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Wireless Networks and Applications
Lecture 20: PAN

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http://www.cs.cmu.edu/~prs/wirelessF18/

Outline

• 802.15 protocol overview
• Bluetooth
• Personal Area Networks – 802.15
  » Applications and positioning
  » Bluetooth
  » High speed WPAN
  » Zigbee
  » Other
• 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. Wifi)
  » 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

- Cellular system (requires representative stationary base stations)
- Conventional ad-hoc systems

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 Alliance**
  - 45+ companies: semiconductor mfrs, IP providers, OEMs, etc.
  - Defining upper layers of protocol stack: from network to application, including application profiles
  - First profiles published mid 2003

- **IEEE 802.15.4 Working Group**
  - Defining lower layers of protocol stack: MAC and PHY
  - PHY based on DSSS – runs at 250 Kbps in 2.4 GHz band
  - Links are encrypted

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

IEEE 802.15.4 – Peer-to-Peer

Peer-Peer Topology

- Point to point
- Cluster tree
- Full function device

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

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

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Low Power Technologies

- Battery life times of years or even decades
  » Ubiquitous deployment of sensors
  » Internet of Things (IoT), automation, ...
  » Replacing batteries is labor intensive
- Bluetooth Low Energy
  » Not backwards compatible; deployed in some phones
  » Profiles for healthcare, proximity sensing, alerts, keyboard/mice/.., ..
  » 2.4 GHz but simpler modulation schemes

Low-Power Wide-Area Networks (LPWAN)

- Longer range to simplify deployment
  » “Metropolitan” area – cite-wide sensor network
  » Single base station covers large area and many sensors
- Many competing proprietary technologies
  » LoRa: chirp spread spectrum
- Sigfox
  » Star topology, 900 MHz, ..
- LTE-MTC
  » Machine Type Communication
  » Defined by 3GPP
https://www.link-labs.com/blog/what-is-lora
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Ultra WideBand

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

- 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 to 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
  \[ B_f = 2 \frac{f_u - f_l}{f_u + f_l} > 0.2 \]
- 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

FCC Regulations
Example Technology: Basic Impulse Information Modulation

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