18-759: Wireless Networks
Lecture 27: PAN

Peter Steenkiste

CS and ECE, Carnegie Mellon University

Peking University, Summer 2016

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 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 functionality is supported**

Bluetooth

- **Think USB, not Ethernet**
  - » Cable replacement technology
- **Created by Ericsson**
- **PAN - Personal Area Network**
  - » 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**
- **Originally defined as IEEE 802.15.1, but standard is now maintained by the Bluetooth Special Interest Group**

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**

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**
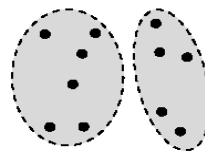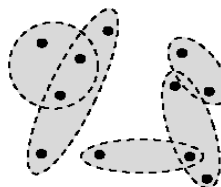 - » **If master, it can link the piconets**
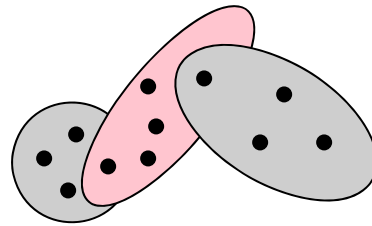
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Wireless Network Configurations
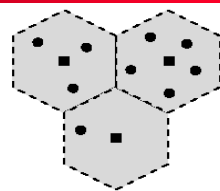
(a) Cellular system (squares represent stationary base stations)

(b) Conventional ad hoc systems

(c) Scatternets

Figure 15.5 Wireless Network Configurations

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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.**

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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**

Usage scenarios: Headset

Usage scenarios: Synchronization

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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**

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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**

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Sharing the Channel

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

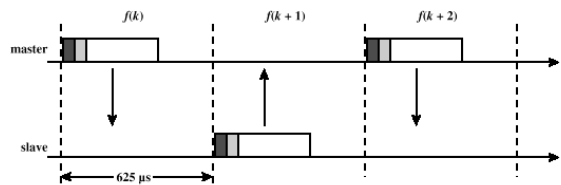**Figure 15.6 Frequency-Hop Time-Division Duplex**

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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

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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.**

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Quality of Service

- **IEEE 802.15.3 supports various traffic types with different QoS requirements**
- **Best-effort data without reservations (contention based)**
- **PNC allocates resources (slots) for devices**
  - » **Devices make requests**
  - » **Periodic slot reservation for synchronous data**
    - – **Voice, video**
  - » **Aperiodic reservation for asynchronous data**
    - – **Allocates a certain time for sending packets**
    - – **Bursty data transmission: file transfer etc.**

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IEEE 802.15.3

- **High data rate WPAN**
- **Higher bandwidths than supported with 802.15.1**
  - » **100 Mbs within 10 meter**
  - » **400 Mbs within 5 meter**
  - » **Typical rates are in 10s of Mbs**
- **Data, High quality TV, Home cinema**

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**

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http://www.csie.nctu.edu.tw/~yctseng/WirelessNet06-02/zigbee-802-15-4.ppt
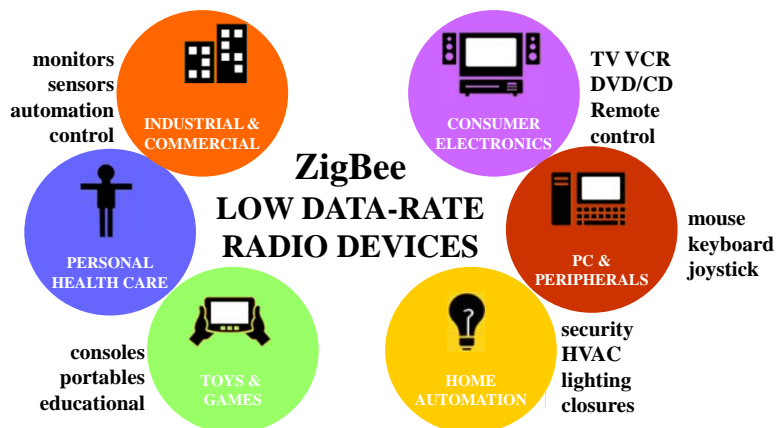
802.15.4 applications
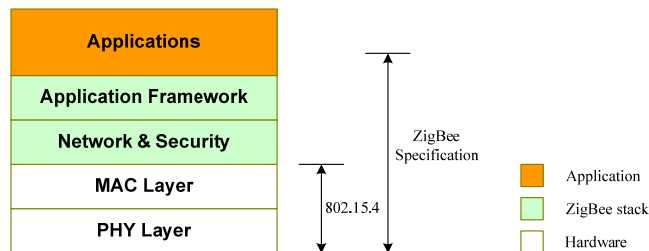
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Zigbee/802.15.4 architecture

- ■ 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

| Applications |
| Application Framework |
| Network & Security |
| MAC Layer |
| PHY Layer |

ZigBee Specification

802.15.4

- ▮ Application
- ▯ ZigBee stack
- ▯ Hardware

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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**

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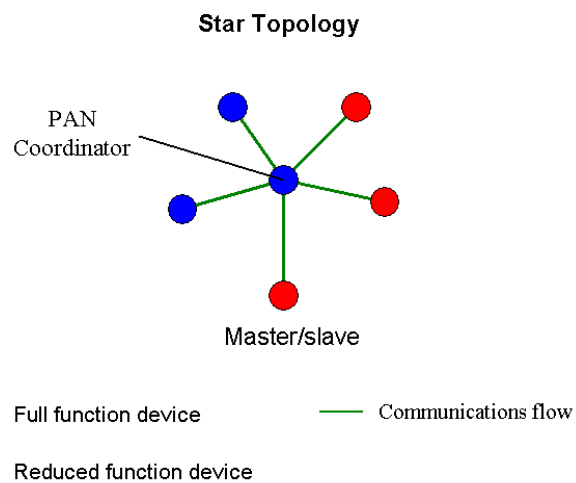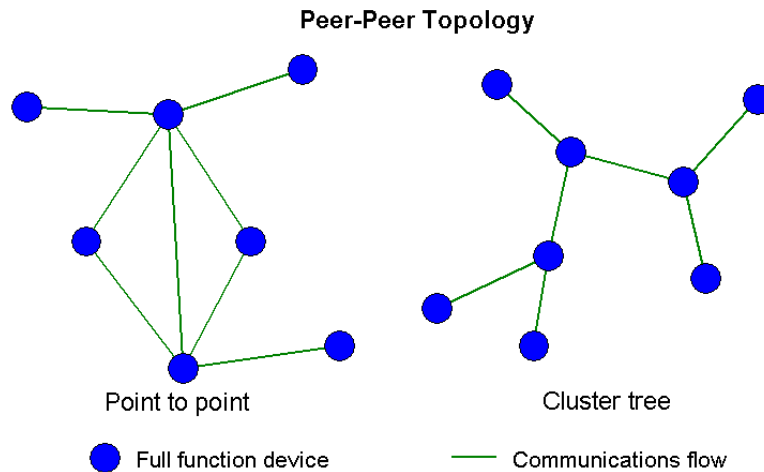
Roles

- **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)**

- **Coordinator**
  - » 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

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IEEE 802.15.4 - Star

Star Topology

PAN Coordinator

Master/slave

● Full function device   —— Communications flow

● Reduced function device

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IEEE 802.15.4 – Peer-to-Peer

Peer-Peer Topology

Point to point   Cluster tree

● Full function device   —— Communications flow
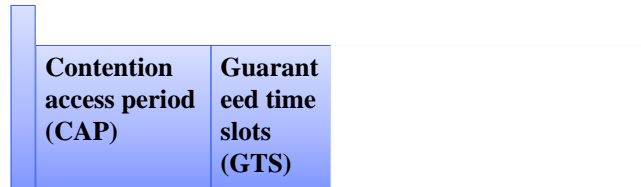

IEEE 802.15.4 - MAC

- **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

Beacon

Contention access period (CAP)	Guaranteed time slots (GTS)	

Active period   **Inactive period**

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Ultra WideBand

$$C = B \log_2 \left(1 + \text{SNR}\right)$$

- **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 Regulations

UWB Emission Limit [1]
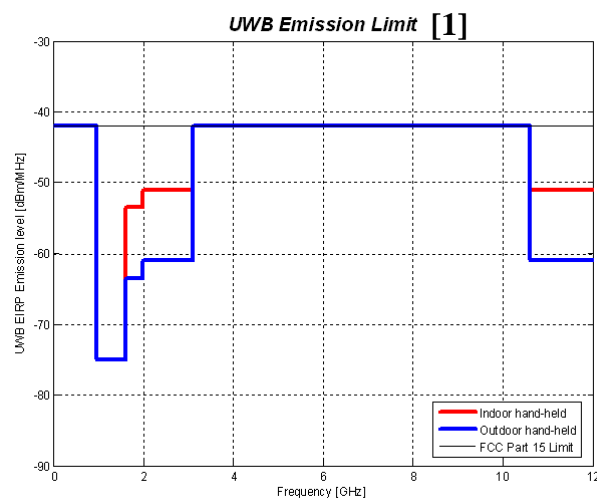
Discussion

- **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**

Peter A. Steenkiste, CMU

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