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 (10 m), 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 (Mattsson/Haartsen), "MC-link" project
  – Renaming of the project: Bluetooth according to Harald "Blåtand" Gormsen
    (son of Gorm), King of Denmark in the 10th century
  – 1999: erection of a rune stone at Ericsson/Lund
  – 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

History and Hi-tech…

…and the real rune stone

Located in Jelling, Denmark, erected by King Harald "Blåtand" in memory of his parents. The stone has three sides – one side showing a picture of Christ.

Inscription:
"Harald king executes these sepulchral monuments after Gorm, his father, and Thyra, his mother. The Harald who won the whole of Denmark and Norway and turned the Danes to Christianity."

Btw: Blåtand means "of dark complexion" (not having a blue tooth…)

This could be the "original" colors of the stone.
Characteristics

- 2.4 Hz 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 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 (in 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

Frequency Selection

Baseband

- 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

SCO payload types

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Payload Format</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV1</td>
<td>audio</td>
<td>(30)</td>
<td>1/3 FEC</td>
</tr>
<tr>
<td>HV2</td>
<td>audio</td>
<td>(30)</td>
<td>2/3 FEC</td>
</tr>
<tr>
<td>HV3</td>
<td>audio</td>
<td>(30)</td>
<td></td>
</tr>
<tr>
<td>DV</td>
<td>audio</td>
<td>(10)</td>
<td>1/3 FEC, CRC, Q</td>
</tr>
</tbody>
</table>

ACL Payload types

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Payload Format</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM1</td>
<td>header</td>
<td>(0-343)</td>
<td></td>
</tr>
<tr>
<td>DH1</td>
<td>header</td>
<td>(0-17)</td>
<td>2/3 FEC</td>
</tr>
<tr>
<td>DH3</td>
<td>header</td>
<td>(0-121)</td>
<td>2/3 FEC</td>
</tr>
<tr>
<td>DH5</td>
<td>header</td>
<td>(0-183)</td>
<td>2/3 FEC</td>
</tr>
<tr>
<td>AUX1</td>
<td>header</td>
<td>(0-17)</td>
<td></td>
</tr>
</tbody>
</table>

Baseband data rates

<table>
<thead>
<tr>
<th>Type</th>
<th>Payload Header Format</th>
<th>User Payload Format</th>
<th>Symmetric Rate [kbit/s]</th>
<th>Asymmetric Rate [kbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL</td>
<td>1 slot</td>
<td>DM1</td>
<td>1</td>
<td>172.8</td>
</tr>
<tr>
<td>ACL</td>
<td>2 slot</td>
<td>DH2</td>
<td>1</td>
<td>258.1</td>
</tr>
<tr>
<td>ACL</td>
<td>3 slot</td>
<td>DH5</td>
<td>2</td>
<td>385.6</td>
</tr>
<tr>
<td>ACL</td>
<td>4 slot</td>
<td>DH5</td>
<td>2</td>
<td>64.0</td>
</tr>
<tr>
<td>ACL</td>
<td>5 slot</td>
<td>HV1</td>
<td>na</td>
<td>64.0</td>
</tr>
<tr>
<td>ACL</td>
<td>6 slot</td>
<td>HV2</td>
<td>na</td>
<td>64.0</td>
</tr>
<tr>
<td>ACL</td>
<td>7 slot</td>
<td>HV3</td>
<td>na</td>
<td>64.0</td>
</tr>
<tr>
<td>ACL</td>
<td>8 slot</td>
<td>DV</td>
<td>1</td>
<td>64.0</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 kba/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

### 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 data 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 Versions

- 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 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