Outline

- 802.15 protocol overview
- Bluetooth
- Personal Area Networks – 802.15
  - Applications and positioning
  - Bluetooth
  - High speed WPAN
  - Zigbee
- UWB

IEEE 802.15: Personal Area Networks

- Target deployment environment: communication of personal devices working together
  - Short-range
  - Low Power
  - Low Cost
  - Small numbers of devices
- Four groups of standards:
  - IEEE 802.15.1 – "Bluetooth"
  - IEEE 802.15.2 – Interoperability (e.g. Wi-Fi)
  - IEEE 802.15.3 – High data rate WPAN (WiMedia)
  - IEEE 802.15.4 – Low data rate WPAN (ZigBee)

Some Common Themes

- Master/slave notion
  - Or simple node versus coordinator
- Use of “piconets”
  - Small groups of devices managed by a master or coordinator
  - Scalability is not a concern
- Support for QoS
  - Want to support voice and other media
- But many variants in how this functionality is supported
Bluetooth

- Think USB, not Ethernet
  » Cable replacement technology
- Originally defined as IEEE 802.15.1, but standard is now maintained by the Bluetooth Special Interest Group
  » Created by Ericsson
- Some features:
  » Up to 1 Mbps connections (original version)
  » 1600 hops per second FHSS
  » Includes synchronous, asynchronous, voice connections
  » Piconet routing
- Small, low-power, short-range, cheap, versatile radios
- Used as Internet connection, phone, or headset
- Master/slave configuration and scheduling

IEEE 802.15.1

- Adopted the Bluetooth MAC and PHY specifications
- IEEE 802.15.1 and Bluetooth are almost identical regarding physical layer, baseband, link manager, logical link control and adaptation protocol, and host control interface
- Range of up to 30 feet, uses FHSS
- Data transfer rates of up to 1 Mbps
  » Up to 3 Mbps for version 2
- Not designed to carry heavy traffic loads

Bluetooth Standards

- Core specifications: defines the layers of the Bluetooth protocol architecture
  » Radio - air interface, txpower, modulation, FH
  » Baseband - power control, addressing, timing, connections...
  » Link manager protocol (LMP) - link setup & mgmt, incl. authentication, encryption, ...
  » Logical link control and adaptation protocol (L2CAP) - adapts upper layer to baseband
  » Service discovery protocol (SDP) – device info, services and characteristics.

Bluetooth “Profiles”

- Profile specifications describe the use of BT in support of various applications
  » Includes which parts of the core specification are mandatory, optional or not applicable
- Data and voice access points
  » Real-time voice and data transmissions
- Cable replacement
  » Eliminates need for numerous cable attachments for connection
Some Example Profiles

- Audio/video profile
- Fax profile
- Basic printing profile
- Serial port profile
- PAN profile
- Phone book access profile
- Headset profile
- LAN access profile
- Service discovery profile
- Cordless phone profile

Frequency Hopping in Bluetooth

- Provides resistance to interference and multipath effects
- Provides a form of multiple access among co-located devices in different piconets
- Total bandwidth divided into 79 1MHz physical channels
- FH occurs by jumping from one channel to another in pseudorandom sequence
- Hopping sequence shared with all devices on piconet
  » Remember that all communication is with the master, i.e., only one transmitter at any time

Sharing the Channel

- Bluetooth devices use time division duplex (TDD)
- Access technique is TDMA
- FH-TDD-TDMA

Piconets are Basis for Topology

- Master with up to 7 active slaves
  » Slaves only communicate with master
  » Slaves must wait for permission from master
- Master picks radio parameters
  » Channel, hopping sequence, timing, ...
- Scatternets can be used to build larger networks
  » A slave in one piconet can also be part of another piconet
  » Either as a master or as a slave
  » If master, it can link the piconets
Wireless Network Configurations

Bluetooth Piconet

- A collection of devices connected via Bluetooth technology in a master-slave network
  - Master functions as the piconet coordination (PNC)
- The piconet starts with two connected devices, and may grow to eight connected devices
  - Devices are added by the master
- All Bluetooth devices are peer units and have identical implementations, but they play a master or slave role when connecting
  - Roles can be reversed
  - Example: headsets connects as master to phone but then becomes slave

Forming a piconet

- Needs two parameters:
  - Hopping pattern of the radio it wishes to connect.
  - Phase within the pattern i.e. the clock offset of the hops.
  - Effectively defines a channel that must be unique to the piconet – master must scan for other piconets first
- The global ID defines the hopping pattern.
- The master shares its global ID and its clock offset with the other radios which become slaves.
- The global ID and the clock parameters are exchanged using a FHS (Frequency Hoping Synchronization) packet.

IEEE 802.15.4 - Overview

- Low Rate WPAN (LR-WPAN)
- Simple and low cost
- Low power consumption
  - Years on lifetime using standard batteries
- Mostly in sensor networks
- Data rates: 20-250 kbps
- Operates at multiple frequencies
  - 868 Mhz, 915 Mhz, 2.4 GHz
- Blends elements from 802.15.3 and 802.11
- Many versions exist for difference application domains
802.15.4 applications

- Zigbee
- Low Data-Rate Radio Devices
- TV VCR/DVD/CD Remote control
- Mouse
- PC and Peripherals
- Home Automation
- Security
- HVAC
- Lighting
- Closures
- Toymakers
- Gamarque
- Consumer Electronics
- Home Automation
- Industrial & Commercial
- Personal Health Care
- Monitors
- Sensors
- Automation
- Control
- Consoles
- Portables
- Educational

802.15.4 devices

- Full function device (FFD)
  - Any topology
  - Network coordinator capable
  - Talks to any other device
- Reduced function device (RFD)
  - Limited to star topology
  - Cannot become a network coordinator
  - Talks only to a network coordinator
  - Very simple implementation

Roles

- Devices (RFD or FFD)
  - must be associated to a coordinator
- Coordinators (FFD)
  - can operate in peer-to-peer mode
  - can form a PAN coordinated by a PAN coordinator
- PAN Coordinator (FFD)
  - manages a list of associate devices
  - devices need to associate and disassociate
  - allocates short addresses
  - beacon frames (in beacon mode)
  - processes requests for fixed time slots
IEEE 802.15.4 - Star

Star Topology

- PAN Coordinator
- Master/slave

- Full function device
- Reduced function device

Communications flow

IEEE 802.15.4 - Peer-to-Peer

Peer-Peer Topology

- Point to point
- Cluster tree

- Full function device

Communications flow

IEEE 802.15.4 - Combined

Combined Topology

- Clustered stars - for example, cluster nodes exist between rooms of a hotel and each room has a star network for control.

- Full function device
- Reduced function device

Communications flow

IEEE 802.15.4 - MAC

- One PAN coordinator & multiple RFDs/FFDs
  - Association/disassociation
- CSMA-CA channel access
  - Reliable delivery of data
- Optional superframe structure with beacons
  - GTS mechanism
- AES-128 security
- QoS – 3 traffic types
  - Periodic data: e.g. Sensor data
  - Intermittent data: generated once a while, e.g. light switch traffic
  - Repetitive low latency data: E.g. Mouse device traffic
802.15.4 superframe structure

<table>
<thead>
<tr>
<th>Beacon</th>
<th>Contention access period (CAP)</th>
<th>Guaranteed time slots (GTS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active period</td>
<td>Inactive period</td>
</tr>
</tbody>
</table>

Outline

- 802.15 protocol overview
- Bluetooth
- Personal Area Networks – 802.15
  - Applications and positioning
  - Bluetooth
  - Zigbee
- UWB

Ultra WideBand

\[ C = B \log_2 (1 + \text{SNR}) \]

- Can achieve high throughputs with low SNR by using a high B
- Motivation is the 802.15.3a (high rate PAN) standards effort
  - Targets high speed, short distance communication
- But where do I find this much spectrum?
- Use a transmit power that is low enough so it will not affect other users
  - Can be used in most licensed frequency bands (with FCC permission, of course)

FCC UWB Rules

- UWB technically defined as:
  - Width of signal > 500 MHz, or \( B > \frac{f_B}{f_H + f_L} > 0.2 \)
- Approved for 3.1 GHz to 10.6 GHz
- Power limit is -41.3 dBm/MHz
  - Note that the limit is not on the total signal but across the part of the spectrum that is used
- Results in a frequency mask that must be satisfied
- Certain narrow bands must be filtered out
  - E.g. certain radio astronomy bands
  - Depends on the country
Example Technology: Basic Impulse Information Modulation

Pulse length ~ 200 ps; Energy concentrated in 2-6 GHz band; Voltage swing ~ 100 mV; Power ~ 10 uW

- Pulse Position Modulation (PPM)
- Pulse Amplitude Modulation (PAM)
- On-Off Keying (OOK)
- Bi-Phase Modulation (BPSK)

Multi-band OFDM

- Divide the spectrum into bands of 528 MHz.
  - Transmitter and receiver process smaller bandwidth signals.
  - Can spread symbols across multiple bands (FH)
  - Can avoid bands based on local regulations
- Use of OFDM offer additional advantages
  - Proven technology that is known to be efficient
  - Can selectively disable subcarriers to protect narrow band signals
  - For example: 128 tones of 5.125 MHz

Discussion

- UWB was included in 802.15 standards
- 802.15.3a was going to use UWB but never materialized
  - Fight between two competing proposals
  - Example on previous slide is one of them
- Also added as 802.15.4a to the low power PAN group
  - Provides for 3 “narrower” bands
  - Not clear it is used