Last Week
- Signal Propagation
  - Path loss model
  - Log normal shadowing model
- Packet reception
  - SINR
- Theory vs Reality
  - Roofnet
- Modulation
  - ASK, FSK, PSK
- Spread Spectrum
  - Frequency Hopping
  - Direct Sequence Spread Spectrum
- MAC
  - Hidden and Exposed Terminal
  - Space Division Multiplexing
  - Frequency Division Multiplexing
  - Time Division Multiplexing

Today
- Medium Access (Cont)
  - CDMA
  - XOR in the AIR
  - BMAC
- Wireless Networks
  - Bluetooth
  - WLAN

CDMA (2)
- What are good chipping sequences (codes) for users?
  - A set of codes is optimal for CDMA if the codes are pairwise orthogonal
  - Definition of orthogonal is same as with vectors
    - Two codes S, T are orthogonal if S*T = 0, with
      \[ S*T = \frac{1}{m} \sum_{i=1}^{m} S_i T_i \quad m=\text{length of codes} \]
  - Bipolar notation: binary 0 is represented as -1
    - Simplifies calculation (in practice 0,1 model together with XOR)

CDMA: Simple example
- Codes of two senders A and B
  - \( A_k = (-1,+1,-1,-1,+1+1) \) is code of sender A
  - \( B_k = (+1,+1,-1,+1,-1,+1) \) is code of sender B
  - Sender A wants to send bit \( A_d = 1 \)
    - \( A_s = +1(-1,+1,-1,-1,+1+1) = (-1,-1,-1,-1,+1+1) \)
  - Sender B wants to send bit \( B_d = 0 \)
    - \( B_s = -1(+1,+1,-1,+1,-1,-1) = (-1,-1,+1,-1,-1,-1) \)
  - Both signals are superimposed, what is received at a receiver is
    - \( R = A_s + B_s = (-2,0,0,-2,2,0) \)
  - To decode the signal of sender A
    - \( R*A_k = 1/6 * (-1,+1,-1,-1,+1+1)*(-2,0,0,-2,2,0) = 1 \)
  - To decode the signal of sender B: \( R*B_k = 0 \)
Why does this work

\[ R^*A_k = (A_s + B_s + C_s + \ldots) \times A_k \]

\[ A_d^*A_k + B_d^*B_k + C_d^*C_k + \ldots = 1 + 0 + 0 + \ldots \]

pairwise orthogonal codes

Near/Far Problem

Terminals A and B send, C receives
- The signal of B hides A's signal
- C cannot receive A

Common problem in CDMA

Solutions:
- Dynamic power adjustment: close transmitters use less power, far away transmitter use higher power
- Affects battery life
- Power control runaway problem: terminals increase transmit power in a loop until until transmitters hit a power wall

Relative differences are smaller, decoding becomes more difficult

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>Idea</td>
<td>Segment space into cells</td>
<td>Segment time into disjoint time-slots</td>
<td>Segment 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</td>
<td>All terminals are active for short periods of time on same frequency</td>
<td>Every terminal has its own frequency</td>
<td>All terminals can be active at the same place at the same moment</td>
</tr>
<tr>
<td>Advantages</td>
<td>Very simple</td>
<td>Established, flexible</td>
<td>Simple, robust</td>
<td>Flexible, less frequency planning needed</td>
</tr>
<tr>
<td>Dis-advantages</td>
<td>Inflexible antennas</td>
<td>Synchronization difficult</td>
<td>Inflexible, frequencies are scarce resource</td>
<td>Needs complicated power control</td>
</tr>
</tbody>
</table>

COPE: Wireless Network Coding

Consider the following request/response scenario:

COPE Approach

Increased throughput: saved transmission can be used to send more data

Beyond Duplex Flows

Source S1 and S2 want to send a data packet to destinations D1 and D2

Requires 4 transmission

Requires 3 transmission

Requires 3 transmission
COPE – Snooping

- Every node snoops on all packets
- A node stores all heard packets for a limited time
- Node sends Reception Reports to tell its neighbors what packets it heard
  - Reports are piggybacked on packets
  - If no packets to send, periodically send reports

COPE – Coding

- To send packet p to neighbor A, XOR p with packets already known to A
  - Thus, A can decode
- But how can multiple neighbors benefit from a single transmission?

COPE – Example

- P1 + P2
  - Bad coding – C can decode but A can’t

- P1 + P3
  - Better coding – both C and A can decode

- P1 + P3 + P4
  - Best coding – Nodes A, C, D can decode
Overview of Wireless Networks

- **Wireless Personal Area Networks (WPANs)**
  - IEEE 802.15.1 (Bluetooth), IrDa, Zigbee, sensor networks, etc.

- **Wireless Local Area Networks (WLANs)**
  - IEEE 802.11, a, b, g, etc. (infrastructure and ad hoc)

- **Wireless Metro Area Networks (WMANs)**
  - IEEE 802.16 WiMAX

- **Wireless Wide Area Networks (WWANs)**
  - GSM, UMTS, EDGE, etc.

**Ingredients of Wireless Systems**

- **Physical Layer:**
  - FSK, BFSK, DSSS, OFDM, QPSK, ...

- **Media Access:**
  - FDMA, TDMA, CDMA, ...

  Network Architecture, Mobility, Network Management, etc.

The 802.15 Family

- Target deployment environment: communication of personal devices working together
  - Short range
  - Low power
  - Low cost
  - Small number of devices

- Four standards:
  - IEEE 802.15.1 – Bluetooth
  - IEEE 802.15.2 – Interoperability (e.g., Wifi)
  - IEEE 802.15.3 – High Data Rate WPAN
  - IEEE 802.15.4 – Low Data Rate WPAN (ZigBee)

Some common themes

- Master/Slave notion
  - Or ‘simple’ node versus coordinator

- Use of Piconets
  - Small group of devices managed by a master or coordinator
  - Scalability is not the main concern

- Support for QoS
  - Voice needs fixed bandwidth and latency
  - Data, transmitted in bursts

- But many variants how functionality is supported

Bluetooth - Overview

- Universal radio interface for ad-hoc wireless connectivity
  - Interconnecting mobile phones, handset, laptops, bar code readers, GPS receivers, printers, etc.

- Cheap, low power, short range (up to 100m)

- 2.4 GHz band, 79 channels (each 1 MHz wide)

- Data rates available to applications:
  - Up to specification version 1.2: 0.7 Mbit/s
  - Specification 2.0 – 4.0: 2.1 Mbit/s

- Range: Up to 100m

- History:
  - First Bluetooth Specification 1994 by Ericsson
  - Foundation of Bluetooth Special Interest Group 1998
  - First consumer products for mass market in 2001, spec. vs. 1.1.)
  - Latest specification, version 4.0
Bluetooth Protocol Stack

- Above Host Controller Interface (HCI): implemented in Software

Radio Access
Connection Management
Logical Channels
Service Discovery

Piconet

- Piconet = Collection of BT devices connected in an ad hoc fashion
- One unit acts as master and the others as slaves for the lifetime of the piconet
- Each piconet has a unique hopping pattern determined by the master
- Participation in a piconet = synchronization to hopping sequence
- Each piconet has one master and up to 7 simultaneous slaves (> 200 could be parked)

Baseband Layer – Frequency Selection

- Master sends in all odd slots, slaves share even slots
- 1-slot, 3-slot or 5-slot packets possible
- Frequency pattern remains regardless of packet size (why?)

Scatternets

- Scatternet = group of piconets
- Device can participate multiple piconets
  - Jumping between the hopping sequences of the different piconets
  - Before leaving a device informs the current master that it will be unavailable for a certain amount of time

Link Types

- SCO (Synchronous connection-oriented)
  - Mostly used for voice
  - The master reserves two consecutive slots (forward and return slots) at fixed intervals
  - A master can support up to 3 SCO links to the same slave or to different slaves
- ACL (Asynchronous connectionless)
  - Typically used for data
  - Variable frame size (1, 3, 5 slots)
  - Master uses polling, a slave may only answer if addressed in the preceding slot
  - Maximum of 1 ACL link per master/slave
- No direct slave to slave communication, packet transmission only between master and slave
Link Types - Example

- Every sixth slot used for SCO link between master and slave 1
- ACL links use single or multiple slots (note: hopping sequence is independent of the transmission of packets)

Robustness

- ACL links can be protected with ARQ scheme (Automatic Repeat Request)
- One extra bit (ACK, NAK) is enough because master/slave have to send alternating

Link Manager – Connection Establishment

- Bluetooth link manager is responsible for authentication, synchronization, power control and device state switching

- A Bluetooth device can be in one of several states:
  - Standby: Each 2048th slot a device listens on 32 of the 79 channels
  - Inquiry: search for other devices
  - Page: set up connections (e.g., hopping sequence)

When device is connected
- Device is either in the transmit or the connected state
- Extra low-power states:
  - Sniff: listen to the piconet at a reduced rate (custom)
  - Hold: device stops ACL transmission
  - Park: device releases AMA address, device still synchronized

States of a Bluetooth device

(power consumption: sniff > hold > park)

L2CAP – Logical Link Control and Adaption Protocol

- Simple data link protocol on top of Baseband ACL link
- L2CAP provides three different channels
  - Connectionless: typically used to broadcast, master to all slaves
  - Connection-oriented: bi-directional channel between master and slave
  - Signaling: used to exchange control information

- Segmentation and re-assembly of user data
  - L2CAP accepts up to 64KB packets
  - This needs to be chopped into smaller basedband packets (5 slot ACL link can carry a maximum of 339 bytes per packet)

L2CAP (2)

- Channel identifiers (CID) used to demultiplex L2CAP channels
  - Signaling used CID of 1
  - Connectionless channels have CID 2 at slave and a dynamically assigned CID at master
    - Additional protocol/service demultiplexer (PSM) needed for connectionless channels
  - Connection-oriented channels get dynamically assigned CID at both master and slave
Higher layer protocols

Telephony
- Control library
- 802.x
- Emulation

Service Discovery Protocol (SDP)
- Find services that are available in radio proximity
- SDP defines the discovery of services, but not their usage
- Client/Server model
  - Devices that want to offer services have to run an SDP server
  - For all other devices running an SDP client is sufficient
- Information about a service is stored in a service record
  - List of service attributes
- SDP is implemented on top of a L2CAP connectionless channel
  - Uses PSM of 1

Sensor Networks
- Wireless networks built from sensor nodes
  - Example: Mica 2
    - 4KB RAM
    - 128KB Program Flash Memory
    - 16Mhz Microcontroller
    - Wireless Radio

Sensor Networks: Applications (1)
- Monitor temperature of goods in supermarket (attach sensor nodes to fridges)
- Monitor environment of plants in agriculture (solar radiation, temperature, humidity)

Sensor Networks: Applications (2)
- Earthquake detection
  - Earthquake speed ~5-10km/h,
  - Instant detection can give warning ~30seconds before the shockwave hits a city 200km from the epicenter
- Structure Monitoring in buildings
  - Understand interactions between ground motions and structure foundation

Concept of operation
- Form Ad Hoc Network (no fixed Infrastructure)
- Gather data and
- Forward it to the user (‘sink’ or gateway node)
Sensor Networks – Medium Access

- In sensor networks energy is often more critical than throughput
  - The radio component should be turned off as much as possible
- Energy management considerations have a big impact on MAC protocols
  - Idle listening costs about as much energy as transmitting

S-MAC

- Coarse-grained TDMA-like sleep/awake cycles
- All nodes choose and announce awake schedules
  - Synchronize to awake schedules of neighboring nodes
- Uses RTS/CTS to resolve contention during listen intervals
  - And allows interfering nodes to go to sleep during data exchange
- Problem: Different schedules may increase end-to-end latency

B-MAC

- Asynchronous
- Low power listening

Shortcomings:
- Problematic in case of shorter packets: relatively long active period

References

- Versatile Low Power Media Access for Wireless Sensor Networks, Joseph Polastre, Jason Hill, David Culler, Sensys 2004