carrier frequency is used for a reverse or forward
  - Different frames travel in each carrier frequency in different directions (from mobile to base and vice versa).
  - Each frame contains the time slots either for reverse channels or forward channel depending on the direction of the frame.

General Frame and Time Slot Structure in TDMA Systems

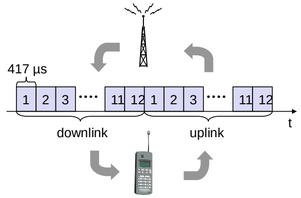


A Frame repeats in time

A TDMA Frame

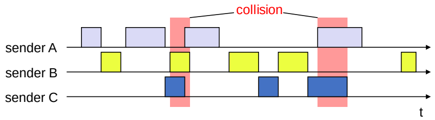
- Preamble contains address and synchronization info to identify base station and mobiles to each other
- Guard times are used to allow synchronization of the receivers between different slots and frames
  - Different mobiles may have different propagation delays to a base station because of different distances.

TDD/TDMA - general scheme, example DECT

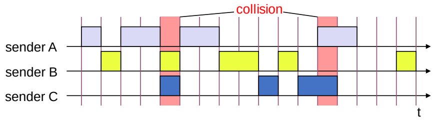


Aloha/slotted aloha

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Aloha



- Slotted Aloha

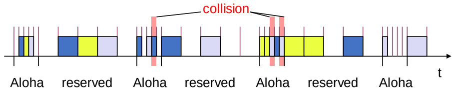


DAMA - Demand Assigned Multiple Access

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha
  - assuming Poisson distribution for packet arrival and packet length
- Reservation can increase efficiency to 80%
  - a sender *reserves* a future time-slot
  - sending within this reserved time-slot is possible without collision
  - reservation also causes higher delays
  - typical scheme for satellite links
- Examples for reservation algorithms:
  - *Explicit Reservation according to Roberts (Reservation-ALOHA)*
  - *Implicit Reservation (PRMA)*
  - *Reservation-TDMA*

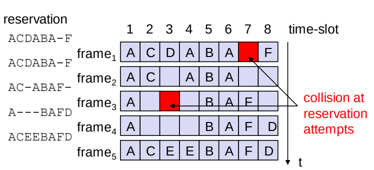
Access method DAMA: Explicit Reservation

- Explicit Reservation (Reservation Aloha):
  - two modes:
    - ALOHA mode for reservation:
      competition for small reservation slots, collisions possible
    - reserved mode for data transmission within successful reserved slots (no collisions possible)
  - it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



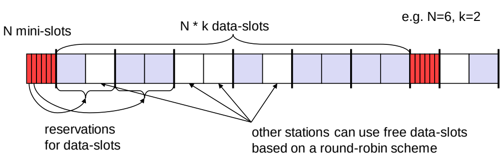
Access method DAMA: PRMA

- Implicit reservation (PRMA - Packet Reservation MA):
  - a certain number of slots form a frame, frames are repeated
  - stations compete for empty slots according to the slotted aloha principle
  - once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
  - competition for this slots starts again as soon as the slot was empty in the last frame



Access method DAMA: Reservation-TDMA

- Reservation Time Division Multiple Access
  - every frame consists of N mini-slots and x data-slots
  - every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

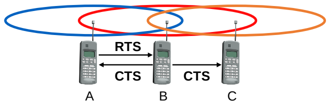


MACA - collision avoidance

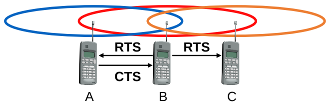
- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
- Signaling packets contain
  - sender address
  - receiver address
  - packet size
- Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

MACA examples

- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B



- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - now C does not have to wait for it, cannot receive CTS from A

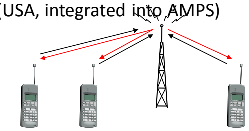


Polling mechanisms

- If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme
  - now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)
- Example: Randomly Addressed Polling
  - base station signals readiness to all mobile terminals
  - terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
  - the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
  - the base station acknowledges correct packets and continues polling the next terminal
  - this cycle starts again after polling all terminals of the list

ISMA (Inhibit Sense Multiple Access)

- Current state of the medium is signaled via a “busy tone”
  - the base station signals on the downlink (base station to terminals) if the medium is free or not
  - terminals must not send if the medium is busy
  - terminals can access the medium as soon as the busy tone stops
  - the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
  - mechanism used, e.g., for CDPD (USA, integrated into AMPS)



Efficiency of a Frame/TDMA-System

- Each frame contains overhead bits and data bits.
  - Efficiency of frame is defined as the percentage of data (information) bits to the total frame size in bits.

$$efficiency = \eta_f = (1 - \frac{b_{OH}}{b_T}) x100\%$$

$$b_T = T_f xR$$

b_T: total number of bits in a frame
T_f: frame duration (seconds)
b_{OH}: number of overhead bits

Number of channels in a TDMA cell: $N = m\frac{(B_{tot} - 2B_{guard})}{B_c}$

m: maximum number of TDMA users supported in a radio channel

TDMA

- TDMA Efficiency
  - GSM: 30% overhead
  - DECT: 30% overhead
  - IS-54: 20% overhead.
- TDMA is usually combined with FDMA
  - Neighboring cells be allocated and using different carrier frequencies (FDMA). Inside a cell TDMA can be used. Cells may be re-using the same frequency if they are far from each-other.
  - There may be more than one carrier frequency (radio channel) allocated and used inside each cell. Each carrier frequency (radio channel) may be using TDMA to further multiplex more user (i.e. having TDMA logical channels inside radio channels)
    - For example: GSM uses multiple radio channels per cell site. Each radio channel has 200KHz bandwidth and has 8 time slots (8 logical channels). Hence GSM is using FHMA combined with TDMA.

CDMA

Code Division Multiple Access

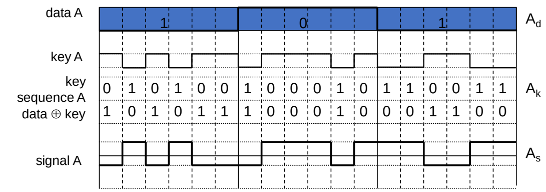
Access method CDMA

- 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, tuning is done via a correlation function
- 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 (very simplified)

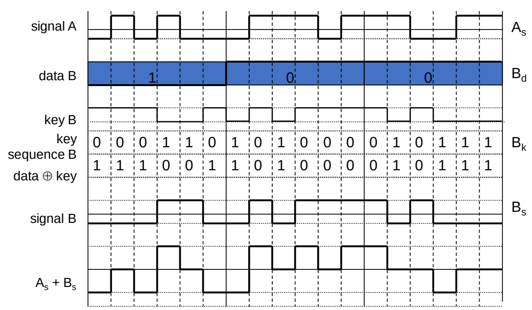
- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: “0”= -1, “1”= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: “0”= -1, “1”= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose 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 on signal level I (still pretty simplified)

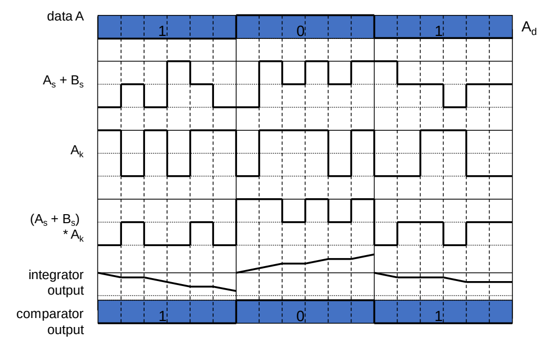


Real systems use much longer keys resulting in a larger distance between single code words in code space.

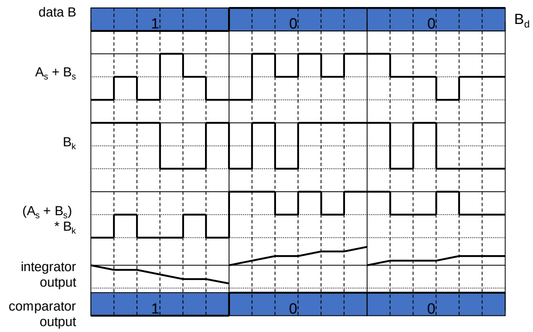
CDMA on signal level II



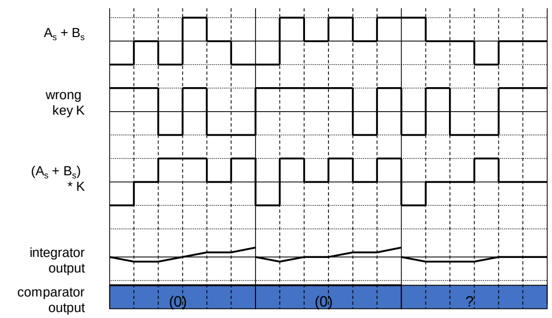
CDMA on signal level III



CDMA on signal level IV



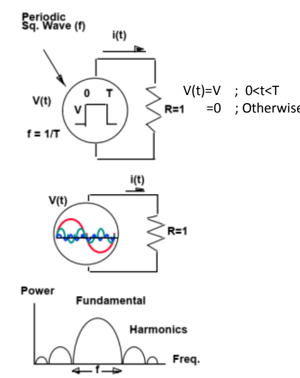
CDMA on signal level V



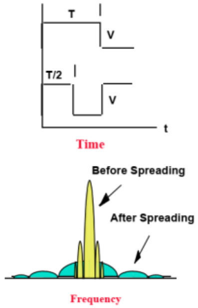
CDMA in details

Spectrum

- A discrete time signal is composed of an infinite number of harmonically related sinusoidal waves – *Spectrum*
- The associated power is due to infinite number of sinusoidal components:
  - main lobe corresponds to the fundamental frequency
  - side lobes correspond to harmonic components
- The bandwidth of the power spectrum is
  proportional to the frequency

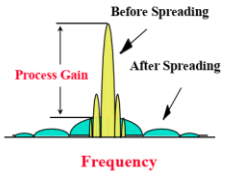


Spectrum Spreading



- Spectrum spreading is accomplished by increasing the frequency of the discrete time signal
- A high frequency signal has wider spectrum than a low frequency signal
- A low frequency signal has higher power amplitude than a low high power signal
- This is due to conservation of energy
- This is one of the key element in DS-CDMA
- It also leads to the concept of "Process Gain"

Process Gain



- Process gain is due to spectrum spreading
- Defined as

$$G = 10 \log\left(\frac{BW}{R_b}\right)$$

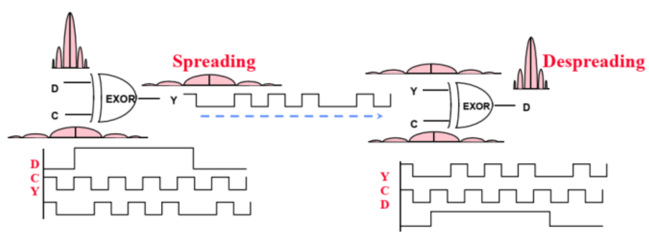
BW= Bandwidth after spreading

R_b= Original bitrate (Before spreading)

CDMA Process Gain: *Illustration*

- Spreading gain gives CDMA a big advantage over traditional, non-spread-spectrum systems
- Example: CDMA vs TDMA Cellular
  - TDMA Cellular
    - BW = 30 KHz Rb = 10 KHz
    - Process Gain = 10 Log (30/10) = 4.7 db
  - CDMA
    - BW = 1.23 MHz Rb = 10 KHz
    - Process Gain = 10 Log (1230/10) = 20.9 db
  - CDMA advantage: 20.9 - 4.7 = 16.2 dB
    - this advantage assumes only one user on CDMA system doubling number of users reduces advantage 3 db
  - with 16 users, CDMA still has 4 db advantage over TDMA

DS-CDMA Concept



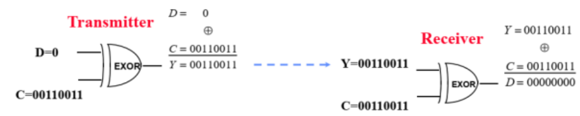
Spreading:
D= Low speed data
C= High speed PN code
Y= D XOR C

Despreading:
y= High Speed received data
C= Same PN code
D= Y XOR C = D XOR C XOR C

Do It Yourself !!!

- Prove using Boolean algebra that after a spreading and dispreading process we will get the same data back.

DS-CDMA: *Example-1*



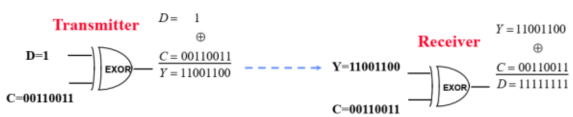
Spreading

- D = 0
- C = 00110011 (8-bit code)
- Y = D XOR C
  = 0 XOR 00110011
  = 00110011

Despreading

- Y = 00110011
- C = 00110011 (same code)
- D = Y XOR C
  = 00110011 XOR 00110011
  = 00000000

DS-CDMA: *Example-2*



Spreading

- D = 1
- C = 00110011 (8-bit code)
- Y = D XOR C
  = 1 XOR 00110011
  = 11001100

Despreading

- Y = 11001100
- C = 00110011 (same code)
- D = Y XOR C
  = 11001100XOR 00110011
  = 11111111

Our observations

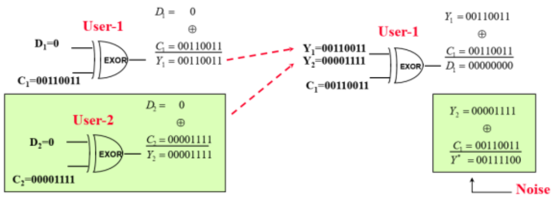
Spreading process

- A PN code multiplied by BIN-0 (binary zero) produces the same PN code:
  Bin-0 XOR PN code = PN code
  0 XOR 00110011 = 00110011
- A PN code, multiplied by BIN-1 produces the inverse code, also known an "Antipodal code"
  BIN-1 EXOR PN code = PN code
  1 EXOR 00110011= 11001100

Despreading process

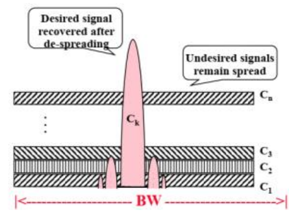
- A PN code multiplied by the same PN code, produces "Zeros"
  PN code XOR PN code = 0
  00110011 XOR 00110011 = 0
- A PN code multiplied by the antipodal code, produces "Ones"
  PN code XOR Antipodal code = 1
  00110011 XOR 11001100 = 1

Multi User DS-CDMA



- Data from User-1:
  - Tx Data D1=0, Code C1=00110011, Output Y1=D1 EXOR C1= 00110011
  - Rx Data D1=Y1 EXOR C1= 00110011 EXOR 00110011 = 0 (O.K)
- Data from User-2:
  - Tx Data D2=0, Code C2=00001111, Output Y2=D2 EXOR C2 = 00001111
  - Rx Data D2 =Y2 EXOR C1= 00001111 EXOR 00110011 = 00111100 (spread, noise)
- All users, other than the desired signal, appears as noise

How Many users can Share the Same Spectrum ?



- Each user contributes noise to the system
- Therefore the number of users that can share the same bandwidth would be given by the process gain minus Total noise contribution.
- Also, an additional margin would be needed for an acceptable performance

This is called CDMA Capacity Issue

PN Codes and Orthogonal Codes

- An n-bit PN code has 2^n -1 PN sequences
- Out of these PN sequences, only n-codes are orthogonal
- A 64-bit (Used in IS-95 CDMA) PN code has 1.8447 x 10^{19} PN sequences
- Only 64 of them are Orthogonal codes
- Orthogonal codes have zero cross-correlation properties

Properties of Orthogonal Codes

Example-1:
x = 0 0 1 1
y = 0 1 1 0

-1 -1 1 1
-1 1 1 -1
R_{xy} = 1 -1 1 -1 = 0

Example-2:
x = 0 0 1 1
y = 1 1 0 0

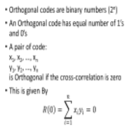
-1 -1 1 1
1 1 -1 -1
R_{xy} = -1 -1 -1 -1 = - 4

- A pair of code:
  $x_1, x_2, \ldots, x_n$
  $y_1, y_2, \ldots, y_n$
  is Orthogonal if the cross-correlation is zero
- This is given By

$$R(0) = \sum_{i=1}^{n} x_i y_i = 0$$

- An Orthogonal code has equal number of 1's and 0's.But not all codes having equal number of 1's and 0's are orthogonal

Properties of Orthogonal Codes: Cont.



Example-2:
x = 0 0 1 1
y = 1 1 0 0

-1 -1 1 1
1 1 -1 -1
R_{xy} = -1 -1 -1 -1 = - 4

Antipodal

- Orthogonal codes are binary numbers (2^n)
- An Orthogonal code has equal number of 1's and 0's
- A pair of code:
  $x_1, x_2, \ldots, x_n$
  $y_1, y_2, \ldots, y_n$
  is Orthogonal if the cross-correlation is zero
- This is given By

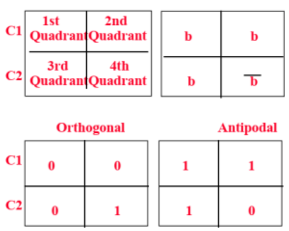
$$R(0) = \sum_{i=1}^{n} x_i y_i = 0$$

Properties of Orthogonal Codes: Cont.

	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1
2	0	0	1	1	0	0	1	1
3	0	1	1	0	0	1	1	0
4	0	0	0	0	1	1	1	1
5	0	1	0	1	1	0	1	0
6	0	0	1	1	1	1	0	0
7	0	1	1	0	1	0	0	1
8	1	1	1	1	1	1	1	1
9	1	0	1	0	1	0	1	0
10	1	1	0	0	1	1	0	0
11	1	0	0	1	1	0	0	1
12	1	1	1	1	0	0	0	0
13	1	0	1	0	0	1	0	1
14	1	1	0	0	0	0	1	1
15	1	0	0	1	0	1	1	0

- An n-bit Orthogonal code has:
  - n Orthogonal codes and
  - n antipodal codes
- Total number of codes = 2n
- The 2n code-set is known as Bi-Orthogonal code-set
  - An 8-bit Orthogonal code has 16 Bi-Orthogonal codes
  - A 64-bit Orthogonal code has 128 Bi-Orthogonal code-set

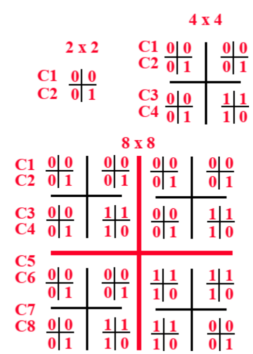
Generation of Orthogonal Codes



- Step-1: Divide N x N matrix as FOUR Quadrants
- Step-2: Make 1st, 2nd and 3rd quadrant identical & Invert the 4th
  - B is the bit value 0 or 1
- Orthogonal Code: C1= 00
  C2=01
- Antipodal Code : C1=11
  C2=10

Repeat the process for longer codes.

Generation of Long Orthogonal Codes



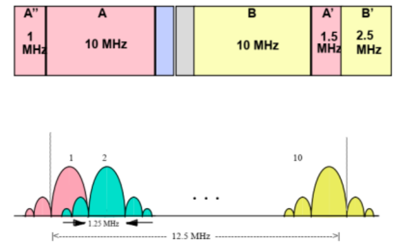
- Begin with a 2 x 2 matrix as before
- Generate a 4 x 4 by repeating 2x2
- Generate a 8 x 8 by repeating 4x4
  so on .....
- Invert the matrix for antipodal codes

This process was developed by J.L. Walsh in 1923 and is also known as Walsh Code

IS-95A Codes & Their Usage

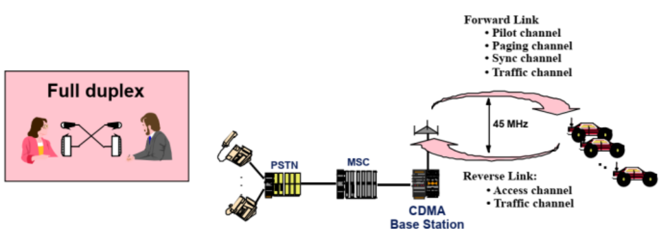
- Walsh Code:
  - 64 bits long, 64 Orthogonal codes, Code rate = 1.2288 Mb/s
  - Unique identifier for mobiles
  - Walsh Code Assignment:
    - W0 = Walsh code 0, used in Pilot Channel
    - W1-W7: Used in paging channels (7-paging channels)
    - W32: Used in Sync. channel
    - W8 to W31 and W33 to W63: Used in Traffic channels
- Long PN Code:
  - 42-bits long, 2^{42}-1=4.398 x10^{12} PN codes, Code rate=1.2288Mb/s
  - Used for reverse channel spreading and data scrambling
- Short PN code:
  - 15-bits long, 2^{15}-1=32,767 PN codes, Code rate=1.2288 Mb/s
  - Used for cell identification in reused cells

IS-95A DS-CDMA *Spectrum*

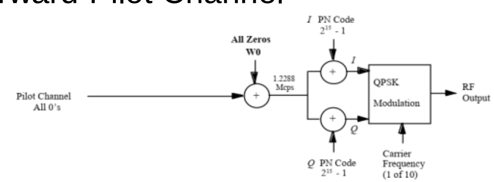


- The existing 12.5 MHz cellular spectrum (A or B) is divided into TEN
- CDMA bands
- Each band is 1.25 MHz
- Each 1.25 MHz band supports 64 Walsh codes

CDMA Architecture

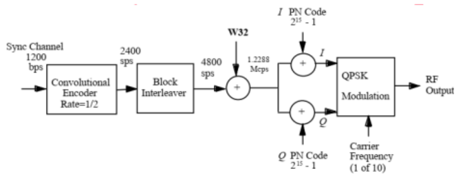


Forward Pilot Channel



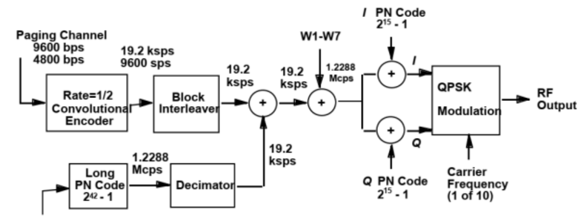
- All zero, uncoded spread spectrum channel
- Spreading Code: W0, 64-zeros
- Continuously transmitted from the base station
- Each base station uses one of 2^{15}-1 PN sequences to identify a forward pilot channel (there are 512 PN offsets)
- Provides phase & Timing reference
- Provides signal strength to the mobile

Forward Sync. Channel



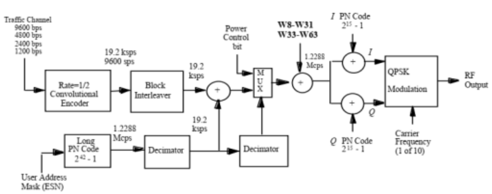
- Rate 1/2 convolutionally encoded spread spectrum channel
- Spread by means of W32 and then MOD2 added (XOR) with a unique 15-bit PN code (same PN code as the pilot)
- Modulated and transmitted
- Provides:
  - Unique timing for synchronization
  - Networks ID’s

Forward Paging Channel



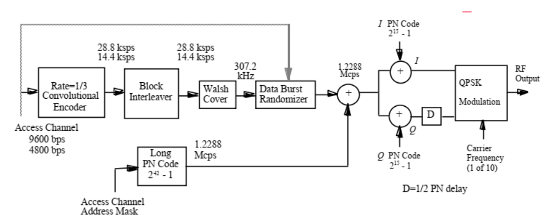
- Spread by means of W1-W7
- Uses the same PN code (offset)
- Pages a mobile
- Provides system parameter MSG
- Assigns traffic channel
- Overhead information
- Neighbor list

Forward Traffic Channel



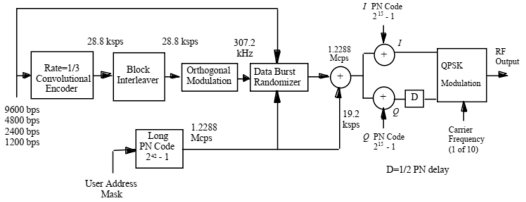
- Spread by means of W8-W31 and W33-W63
- Uses the same PN code (offset)
- Used for voice communications, Signaling
- Provides power control
- Assigns traffic channel
- Overhead information
- Neighbor list

Reverse Access Channel



- Works in association with Forward Paging Channel
- Spread by means of Long PN code (42-bits, 1.2288Mb/s)
- Used for Call origination, system access
- Channel request
- Page response
- Registration

Reverse Traffic Channel



- Used for voice communications
- Spread by means of Long PN code (42-bits, 1.2288Mb/s)
- Same short PN offset
- Response to command
- Seeks information from the base

CDMA Capacity *WITHOUT* Cellular Features

- Carrier to interference ratio is given by

$$\frac{C}{I} = \frac{R_b \times E_b}{N_o \times W} \qquad (A)$$

- Carrier to interference ratio is given by

$$I = C(N-1)$$

$$\frac{C}{I} = \frac{1}{N-1} \qquad (B)$$

- Equating (A) and (B) we get

$$N = 1 + \frac{\frac{W}{R_b}}{\frac{E_b}{N_o}}$$

$$\frac{W}{R_b} = Process\ Gain$$

Where
E_b = energy per bit
R_b = bit rate
N_o= thermal noise
W = transmission bandwidth

CDMA Capacity *WITH* Cellular Features

- In the cellular environment, the maximum achievable capacity is given by

$$N = 1 + \frac{W/R_b}{E_b/N_o} \bullet \frac{F}{D} \bullet S \bullet H$$

F=frequency reuse factor (1)

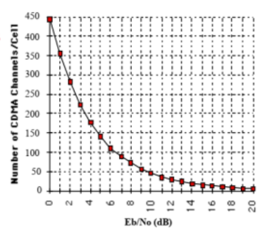
d=voice duty cycle (0.45)

S=sectorization factor (3)

H=soft hand-off factor

W=1.25MHz

R_b=9600bps



Low Eb/No is the key to enhance CDMA capacity

CDMA Hand-Off

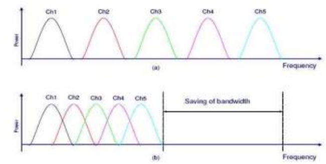
- CDMA to CDMA Soft Hand-Off
  - Mobile is directed to adjacent cell or sector, same frequency, different code, without dropping the serving code
  - Mobile keeps both channels during the process
  - Once the new link is well established, the original link is dropped
  - This process is known as “Soft-Hand Off” or “Make before Break”
- CDMA to CDMA Hard Hand-Off
  - Mobile is directed to a different CDMA frequency
  - Voice is muted momentarily during this process
- CDMA to AMPS Hard Hand-Off
  - A dual mode mobile is directed to an AMPS channel
  - Voice is muted momentarily during this process

Comparison SDMA/TDMA/FDMA/CDMA

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
Disadvantages	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)	higher complexity, lowered expectations; integrated with TDMA/FDMA

OFDM

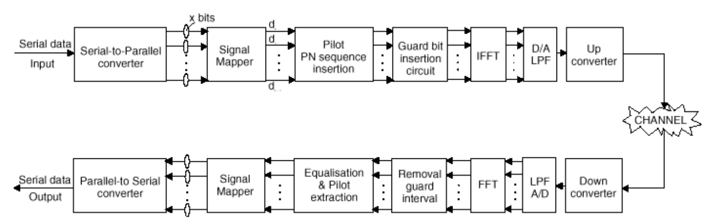
- OFDM, Orthogonal Frequency Division Multiplexing, is a special kind of FDM.
- The spacing between carriers are such that they are orthogonal to one another meaning the peak of one sub-carrier coincides with the null of an adjacent sub-carrier.
- Therefore no need of guard band between carriers and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

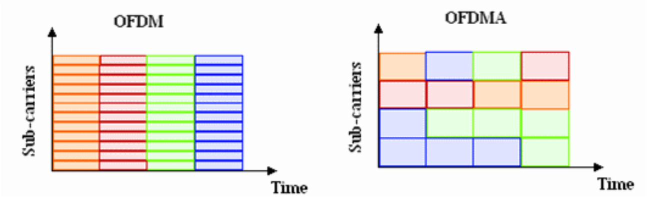
OFDM



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.

OFDMA



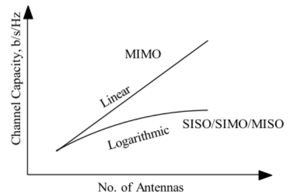
Multiple Access techniques used in different Wireless communication System

System	Multiple Access
Advanced Mobile Phone System (AMPS)	FDMA/FDD
2G Global Sy ( ) stem for Mobile (GSM)	TDMA/FDD
US Digital Cellular (USDC)	TDMA/FDD
Japanese Digital Cellular (JDC)	TDMA/FDD
Cordless Telephone (CT2)	FDMA/TDD
Digital European Cordless Telephone (DECT)	FDMA/TDD
US Narrowband Spread Spectrum (IS-95)	CDMA/FDD
CDMA200	CDMA/FDD or CDMA/TDD
Satellite Communication	TDMA, FDMA, CDMA
3G	WCDMA/FDD
LTE	OFDMA/FDD or TDD
WiMax	OFDMA/FDD or TDD

MIMO Technique

What is MIMO

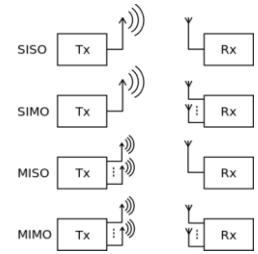
- A traditional communications link, which we call a single-in-single-out (SISO) channel, has one transmitter and one receiver.
- But instead of a single transmitter and a single receiver we can use several of each.
- The SISO channel then becomes a multiple-in-multiple-out, or a MIMO channel; i.e. a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



MIMO Forms/Topologies

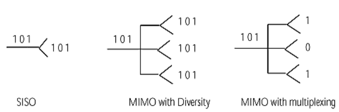
- SISO
- SIMO
- MISO
- MIMO

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

Recommended Text for this lecture

- Mobile Communications by Jochen Schiller
  - Chapter 3 (Full), Chapter 2.7
- Wireless Communications Principle and Practice by Theodore S. Rappaport
  - Chapter 8/9 [Depending on edition]
- Cellular Mobile Systems Engineering by Saleh Faruque
  - Chapter 4 (Full)
  - List Chapters about TDMA and FDMA
- Data Communications and Networking by Behrouz A. Forouzan
  - Chapter 12

Disclaimer

- This Presentation contains some edited version of slides provided by Jochen Schiller writer of the book Mobile Communications.
- This Presentation contains some edited version of slides provided by Professor Saleh Faruque.
- There is also some screenshots from different books.
- Some online images are also used.

*I have tried to cite any source. But if any citation is missed, kindly contact me to add your citation.

Homework Based on Lecture 1

- From Wireless Communications Principle and Practice by Theodore S. Rappaport
  - Chapter 8/9: Example 8.1-8.5

END