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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

Despreading

Wideband Modulator

Despreading

Data Demodulator

Code Generator

Carrier Generator

Code Synchronization/tracking

Code Generator

Carrier Generator

Baseband

Bandpass

Despreading and Despreading (1)

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

Processing Gain = \frac{T_c}{T_r}
Autocorrelation Detection

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

\[ C^i = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \quad C^i = \begin{bmatrix} C^{i-1} & C^{i-1} \\ C^{i-1} & -C^{i-1} \end{bmatrix} \]

ML sequence
- m-stage shift register with linear feedback, length is \( L = 2^m - 1 \)

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

1. SNR is defined as
   \[ SNR = \frac{P}{(N-1)P} \]

2. SNR can be replaced by \( \frac{E_b}{N_0} \)
   \[ \frac{E_b}{N_0} = \frac{W/R}{(N-1)P/W} = \frac{W/R}{N-1} \]

3. If consider background thermal noise in spread bandwidth
   The users served in a single cell are
   The load factor is defined as
   \[ N = 1 + \frac{W/R}{\alpha E_b / N_0} (\eta / S) \]
   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

1. System occupies a large number of active frequency channels
2. When the users transmit their bits through the transmission channel, they will keep hopping over the available frequency channels
3. The hopping order is controlled by PN code, Hopping every 400 ms
4. 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

Multopath 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

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

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**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
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!