Wireless Multiaccess Using Code Division Multiple Access

Zartash Afzal Uzmi
LUMS, Lahore. Pakistan
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Outline

- Cellular systems
  - Cellular concept
  - Frequency reuse
- Multiaccess techniques
  - Static Multiaccess (FDMA, TDMA)
  - Dynamic Multiaccess and CDMA
- Code division multiple access (CDMA)
  - Transmitter
  - Channel
  - Receiver
Outline

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Wireless Systems

- Wireless systems are inherently different from wireline systems
  - Bandwidth is limited
  - Transmitted power is limited
- Power and bandwidth constraints limit the service areas to the vicinity of base stations
A Single Base Station System

- All users communicate with this single entity
- Not practical
  - Client perspective
    - Far users need to transmit high powers
    - Reduced battery life
  - System perspective
    - Single point of failure
  - Base station perspective
    - Transmission at high powers ➔ not permitted
    - Required bandwidth in an area becomes enormous
Cellular Concept

- A large geographical area is divided into smaller areas called cells
- Many low power transmitters are placed within cells at approx their centers
- “Cellularization” is flexible
  - Cell size can be changed based on demand
- Cell size (and shape) is primarily controlled by
  - Power transmitted by the base station
  - Terrain within the region of the cell
  - Presence of man-made features, e.g., buildings
Cellular Concept

- Each active user “belongs” to a cell
- Other base stations neglect the signal from the users who don’t belong to this cell
- Can users move from one cell to another?
  - Yes, when the link with the new base station becomes more reliable
  - Handoff
    - New base station starts and old base station ceases to interpret signals from the user undergoing handoff
    - Creates challenges that are unique to cellular systems
What Do Base Stations Do?

- Provide a mediation point
  - Every user communicates with the base station
  - Two users don’t communicate directly. Why?
- Provide connectivity to the PSTN
  - Base stations are connected to MTSO that provides connectivity between the wireless and wireline networks
    - MTSO can provide simple interfacing
    - MTSO can also perform complex protocol translation functions (WAP to HTTP, for example)
Frequency Reuse

- Same set of frequencies can be used in different cells that are sufficiently apart
  - Interference prohibits reusing frequencies in cells that are fairly close
  - A “cluster” defines the set of cells in which frequency is not reused
- For FDMA systems, cluster size is 3 to 7
- CDMA systems use single cell clusters
  - Frequency reused in every cell
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Multiaccess Systems

- Two communication paradigms
  - Point to point
    - Two entities communicate over isolated link
  - Multipoint to multipoint
    - More than two entities communicate simultaneously

- Sharing of links is desirable
  - Examples include LAN and cellular systems
  - Direct communication (Multiuser system)
    - LAN environment
  - Indirect communication (Multiaccess system)
    - Communication through an entity – e.g., Base station
Why Link Sharing Is Needed?

N nodes or stations
With no link sharing:

Wireline:
   Need $N(N-1)/2$ links

Wireless:
   Users too far off to communicate
Multiuser System

- Direct communication between users
- Links are shared
- A sharing protocol is used
  - ALOHA, slotted ALOHA, CSMA/CD, etc.

**Why users communicate directly?**

- End stations have high processing power
- An entity is still needed to talk to external stations
  - A bridge or a router

- User stations typically **filter** the data
- Every user receives data from every other user
Multiaccess System

- Indirect connection between users
  - A mediating entity is used – a base station
- Links are still shared
- A media access protocol is used
- End stations (usually cell phones) have low processing powers
- User handsets only receive what they are supposed to receive – no need of filtering as in the case of ethernet LAN stations
Two Problems

- How to identify the source and the destination
  - Addressing solves the identification problem
- How to share the communication channel
  - Use the MAC protocols
- Multiuser systems (MAC and addressing in either direction of communication)
  - Links are typically symmetric, e.g., LANs
- Multiaccess systems
  - Downlink uses multiplexing to provide addressing
    - Based on frequency (FDM), time (TDM) or code (CDM)
  - Uplink uses multiaccess to provide channel sharing
    - FDMA, TDMA, and CDMA
Uplink Channel Sharing

- Uplink sharing is provided by the multiaccess protocols:
  - Static Multiaccess
  - Dynamic Multiaccess
    - Demand assigned multiple access
    - Random Multiaccess
- Choice of a particular protocol depends upon the traffic characteristics
Static Multiaccess

- Channel’s capacity is divided into fixed portions
- One portion is allocated to each user
  - May combine portions and allocate to one user
- Portions can be made on the basis of
  - Frequency
  - Time
  - Code
- There are no shared resources
  - If the user doesn’t use the allocated portion, that portion just goes unused and hence wasted
- Works better with predictable traffic and predictable set of users that doesn’t change much over time
Multiaccess Examples

- **FDMA**
  - AMPS system – 30khz per channel – 800 to 900Mhz band
  - Different frequencies, same time

- **TDMA**
  - First US digital standard (IS-54)
  - GSM
  - Different times, same frequency

- **CDMA**
  - 2nd US digital standard (IS-95)
  - Technology for the 3rd generation systems
  - Same time, same frequency
Dynamic Multiaccess

- Traffic from users is bursty
  - Transmission rates varying significantly
- Set of active users change
- Desirable to assign portions dynamically
  - Demand assigned multiple access (DAMA)
  - Random Multiaccess
DAMA

- Two channel paradigm
  - Data channel
    - Divided into as many portions as the number of active users
  - Request channel
    - Users send requests for the allocation of a portion in the data channel
    - Static – divided into as many chunks as the total number of users – active or inactive
      - Multiaccess problem shifted from the data channel to the request channel
    - Random Multiaccess in the request channel
Random Multiaccess

- When request channel in DAMA uses static multiaccess
  - What if total number of users is much larger than the number of active users?
  - What if the data is too bursty such that the control overhead of DAMA is unacceptable?
  - Solution: allow random multiaccess in DAMA request channel

- Random Multiaccess used in the data channel
  - Users transmit simultaneously at the same frequency
  - Possible collisions and retransmissions
  - CDMA can provide inherent random multiaccess
    - Without requiring retransmissions!!!
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A simplified DS-CDMA Transmitter

User Data rate $1/T_b$

PN sequence rate $1/T_c$

Sinusoidal Carrier

Transmitted Signal

$T_c << T_b$
DS-CDMA Signal

Time domain

Original Data Signal

Spreading Signal

Product signal

Frequency domain
DS-CDMA

- Each user has a unique spreading code
- Spreading gain
  - Ratio of the signal bandwidth after spreading and the original signal bandwidth
- Processing gain
  - Number of chips periods over which detection is carried out at the receiver
- Base station receives sum of all the signals from various users
- Base station transmits sum of signals intended for various users
A simplified DS-CDMA Receiver

PN sequence rate $1/T_c$

Received Signal

Sinusoidal Carrier

To Detector

PN sequence “exactly” matches the one in transmitter
Interference in CDMA

- Users transmit simultaneously and at the same frequency
- In “usual” random multiaccess, a collision will require retransmission
- In CDMA, signal from users can still be detected even if they “collide”
- For each user, signal from every other user is interference (MAI) – generally regarded as gaussian noise. Is it a good idea?
Advanced CDMA Receivers

- Multiuser detectors
  - Use of filters to eliminate MAI
  - Use knowledge of spreading sequences to iteratively subtract the interference
- Beamformers
  - Enhance signals coming from one direction while suppressing signals coming from other directions
Advanced CDMA Receivers

Received Signal

$K_1 \rightarrow \int()_{\text{symbol period}} \rightarrow y_1 \rightarrow \hat{y}_1$

$K_2 \rightarrow \int()_{\text{symbol period}} \rightarrow y_2 \rightarrow \hat{y}_2$

$K_{Nu} \rightarrow \int()_{\text{symbol period}} \rightarrow y_{Nu} \rightarrow \hat{y}_{Nu}$

Traditional Design

New Designs
What Does CDMA Do To…?

- Narrowband interference
  - Addressed by spreading
- Gaussian noise
  - No effect
- Multipath and delayed ISI
  - Addressed by autocorrelation properties
- MAI
  - Addressed by crosscorrelation properties