Code Division Multiple Access

S-72.4210 Postgraduate Course in Radio Communications

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Content Outline

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  - Frequency Hopping
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- CDMA Challenges
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  - Near-Far Problem
  - Power Control
  - Soft and softer Handover
- CDMA Applications in Mobile Network
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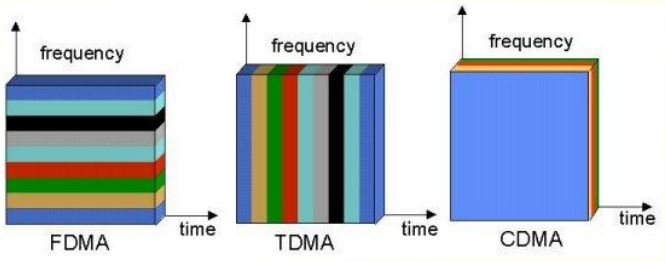
  - CDMA2000
  - WCDMA
- Conclusion
- Homework

CDMA History

- Code Division Multiple Access (CDMA) is both a modulation and multiple access scheme
- Researches started even from 1950's
- Claude Shannon and Robert Pierce had provided CDMA framework in 1949
- De-Rosa-Rogoff defined the direct sequence spread spectrum method in 1950
- Rake receiver was first patented by Price and Green in 1956
- Cellular spread-spectrum application was suggested by Cooper and Nettleton in 1978
- IS-95, the narrow band CDMA mobile network, has been standardized in 1993 and commercial networks were introduced in 1995
- 3G wideband CDMA systems, such as CDMA2000 in U.S. and European WCDMA developed from 1990s and still ongoing

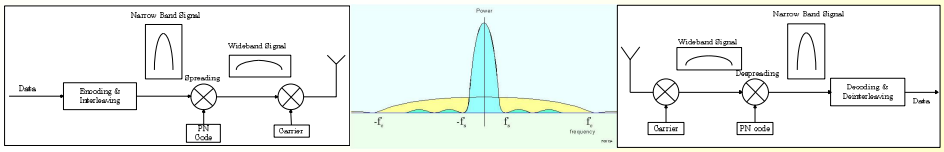
Different Multiple Access Methods

- TDMA
  - Divide radio spectrum into time slots
- FDMA
  - Frequency has been divided into subchannels
- SDMA
  - Control radiated energy for each user in space
- CDMA
  - Different user separated by different spread code



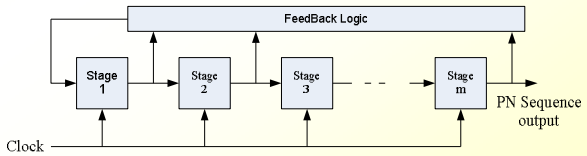
Spread Spectrum Technology

- Originally developed for military and navigation purposes
  - Hard to be intercepted
  - Anti-jamming
- Nowadays feasible for commercial applications especially for mobile communication systems
- Average energy of the transmitted signal is spread over a bandwidth W_{ss} , which is wider than the information bandwidth B_{signal}
- The spread factor F_{ss} is defined as $F_{ss} = \frac{W_{ss}}{B_{signal}}$
- Classifications
  - Direct Sequence, Frequency Hopping and Time Hopping



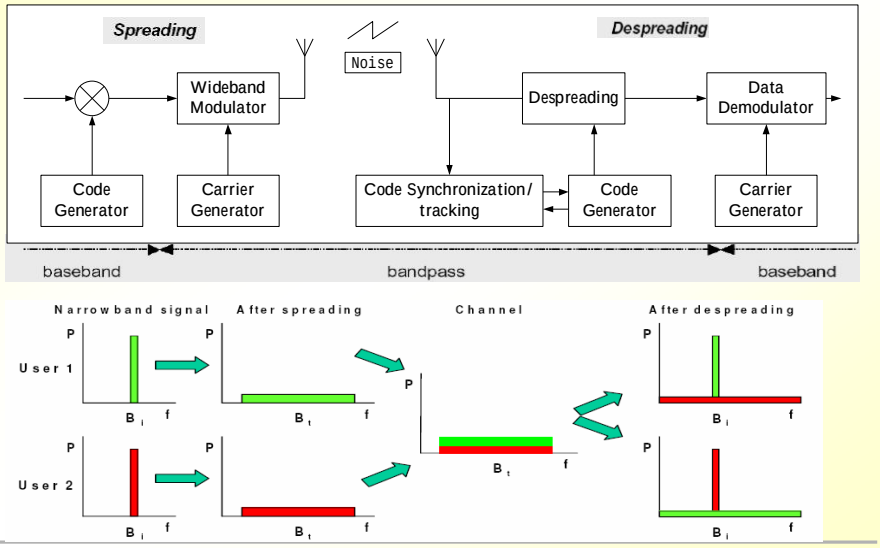
PN Sequence

- Pseudo-randomness is a characteristic of a spread spectrum system
- Achieved by using pseudo-noise (PN) or pseudo-random code
- A binary sequence with fixed length and has noise-like randomness
  - Nearly equal number of zeros and ones
  - Low correlation between shifted versions of the sequence
  - Low cross-correlation with other user signals (interference) and noise
  - Good autocorrelation properties with own signal in synchronization
- Examples
  - M-sequences, Gold codes and Kasami sequences



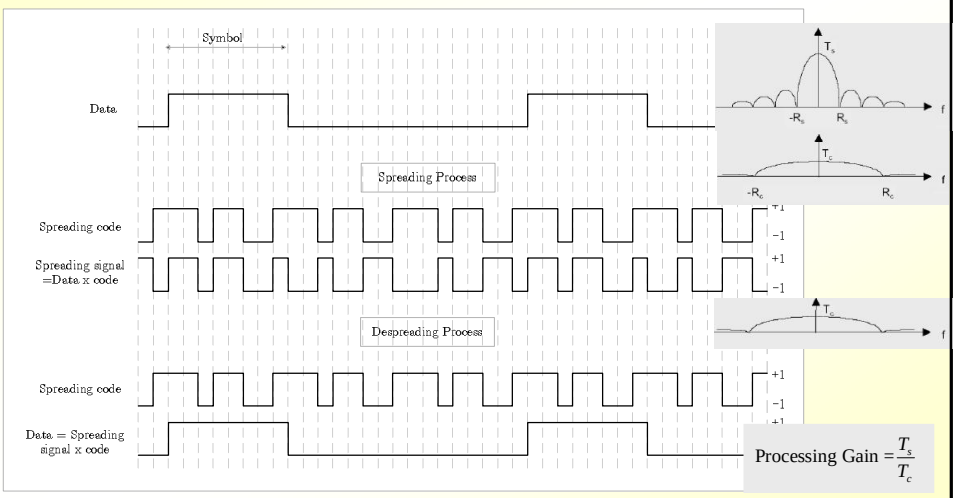
Direct Sequence (DS) CDMA

- System Architecture

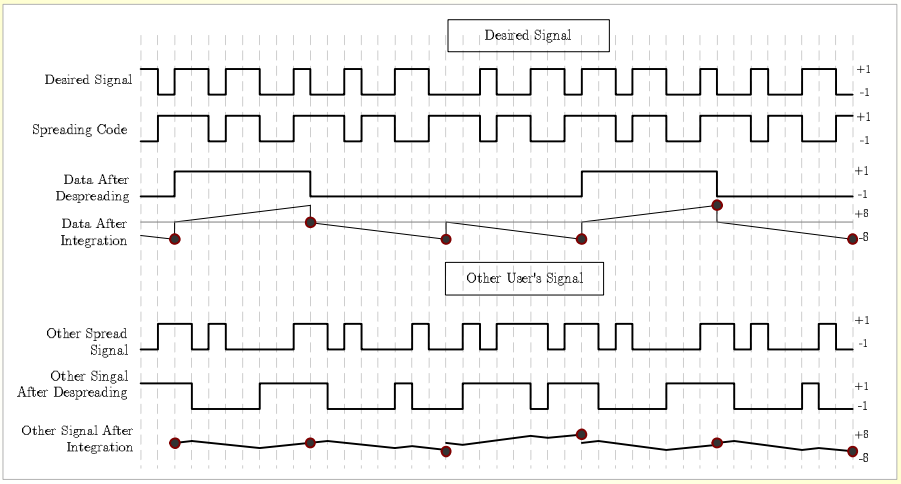


Spreading and Despreading (1)

- Spread the baseband data by directly multiplying it with a PN code



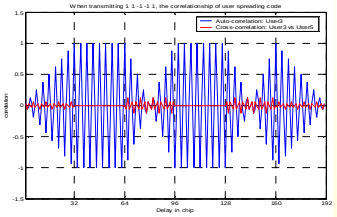
Autocorrelation Detection



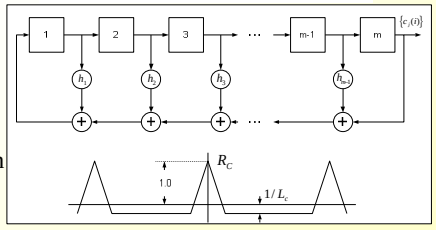
Spreading Code

- Walsh-Hadamard code: Simple and easy in implementation
  - Used in time synchronous condition
  - IS-95 system uses a 64 by 64 Walsh matrix
  - Have poor autocorrelation and cross-correlation properties, > 1 peak

$$C^1 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \quad C^l = \begin{bmatrix} C^{l-1} & C^{l-1} \\ C^{l-1} & -C^{l-1} \end{bmatrix}$$



- ML sequence
  - m-stage shift register with linear feedback, length is $L_c = 2^m - 1$
- Gold code
  - Proposed by Gold in 1967
  - Constructed by feeding two ML sequences of the same length through an XOR (Exclusive OR) circuit



CDMA Capacity

- SNR is defined as $SNR = \frac{P}{(N-1)P} = \frac{1}{N-1}$
- SNR can be replaced by Eb/N0
  - W is chip rate
  - R is data rate

$$\frac{E_b}{N_0} = \frac{P/R}{(N-1)(P/W)} = \frac{W/R}{N-1}$$

- If consider background thermal noise in spread bandwidth

$$\frac{E_b}{N_0} = \frac{W/R}{(N-1)+(\eta/S)}$$

- The users served in a single cell are

$$N = 1 + \frac{W/R}{E_b/N_0} - (\eta/S)$$

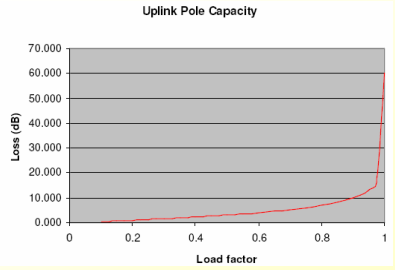
- If also consider the voice activity

$$N = 1 + \frac{1}{\alpha}\frac{W/R}{E_b/N_0}$$

- The load factor is defined as

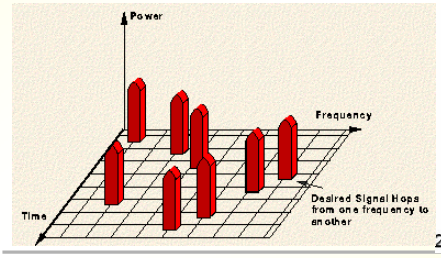
$$\eta = \sum_{j=1}^{K} \frac{1}{1+\frac{1}{\alpha}\frac{W/R}{E_b/N_0}}$$

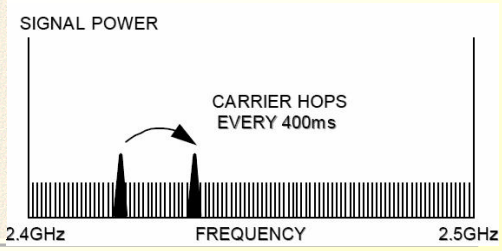
  - Load factor comes near 1, the interference margin is getting higher quite fast
  - Typically, load target should be maintained between 50 % and 75 % because at those points the system is stable and can serve users.



Frequency Hopping (FH) CDMA

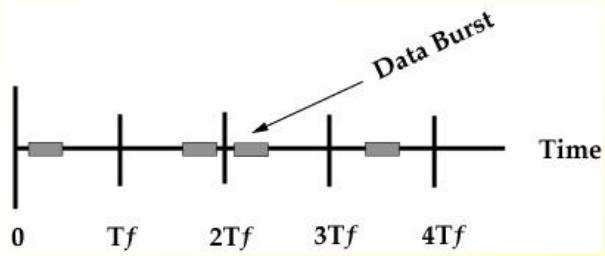
- System occupies a large number of active frequency channels
- When the users transmit their bits through the transmission channel, they will keep hopping over the available frequency channels
- The hopping order is controlled by PN code, Hopping every 400 ms
- Fast frequency hopping (FFH) and Slow frequency Hopping (SFH)
  - FFH – several hops per symbol
  - SFH – several symbols per hop





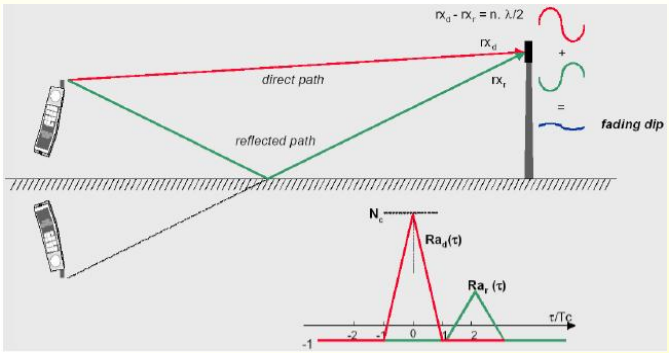
Time Hopping (TH) CDMA

- The data is transmitted in burst, not continuous
  - Each burst consists of k bits data
- Exact transmission time is determined by PN sequence
  - The time axis is divided into frames
  - Each frame is divided into M time slots
  - Each user will transmit or receive in 1 of M slots
  - Which of the M slots will be used depending on PN code
- Normally is used combined with frequency hopping



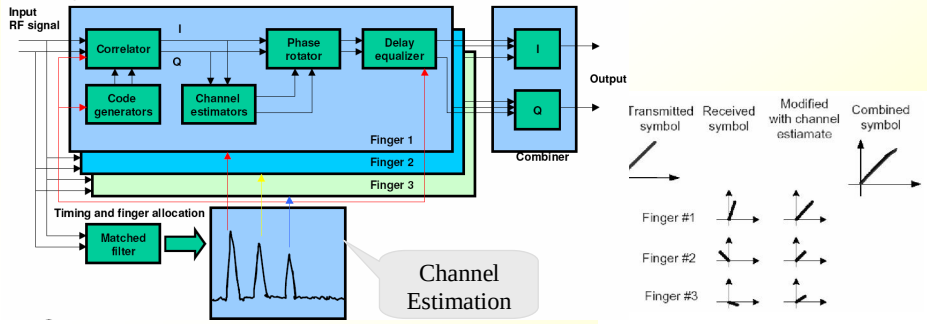
Multipath Environment

- Reception of multiple, possibly interfering copies of the same signal
  - Atmospheric reflection or refraction
  - Reflections from ground, buildings, or other objects
- CDMA should have a tolerance of multipath



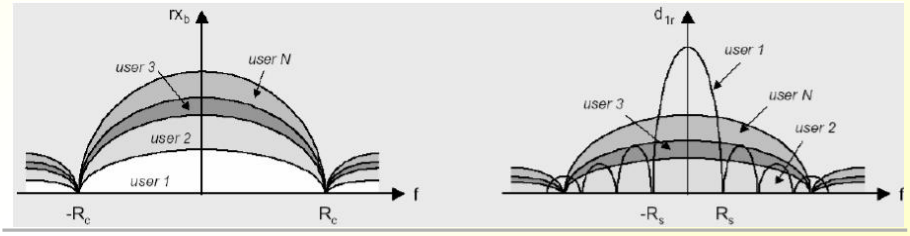
Rake Receiver

- Multipath diversity principle
  - Uses several baseband correlators to individually process several signal multipath components.
  - The correlator outputs are combined to achieve improved communications reliability and performance
- Performance will degrade fast if with many multipaths due to poor channel estimation



CDMA Interference

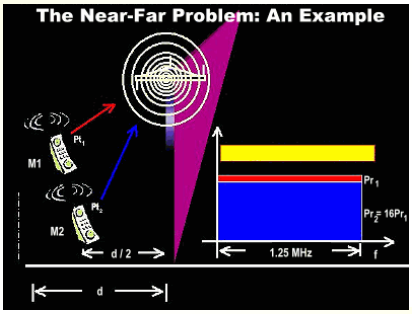
- MAI – Multiple Access Interference
  - The detector receives a signal composed of the sum of all users' signals, which overlap in time and frequency
  - MAI refers to the interference between users
  - MAI is directly proportional to the channel loading
  - MAI can be divided in two parts
    - intra-cell and inter-cell interference
  - With CDMA systems, the same frequency channel can be used in the adjacent cell, as long as multiple access interference is kept below a given level.
  - This is achieved by using power control

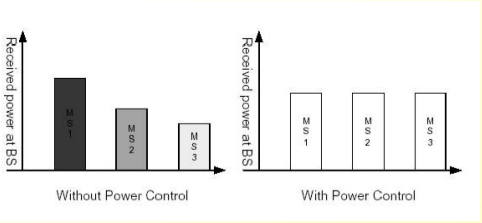


Near-Far Problem

- Users near the base station are received with high power
- Users far from the base station are received with low power
- Nearby users will completely swamp far away users

- Solution **Power Control**





Power Control

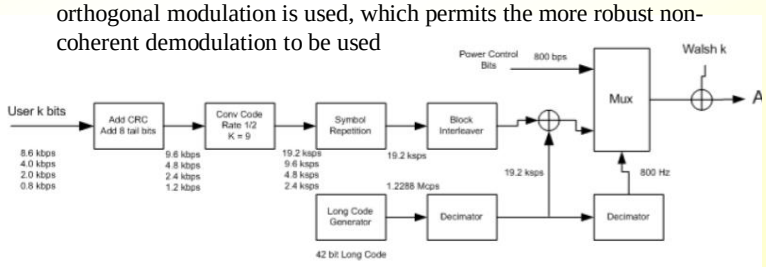
- Interference limited multiple access system
- The power control problem arises due to multiple access interference (MAI)
  - Each user looks like random noise to other users and causes unnecessary interference to the system
- Power control is implemented to overcome the near-far problem, reduce MAI, and to maximize the capacity of CDMA system
- Maximum capacity is achieved when SNR of every user is at the minimum level needed for the acceptable channel performance
- Classification
  - **Open loop power control** (initial **uplink** and **downlink** transmission powers)
  - **Inner loop power control** (also called fast closed loop power control)
  - **Outer loop power control** (setting a target SIR)

Soft and Softer Handover

- Hard Handover - “break-before-make”
  - All the old radio links in the UE are removed before the new radio links are established,
  - Can be seamless or non-seamless.
  - In practice a handover that requires a change of the carrier frequency (inter-frequency handover) is always performed as hard handover
- Soft Handover – “make-before-break”
  - The radio links are added and removed in a way that the UE always keeps at least one radio link to the RAN.
  - Soft handover is performed by means of macro diversity
    - several radio links are active at the same time
    - selection combining is applied
  - Normally soft handover can be used when cells operated on the same frequency are changed.
- Softer handover
  - A special case of soft handover
    - The radio links that are added and removed belong to the same BTS or node B
    - Macro diversity with maximum ratio combining is applied

IS-95 System

- Mainly used in U.S.
  - Standard was finished in 1993 and first commercially launched in 1996
  - Basic data rate is 9,6 kbps
  - Chip rate of 1.2288 Mchip/s
  - Allocated bandwidth is 1.25 MHz
  - “CDMA-One” was launched in 1999 with data rates up to 115,5 kbps
  - Fixed spreading code of length 64
  - Uses pilot channel in downlink direction to provide synchronization, channel tracking, and handover functions. In the uplink direction, orthogonal modulation is used, which permits the more robust non-coherent demodulation to be used



CDMA-2000

- The third generation evolution phase of IS-95A/B
  - CDMA2000 1x
    - Offer up to 307 kbps data rates (compare to EDGE)
    - Use same 1.25 MHz as IS-95/CDMAOne
  - CDMA2000 1xEV-DO
    - CDMA2000 1xEV-DO delivers peak data speeds of 2.4Mbps and supports applications such as MP3 transfers and video conferencing
  - CDMA2000 1xEV-DV
    - CDMA2000 1xEV-DV provides integrated voice and simultaneous high-speed packet data multimedia services at speeds of up to 3.09 Mbps.
  - 1xEV-DO and 1xEV-DV are both backward compatible with CDMA2000 1X and CDMAOne
  - The first 3G networks to be commercially deployed were launched in Korea in October 2000

WCDMA

- The faster chip rate of 3,84 Mchips/s
  - Implies that WCDMA receiver can provide greater multipath resolution
- 5 MHz bandwidth
  - Wider bandwidth implies greater frequency diversity Rake Receiver
- Data rates
  - Up to 384 kbps for circuit switched data
  - Up to 2 Mbps for packet switched data
- Spreading factor
  - Downlink is from 4 to 512
  - Uplink is from 4 to 256
- Coherent detection
  - Available on both uplink and downlink direction by using pilot bits in transmission
- Enhancement
  - HSDPA 3GPP R5 using new modulation (QPSK+16QAM) and coding schemes to give higher data rates for packet switched data in WCDMA

IMT-2000 Specs

	WCDMA	TD-SCDMA	CDMA 2000
Multiplexing	FDD	TDD	FDD/TDD
Slots	15	10	4 (for 5 ms)
Carrier BW	5 MHz	1.6 MHz	1.25(1MC)/5(3MC) MHz
Chip Rate	3.84 Mchip/s	1.28 Mchip/s	1.228/3.6864 Mchip/s
Frame Length	10 ms	10 ms	10 / 5 ms
Channel coding	Convolutional, turbo	Convolutional, turbo	Convolutional, turbo
Modulation	QPSK (DL), BPSK (UP)	QPSK, 8PSK	QPSK (DL), BPSK (UL)
Spread Factor	4-512	1-16	4-512
Power Control	Open+close loop, step 1,2 or 3 dB	Open+close loop, step 1,2 or 3 dB (200 times /s)	Open+close loop, step 1, 0.5 or 0.25 dB
Diversity	Rake	Joint detection	Rake
Sync BTS	Sync or non-sync	Sync	GPS sync
Core Network	GSM-MAP	GSM-MAP	ASNI-41

Conclusion

- DS-CDMA is probably the most interesting multiple access method provided by spread-spectrum technology
- Nowadays systems such as CDMA2000, its evolution versions, and European WCDMA are becoming more and more popular, as the networks are open commercially around the world
- CDMA appears to be an underdog for 4G, but still may win
- Ongoing researches on CDMA
  - Increase capacity by joint decoding (multi-user detection & interference cancellation)
  - Applying CDMA to other applications: optical CDMA, ad hoc networks, dense wireless LANs
  - “Multi-CDMA”: multiple antenna CDMA, multi-carrier CDMA, multi-code CDMA

Homework

- CDMA Capacity
  - If chip rate is 1.25 MHz, data rate is 9600 bps. The minimum acceptable SNR is 10 dB

    (1) determine the maximum number of users that can be supported in a single cell CDMA system?

    (2) if voice activity factor is 3/8, how about the result?
- Spreading Code
  - Construct a Gold code with length of 31.
  - Construct a Walsh code with length of 32 by using initial matrix

$$C^1 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

  - Plot the auto-correlation figures of Gold code and Walsh code, and analysis their auto-correlation properties respectively, based on the figures you plot..

Any Questions ?

Thank you !

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