Wireless Personal Area Networks

- Bluetooth
  - User Scenarios
  - Architecture
  - Protocol Stack
- IEEE 802.15.1 and IEEE 802.15.2
- IEEE 802.15.4 (Low-Rate Wireless Personal Area Networks)
Bluetooth

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, goal: 5€/device
- Short range (10 m), low power consumption, license-free 2.45 GHz ISM
- Voice and data transmission, approx. 1 Mbit/s gross 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
- 1999: erection of a rune stone at Ericsson/Lund
- 2001: first consumer products for mass market

Special Interest Group

- Original founding members: Ericsson, Intel, IBM, Nokia, Toshiba
- Added promoters: 3Com, Agere, Microsoft, Motorola
- > 2500 members
- Common specification and certification of products
User Scenarios

- Connection of peripheral devices
  - Keyboard, mouse, headset, etc.
- Support of ad hoc networking
  - Temporary networking,
- Bridging of networks
  - Mobile phone acting as a bridge between a Bluetooth network and GSM
Characteristics

2.4 GHz ISM band, 79 (23) RF channels, 1 MHz carrier spacing
- Channel 0: 2402 MHz ... channel 78: 2480 MHz
- G-FSK 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
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 < 1 Mbit/s)
Core protocol stack

- Radio: Specification of the air interface
  - Frequencies, modulation, transmit power
- Baseband: Basic connection establishment
  - Packet formats, timing, basic QoS parameters
- Link manager protocol: Link set-up and management
  - Security functions, etc.
- Logical Link Control and Adaptation Protocol (L2CAP)
  - Adaptation of higher layers to the baseband
- Service Discovery: Device discovery in close proximity
  - Querying of service characteristics
Baseband

Piconet/channel definition

Frequency hopping for interference mitigation and medium access

Low-level packet definition

Physical Links

- Synchronous Connection Oriented
- Asynchronous Connectionless
Frequency selection during data transmission

625 µs

\( f_k \) \( f_{k+1} \) \( f_{k+2} \) \( f_{k+3} \) \( f_{k+4} \) \( f_{k+5} \) \( f_{k+6} \)

M S M S M S M

M S M S M S M

M

S

M

1,3,5 slot packets
Medium Access Control and Link Types

MAC

Polling-based TDD packet transmission
- 625µs slots, master polls slaves

Reservation based for SCO Links

Link types
- 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
Example Data Transmission

Master uses the even frequency slots, odd slots are for the slaves.
Every sixth slot is reserved for an SCO.
ACL links use single or multiple slots.
Link Manager Protocol

Authentication, pairing and Encryption

- Exchange of random numbers and signed responses

Synchronization

- Adjusting clock offset each time a packet is received from the master

Capability Negotiation

- Exchange of supported features: Not all the BT devices have the same capabilities (SCO links, multi-slot packets, encryption)

QoS-Negotiation

- Poll interval, number of repetitions for packet transmission, etc.,

Power Control

Link Supervision: control the activity of a link

State and transmission mode change:

- Master/slave role, detach, etc.
Baseband states of a Bluetooth device

Standby: do nothing
Inquire: search for other devices
Page: connect to a specific device
Connected: participate in a piconet

Park: release AMA, get PMA
Sniff: listen periodically, not each slot
Hold: stop ACL, SCO still possible, possibly participate in another piconet
SDP – Service Discovery Protocol

Inquiry/response protocol for discovering services

- Searching for and browsing services in radio proximity
- Adapted to the highly dynamic environment
- Can be complemented by others like SLP, Jini, Salutation, ...
- Defines discovery only, not the usage of services
- Caching of discovered services

Service record format

- Information about services provided by attributes
- Attributes are composed of an 16 bit ID (name) and a value
- values may be derived from 128 bit Universally Unique Identifiers (UUID)
### WPAN: IEEE 802.15-1 – Bluetooth

<table>
<thead>
<tr>
<th><strong>Data rate</strong></th>
<th><strong>Connection set-up time</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Synchronous, connection-oriented: 64 kbit/s</td>
<td>□ Depends on power-mode</td>
</tr>
<tr>
<td>□ Asynchronous, connectionless</td>
<td>□ Max. 2.56s, avg. 0.64s</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>● 433.9 kbit/s symmetric</td>
<td></td>
</tr>
<tr>
<td>● 723.2 / 57.6 kbit/s asymmetric</td>
<td></td>
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</tbody>
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<tr>
<th><strong>Transmission range</strong></th>
<th><strong>Quality of Service</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>□ POS (Personal Operating Space) up to 10 m</td>
<td>□ Guarantees, ARQ/FEC</td>
</tr>
<tr>
<td>□ with special transceivers up to 100 m</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Frequency</strong></th>
<th><strong>Manageability</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Free 2.4 GHz ISM-band</td>
<td>□ Public/private keys needed, key management not specified, simple system integration</td>
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<tr>
<th><strong>Cost</strong></th>
<th><strong>Special Advantages/Disadvantages</strong></th>
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<tbody>
<tr>
<td>□ 50€ adapter, drop to 5€ if integrated</td>
<td>□ Advantage: already integrated into several products, available worldwide, free ISM-band, several vendors, simple system, simple ad-hoc networking, peer to peer, scatternets</td>
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<th><strong>Availability</strong></th>
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<tr>
<td>□ Integrated into some products, several vendors</td>
<td>□ Disadvantage: interference on ISM-band, limited range, max. 8 devices/network&amp;master, high set-up latency</td>
</tr>
</tbody>
</table>
WPAN: IEEE 802.15 – future developments 1

802.15-2: Coexistence

- Coexistence of Wireless Personal Area Networks (802.15) and Wireless Local Area Networks (802.11), quantify the mutual interference

802.15-3: High-Rate

- Standard for high-rate (20Mbit/s or greater) WPANs, while still low-power/low-cost
- Data Rates: 11, 22, 33, 44, 55 Mbit/s
- Quality of Service isochronous protocol
- Ad hoc peer-to-peer networking
- Security
- Low power consumption
- Low cost
- Designed to meet the demanding requirements of portable consumer imaging and multimedia applications
802.15-4: Low-Rate, Very Low-Power

- Low data rate solution with multi-month to multi-year battery life and very low complexity
- Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation
- Data rates of 20-250 kbit/s, latency down to 15 ms
- Master-Slave or Peer-to-Peer operation
- Support for critical latency devices, such as joysticks
- CSMA/CA channel access (data centric), slotted (beacon) or unslotted
- Automatic network establishment by the PAN coordinator
- Power management to ensure low power consumption
- 16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz US ISM band and one channel in the European 868 MHz band