CS236/NetSys230
Wireless Networking

Medium Access Control

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Announcements

- Project Groups...
  - Please email me the group members.
  - Does everyone have a group?

Agenda

- Basic Medium Access Methods
- Dynamic TDM / Random Access
- CDMA
- Comparison

Can we apply fixed network MACs?

- Example CSMA/CD
  - Carrier Sense Multiple Access with Collision Detection
  - send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)
- Problems in wireless networks
  - signal strength decreases proportional to 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"

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

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!
### Basic access methods

- **SDMA (Space Division Multiple Access)**
  - segment space into sectors, use directed antennas
  - cell structure
- **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
- **CDMA (Code Division Multiple Access)**
  - assign a code to a transmission channel between a sender and a receiver for a certain amount of time

### Duplexing

- **Simultaneous transmission and reception of up and down-link channels**
- **Time and frequency domain techniques:**
  - FDD: Frequency division duplex
  - TDD: Time division duplex

  (Code division duplex would give an extreme near-far problem)

### FDD/FDMA - example GSM

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>960 MHz</td>
<td>20 MHz</td>
</tr>
<tr>
<td>935.2 MHz</td>
<td>20 MHz</td>
</tr>
<tr>
<td>915 MHz</td>
<td>20 MHz</td>
</tr>
<tr>
<td>890.2 MHz</td>
<td></td>
</tr>
</tbody>
</table>

### TDD/TDMA - example DECT

- **417 µs**
- **1112 1112**
- **uplink**
- **downlink**

### TDMA

- **Flexible**
- Simple receivers and transmitters
- **Fixed TDM**
  - Assigned by base station
  - Suitable for fixed bandwidth services
- **Dynamic TDM (Demand oriented)**
  - Suitable for asymmetric and bursty services
  - Scheduling / polling
    - Suitable for systems with central controller (e.g., base station)
  - Random access
    - Also suitable for systems without central controller (e.g., base station)

### Aloha / Slotted Aloha

- **Mechanism**
  - random, distributed (no central arbiter), time-multiplex
  - no carrier sense, retransmission (after collision) with probability p
- Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
Reservations in dynamic TDM

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrivals)
- 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 (Reservation-ALOHA)
- Implicit Reservation (PRMA)

Explicit Reservation

Reservation Aloha / DAMA (Demand Assigned Multiple Access)
- 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)
- Synchronization needed (of reserved / reservation slots)
- It is important for all stations to keep the reservation list consistent at any point in time

Implicit reservation

Packet Reservation Multiple Access (PRMA)
- 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
- Competition for this slot starts again as soon as the slot was empty in the last frame

Carrier Sense Multiple Access (CSMA)

*Listen before Speak*
- Not always possible:
  - Satellite systems
  - Hidden terminal problem
- Collision detection (*Listen while speak*) does not work in wireless:
  - Cost of collision is high (only detected after transmitting entire packet and not receiving ack)
- Try to avoid collisions:
  - Non-persistent CSMA: wait random amount of time if medium is busy
  - P-persistent CSMA: transmit with probability p if medium is idle, defer 1 "slot" with probability 1-p
- CSMA/CA (CSMA with Collision Avoidance)

CSMA/CA (CSMA with Collision Avoidance)

- If medium idle:
  - Transmit
- Otherwise:
  - Wait until medium becomes idle
  - Wait until the medium is idle for a randomly taken time (uniform from back-off window)
  - RTS/CTS
  - Retransmission doubles back-off window
- Used in IEEE 802.11 Wireless LAN
- Detailed explanation later
### RTS/CTS examples
- Reduce the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B
- Reduce 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 can poll all other terminals according to a certain scheme
  - master-slave scheme
  - now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)
  - round robin, random, reservation based
- Used in Bluetooth, IEEE802.11 (option)

### 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)

### Code Division Multiple Access (CDMA)
- 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, a code, the sender XORs (or XNORs) the signal with this code
- The receiver can “tune” into this signal if it knows the pseudo random number, tuning is done via a correlation function
- Different codes should be orthogonal
  - Inner product should be 0
- Ideally, code should have good auto-correlation
  - Inner product with itself should be large, inner product with shifted version should be low
  - Good for synchronization

### CDMA in theory
- **Sender A**
  - Sends \( A_s = 1 \), key \( A_k = 010011 \) (assign: \( '0' = -1, '1' = +1 \))
  - Sending signal \( A_s = A_k \times A_k = (-1, +1, -1, +1, +1) \)
- **Sender B**
  - Sends \( B_s = 0 \), key \( B_k = 110101 \) (assign: \( '0' = -1, '1' = +1 \))
  - Sending signal \( B_s = B_k \times B_k = (-1, -1, -1, +1, -1) \)
- Both signals are superimposed at the receiver
  - 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)
    - \( A_s = (2, 0, 0, -2, 0, +2) \times A_k = 2 \times 0 + 0 + 2 + 2 = 0 \) (result greater than 0, therefore, original bit was ‘1’)
  - Receiving B
    - \( B_s = (2, 0, 0, -2, 0, +2) \times B_k = 2 \times 0 - 2 - 2 = 0 \), i.e. ‘0’

### CDMA on signal level I

<table>
<thead>
<tr>
<th>Data A</th>
<th>1</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Key sequence A</td>
<td>A1 = 0 1 0 1 0 0 0 1 0 0 1 1 1 0 0 1 1 0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data @ Key</td>
<td>1 0 1 0 1 1 0 0 0 1 0 0 1 1 0 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal A</td>
<td></td>
<td></td>
<td>A6</td>
</tr>
</tbody>
</table>

Real systems use much longer keys resulting in a larger distance between single code words in code space.
CDMA on signal level II

<table>
<thead>
<tr>
<th>Signal A</th>
<th>B_0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

CDMA on signal level III

<table>
<thead>
<tr>
<th>Data A</th>
<th>1</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A + B_0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A + B_1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A + B_0) * A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CDMA on signal level IV

<table>
<thead>
<tr>
<th>Data B</th>
<th>1</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A + B_0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B_1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A + B_0) * B_1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CDMA on signal level V

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A + B_0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A + B_1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A + B_0) * A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Random Access in UMTS

- 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. 2^12) compared to frequency space
  - Interferences (e.g. white noise) is not coded
  - Forward error correction and encryption can be easily integrated

- Used to get resources (e.g. code) from the base station, when the mobile starts to communicate.
- Reservation Aloha with CDMA and power ramp-up
  - Send preamble at low power: special signature of 16 chips (repeated 256 times) (16 orthogonal codes available) to BS. 16 signatures available, 15 slots available
  - If ACK (using signature): continue accessing the medium
  - If NACK (using signature): back-off, try with different signature
  - If no response: repeat access with increased power
<table>
<thead>
<tr>
<th>Approach</th>
<th>SDMA</th>
<th>TDMA</th>
<th>FDMA</th>
<th>CDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea</td>
<td>segment space into cells/sectors</td>
<td>segment sending time into disjoint time-slots, demand driven or fixed patterns</td>
<td>segment the frequency band into disjoint sub-bands</td>
<td>spread the spectrum using orthogonal codes</td>
</tr>
<tr>
<td>Terminals</td>
<td>only one terminal can be active in one cell/zone sector/</td>
<td>all terminals are active for short periods of time on the same frequency</td>
<td>every terminal has its own frequency, uninterupted</td>
<td>all terminals can be active at the same place at the same moment, uninterupted</td>
</tr>
<tr>
<td>Signal separation</td>
<td>cell structure, directed antennas</td>
<td>synchronization in the time domain</td>
<td>filtering in the frequency domain</td>
<td>code and special receivers</td>
</tr>
<tr>
<td>Advantages</td>
<td>very simple, increases capacity per km²</td>
<td>established, fully digital, flexible</td>
<td>simple, established, robust</td>
<td>flexible, less frequency planning needed, soft handover</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>inflexible, antennas typically fixed</td>
<td>guard space needed (multipath propagation), synchronization (PSS/SS)</td>
<td>inflexible, frequencies are a scarce resource</td>
<td>complex receivers, needs more complicated power control for senders</td>
</tr>
<tr>
<td>Comment</td>
<td>only in combination with TDMA, FDMA or CDMA useful</td>
<td>standard in fixed networks, together with FDMA/SDMA used in many mobile networks</td>
<td>typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)</td>
<td>still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/TDMA</td>
</tr>
</tbody>
</table>

Wireless Networking