MOBILE COMPUTING
CSE 40814/60814
Fall 2015

Bluetooth

- Basic idea
  - Universal radio interface for ad-hoc wireless connectivity
  - Interconnecting computer and peripherals, handheld devices, PDAs, cell phones – replacement of IrDA
  - Embedded in other devices, very cheap
  - Short range (10m), low power consumption, license-free 2.45 GHz ISM
  - Voice and data transmission, approx. 1 Mbit/s data rate

One of the first modules (Ericsson).
Bluetooth

- History
  - 1994: Ericsson (Mattison/Haartsen), “MC-link” project
  - Renaming of the project: Bluetooth according to Harald “Blåtand” Gormsen [son of Gorm], King of Denmark in the 10th century
  - 2001: first consumer products for mass market, spec. version 1.1 released
  - 2005: 5 million chips/week

- Special Interest Group
  - Original founding members: Ericsson, Intel, IBM, Nokia, Toshiba
  - Added promoters: 3Com, Agere (was: Lucent), Microsoft, Motorola
  - > 10000 members
  - Common specification and certification of products

Characteristics

- **2.4 GHz** ISM band, **79 RF channels**, 1 MHz carrier spacing
  - Channel 0: 2402 MHz … channel 78: 2480 MHz
  - GFSK modulation, 1-100 mW transmit power

- FHSS and TDD
  - **Frequency hopping** (spread spectrum) with 1600 hops/s
  - Hopping sequence in a pseudo random fashion, determined by a master
  - Time division duplex for send/receive separation

- **Voice link – SCO** (Synchronous Connection Oriented)
  - **FEC (forward error correction)**, no retransmission, 64 kbit/s duplex, point-to-point, circuit switched

- **Data link – ACL** (Asynchronous Connection Less)
  - Asynchronous, acknowledgments, point-to-multipoint, up to 433.9 kbit/s symmetric or 723.2/57.6 kbit/s asymmetric, packet switched

- **Topology**
  - Overlapping piconets (stars) forming a scatternet
Piconet

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

Forming a Piconet

- All devices in a piconet hop together
  - Master gives slaves its clock and device ID
    - Hopping pattern: determined by device ID (48 bit, unique worldwide)
    - Phase in hopping pattern determined by clock
- Addressing
  - Active Member Address (AMA, 3 bit)
  - Parked Member Address (PMA, 8 bit)
Scatternet

• Linking of multiple co-located piconets through the sharing of common master or slave devices
  • Devices can be slave in one piconet and master of another
  • Communication between piconets
    • Devices jumping back and forth between the piconets

M=Master
S=Slave
P=Parked
SB=Standby

Piconets (each with a capacity of 720 kbit/s)

Frequency Selection

625 µs

625 µs

625 µs

...
Baseband (remainder of slides not on exam!)

- Piconet/channel definition
- Low-level packet definition
  - Access code
    - Channel, device access, e.g., derived from master
  - Packet header
    - active member address (broadcast + 7 slaves), link type, alternating bit ARQ/SEQ, checksum

![Packet structure diagram]

SCO payload types

<table>
<thead>
<tr>
<th>Type</th>
<th>Payload</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV1</td>
<td>audio (10)</td>
<td>FEC (20)</td>
</tr>
<tr>
<td>HV2</td>
<td>audio (20)</td>
<td>FEC (10)</td>
</tr>
<tr>
<td>HV3</td>
<td>audio (30)</td>
<td></td>
</tr>
<tr>
<td>DV</td>
<td>audio (10)</td>
<td>Header (1)</td>
</tr>
</tbody>
</table>
ACL Payload types

<table>
<thead>
<tr>
<th>Type</th>
<th>Payload Header [byte]</th>
<th>User Payload [byte]</th>
<th>FEC</th>
<th>CRC</th>
<th>Symmetric max. Rate [kbit/s]</th>
<th>Asymmetric max. Rate [kbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM1</td>
<td>header (1/2)</td>
<td>payload (0-339)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM3</td>
<td>header (2)</td>
<td>payload (0-121)</td>
<td>2/3</td>
<td>yes</td>
<td>258.1</td>
<td>585.6</td>
</tr>
<tr>
<td>DM5</td>
<td>header (2)</td>
<td>payload (0-224)</td>
<td>2/3</td>
<td>yes</td>
<td>286.7</td>
<td>387.2</td>
</tr>
<tr>
<td>DH1</td>
<td>header (1)</td>
<td>payload (0-27)</td>
<td></td>
<td></td>
<td>172.8</td>
<td>172.8</td>
</tr>
<tr>
<td>DH3</td>
<td>header (2)</td>
<td>payload (0-183)</td>
<td></td>
<td></td>
<td>390.4</td>
<td>585.6</td>
</tr>
<tr>
<td>DH5</td>
<td>header (2)</td>
<td>payload (0-339)</td>
<td></td>
<td></td>
<td>433.9</td>
<td>723.2</td>
</tr>
<tr>
<td>AUX1</td>
<td>header (1)</td>
<td>payload (0-29)</td>
<td></td>
<td></td>
<td>185.6</td>
<td>185.6</td>
</tr>
</tbody>
</table>

Baseband data rates

<table>
<thead>
<tr>
<th>Type</th>
<th>Payload Header [byte]</th>
<th>User Payload [byte]</th>
<th>FEC</th>
<th>CRC</th>
<th>Symmetric max. Rate [kbit/s]</th>
<th>Asymmetric max. Rate [kbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 slot</td>
<td>DM1 1</td>
<td>0-17</td>
<td>2/3</td>
<td>yes</td>
<td>108.8</td>
<td>108.8</td>
</tr>
<tr>
<td></td>
<td>DH1 1</td>
<td>0-27</td>
<td>2/3</td>
<td>yes</td>
<td>172.8</td>
<td>172.8</td>
</tr>
<tr>
<td>3 slot</td>
<td>DM3 2</td>
<td>0-121</td>
<td>2/3</td>
<td>yes</td>
<td>258.1</td>
<td>387.2</td>
</tr>
<tr>
<td></td>
<td>DH3 2</td>
<td>0-183</td>
<td></td>
<td></td>
<td>390.4</td>
<td>585.6</td>
</tr>
<tr>
<td>5 slot</td>
<td>DM5 2</td>
<td>0-224</td>
<td>2/3</td>
<td>yes</td>
<td>286.7</td>
<td>387.2</td>
</tr>
<tr>
<td></td>
<td>DH5 2</td>
<td>0-339</td>
<td></td>
<td></td>
<td>433.9</td>
<td>723.2</td>
</tr>
<tr>
<td></td>
<td>AUX1 1</td>
<td>0-29</td>
<td></td>
<td></td>
<td>185.6</td>
<td>185.6</td>
</tr>
<tr>
<td>SCO</td>
<td>HV1 na</td>
<td>10</td>
<td>1/3</td>
<td>no</td>
<td>64.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HV2 na</td>
<td>20</td>
<td>2/3</td>
<td>no</td>
<td>64.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HV3 na</td>
<td>30</td>
<td></td>
<td>no</td>
<td>64.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DV 1 D</td>
<td>10+(0-9) D</td>
<td>2/3</td>
<td>yes D</td>
<td>64.0+57.6 D</td>
<td></td>
</tr>
</tbody>
</table>

Data Medium/High rate, High-quality Voice, Data and Voice
**Baseband Link Types**

- Polling-based TDD packet transmission
  - 625μs slots, master polls slaves
- SCO (Synchronous Connection Oriented) – Voice
  - Periodic single slot packet assignment, 64 kbit/s full-duplex, point-to-point
- ACL (Asynchronous ConnectionLess) – Data
  - Variable packet size (1, 3, 5 slots), asymmetric bandwidth, point-to-multipoint

**Robustness**

- Slow frequency hopping with hopping patterns determined by a master
  - Protection from interference on certain frequencies
  - Separation from other piconets (FH-CDMA)
- Retransmission
  - ACL only, very fast
- Forward Error Correction
  - SCO and ACL

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**Diagram 1:**

- Master
- Slave 1
- Slave 2
- SC0
- ACL
- Frequency hopping patterns

**Diagram 2:**

- Master
- Slave 1
- Slave 2
- Error in payload (not header?)
- Forward Error Correction
- Acknowledgment (ACK), Negative Acknowledgment (NAK)
Bluetooth Versions

• Bluetooth 1.1
  • also IEEE Standard 802.15.1-2002
  • initial stable commercial standard
• Bluetooth 1.2
  • also IEEE Standard 802.15.1-2005
  • eSCO (extended SCO): higher, variable bitrates, retransmission for SCO
  • AFH (adaptive frequency hopping) to avoid interference
• Bluetooth 2.0 + EDR (2004, no more IEEE)
  • EDR (enhanced date rate) of 3.0 Mbit/s for ACL and eSCO
  • lower power consumption due to shorter duty cycle
• Bluetooth 2.1 + EDR (2007)
  • better pairing support, e.g., using NFC
  • improved security

• Bluetooth 3.0 + HS (2009)
  • speeds up to 24Mbps (using co-located Wi-Fi link!)
• Bluetooth 4.0
  • Classic Bluetooth
  • Bluetooth High Speed
  • Bluetooth Low Energy
• Bluetooth Low Energy (BLE):
  • Marketed as Smart Bluetooth
  • Lower power, lower cost
  • Use if healthcare, fitness, security, entertainment devices
  • 40 channels

• Bluetooth Profiles (different types of applications)
ZigBee

- Relation to 802.15.4 similar to Bluetooth (802.15.1)

- Pushed by Chipcon (now TI), Ember, Freescale (Motorola), Honeywell, Mitsubishi, Motorola, Philips, Samsung…

- More than 260 members
  - about 15 promoters, 133 participants, 111 adopters
  - must be member to commercially use ZigBee spec

- ZigBee platforms comprise
  - IEEE 802.15.4 for layers 1 and 2
  - ZigBee protocol stack up to the applications