Mobile Computing

Chapter 3: Medium Access Control

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1. Motivation

- Can we apply media access methods from fixed networks?
- 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: cause collisions
  - 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: C is “hidden” for A

- Exposed terminals: cause unnecessary delay
  - 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
    - A collision at B does not matter because the collision is too weak to propagate to A.
  - 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 (base station) 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! (why?)

2. Access methods SDMA/ FDMA/ TDMA

- **SDMA** (Space Division Multiple Access)
  - allocating separate space to users in wireless networks.
  - segment space into cells, or sectors with directed antennas
  - SDMA is never used in isolation.
    - But always in combination with one or more other schemes (FDMA, TDMA, CDMA)

- **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)
  - Frequency Division Duplex (FDD)
    - used to divide up-link & down link channels.
**FDD/ FDMA - GSM**

- **960 MHz**: 124
- **935.2 MHz**: 1
- **915 MHz**: 124
- **890.2 MHz**: 1

FDD/FDMA - GSM

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**Access methods SDMA/ FDMA/ TDMA**

- **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.
  - **Fixed**: (fixed TDM)
    - Allocating a certain time slot for a channel in a fixed pattern.
  - **Dynamic (Aloha)**
    - MAC addresses are open used as identification.
    - It is flexible considering varying bandwidth requirements.

- **Fixed TDM**
  - Results in a fixed bandwidth and delay for each channel.
  - Wireless phone systems - IS 136 (NA TDMA), GSM, DECT, PHS.
  - Base station assigns the fixed time slot pattern.
    - No competition.
  - **Time Division Duplex (TDD)**
    - Assign different slots for uplink and down link using the same frequency.
TDD/ TDMA - DECT

Multiplexing/ Multiple Access/ Duplex

- Three technologies are open confused.
  - But, conceptually different.
  - In practice, they are combined and there exist many possible combinations.
3. Aloha

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

- **Aloha**
  - neither coordinates medium access nor does it resolve contention on the MAC layer (left to higher layers)
  - works fine for a light load.

### Slotted Aloha

- **Slotted Aloha**
  - All sender have to be synchronized.
  - Transmission can only start at the beginning of a time slot.
  - Slotting doubles the throughput (36%)
  - does not guarantee bandwidth or delay to each user.
4. Carrier Sense Multiple Access (CSMA)

- Simple improvement to the basic Aloha
  - Sensing the carrier before accessing the medium
    - Accessing the medium only if the carrier is idle: decrease collision probability.
    - Used in Wireless LAN system

- Non-persistent CSMA
  - Sending immediately if medium is idle.
  - If it is busy, the station pauses a random amount of time before sensing again.

- P-persistent CSMA
  - Only transmit with a probability of $p$,
  - With $1-p$ the station deferring to the next slot.

- CAMA/CA
  - IEEE 802.11

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
  - Collisions may occur during the reservation periods.
  - Reservation also causes higher delays
    - Because of reservation periods
  - 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.

**Diagram:**
- Timing slots:
  - Each slot represents a time period during which a station can send data.
  - The reservation process is illustrated with multiple frames showing the allocation of slots.
  - Collisions are indicated by red marks, suggesting failed reservation attempts.

**Code:**
- Different letters (A, B, C, D, E, F) represent stations trying to reserve slots.
- The sequence of slots is shown from frame to frame, indicating the reservation process and collisions.
**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. \( x = N \times k \)).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

\[ \text{N mini-slots} \quad \text{N} \times k \text{ data-slots} \]

\[ \text{reservations for data-slots} \quad \text{other stations can use free data-slots based on a round-robin scheme} \]

**MACA - collision avoidance**

- MACA (Multiple Access with Collision Avoidance)
  - solves hidden terminal problem
  - does not need a base station
  - still random access but dynamic reservation

- short signaling packets for collision avoidance
  - RTS (request to send): a sender requests 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

MACA variant: DFWMAC in IEEE802.11

sender

idle

packet ready to send; RTS →

wait for the right to send

ACK

RxBusy

time-out; RTS

wait for ACK

time-out ∨ NAK; RTS

CTS; data

receiver

idle

RTS; CTS →

wait for data

ACK; positive acknowledgement

NAK; negative acknowledgement

RxBusy; receiver busy

data; ACK

time-out ∨ data; NAK

RTS; RxBusy
Polling mechanisms

- If one terminal can be heard by all others, this “central” terminal (e.g., 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.
  - 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 (Cellular Digital Packet Data)
  - (USA, integrated into AMPS)
6. 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 (chipping sequence), 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.

- **Good code for CDMA**
  - should be orthogonal to other codes
    - **orthogonal**: for two vectors their inner product is 0.
  - should have a good autocorrelation
    - **autocorrelation**: absolute value of the inner product of a vector multiplied with itself.

- **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

- **Sender A**
  - sends $A_d = 1$, key $A_k = 010011$ (assign: „0“ = -1, „1“ = +1)
  - sending signal $A_s = A_d \cdot A_k = (-1, +1, -1, -1, +1, +1)$

- **Sender B**
  - sends $B_d = 0$, key $B_k = 110101$ (assign: „0“ = -1, „1“ = +1)
  - sending signal $B_s = B_d \cdot B_k = (-1, -1, +1, -1, +1, -1)$

- **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)
    - $A_e = (-2, 0, 0, -2, +2, 0) \cdot A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was „1“
  - receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \cdot B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. „0“

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CDMA on signal level (1)

<table>
<thead>
<tr>
<th>data A</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>key A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>key sequence A</td>
<td>0 1 0 1 0 0 0 1 0 1 1 0 0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data $\oplus$ key</td>
<td>1 0 1 0 1 1 1 0 0 0 1 0 0 0 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>signal A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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 (2)**

<table>
<thead>
<tr>
<th>signal A</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>data B</td>
<td>1:</td>
</tr>
<tr>
<td>key B</td>
<td>0:</td>
</tr>
<tr>
<td>sequence B</td>
<td>0 0 0 1 1 0 1 0 0 0 0 1 0 1 1 1</td>
</tr>
<tr>
<td>data ⊕ key</td>
<td>1 1 1 0 0 1 1 0 1 0 0 0 0 1 0 1 1 1</td>
</tr>
<tr>
<td>signal B</td>
<td></td>
</tr>
<tr>
<td>As + Bs</td>
<td></td>
</tr>
</tbody>
</table>

**CDMA on signal level (3)**

<table>
<thead>
<tr>
<th>data A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Ad</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A_s + B_s</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_k</td>
</tr>
</tbody>
</table>

| (A_s + B_s) * A_k |

| integrator output |
| comparator output |
| 1: |
| 0 |
| 1: |
CDMA on signal level (4)

\[
\begin{array}{c|c|c|c}
\text{data B} & 1 & 0 & 0 \\
\hline
\text{As + Bs} & & & \\
\hline
\text{Bk} & & & \\
\hline
(A_s + B_s) * B_k & & & \\
\hline
\text{integrator output} & 1 & 0 & 0 \\
\hline
\text{comparator output} & (0) & (0) & ? \\
\end{array}
\]

CDMA on signal level (5)

\[
\begin{array}{c|c|c|c}
\text{As + Bs} & & & \\
\hline
\text{wrong key K} & & & \\
\hline
(A_s + B_s) * K & & & \\
\hline
\text{integrator output} & & & \\
\hline
\text{comparator output} & (0) & (0) & ? \\
\end{array}
\]
**SAMA - Spread Aloha Multiple Access**

- Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time.
- **Idea:** use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha

![Spread Aloha Multiple Access Diagram](image)

Problem: find a chipping sequence with good characteristics

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**Comparison SDMA/ TDMA/ FDMA/ CDMA**

<table>
<thead>
<tr>
<th>Approach</th>
<th>SDMA</th>
<th>TDMA</th>
<th>FDMA</th>
<th>CDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Idea</strong></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><strong>Terminals</strong></td>
<td>only one terminal can be active in one cell/one sector</td>
<td>all terminals are active for short periods of time on the same frequency</td>
<td>every terminal has its own frequency, uninterrupted</td>
<td>all terminals can be active at the same place at the same moment, uninterrupted</td>
</tr>
<tr>
<td><strong>Signal separation</strong></td>
<td>cell structure, directed antennas</td>
<td>synchronization in the time domain</td>
<td>filtering in the frequency domain</td>
<td>code plus special receivers</td>
</tr>
<tr>
<td><strong>Advantages</strong></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><strong>Disadvantages</strong></td>
<td>inflexible, antennas typically fixed</td>
<td>guard space needed (multipath propagation), synchronization difficult</td>
<td>inflexible, frequencies are a scarce resource</td>
<td>complex receivers, needs more complicated power control for senders</td>
</tr>
<tr>
<td><strong>Comment</strong></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/FDMA</td>
</tr>
</tbody>
</table>