
18-452/18-750
Wireless Networks and Applications

Lecture 19: PAN

Bluetooth

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<http://www.cs.cmu.edu/~prs/wirelessS24/>

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1

1

Announcements

- **I updated the table with course deadlines on the course web site.**
- **Project 2 has two checkpoints**
 - » I will schedule short meetings with each team after each checkpoint to discuss issues
 - » You can always use office hours to discuss your P2
- **The deadline for submitting a draft of your Survey slides is in 3 weeks**
 - » If you replace any papers in the paper list for your topic, please send me mail so I can look have a look
- **I also updated the course schedule on the web page**
 - » Some adjustments were needed because of travel

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2

2

Updated Deadlines

Rough deadlines for various assignments					
The exact deadlines are in the handouts for each assignment					
Week	Project 1	Project 2	Midterm	Surveys	Homeworks
Jan 15					
Jan 22					
Jan 29					
Feb 5	Out Mo	Out Mo		Out Mo	HW1 out Mo
Feb 12		Team/Topic, We			HW1 due Mo HW2 out Fr
Feb 19	Due Mon			Topics/Teams, Fr	HW2 due Fr
Feb 26		Proposal, Mo	Wed Feb 28	Topics/Team, before Spr Break	
Mar 4			Midsemester Break		
Mar 11					
Mar 18					HW 3 out Tu
Mar 25		Checkpoint, Tu			HW3 due Fr
Apr 1				Draft Slides Fr	HW4 out Fr
Apr 8		Checkpoint, Tu			
Apr 15				Mo and Friday	HW4 due Mo
Apr 22		Presentation, Mo Final Report Fr		Wed	

3

Outline

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

4

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)**
 - » IEEE 802.15.6 – Body Area Networking
 - » IEEE 802.15.7 – Visible Light Communication

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5

5

Some Common Themes

- **Master/slave notion**
 - » Or basic node versus coordinator
- **Use of "piconets"**
 - » Small groups of devices managed by a master or coordinator
 - » Typically supports only small numbers of devices - scalability is often not a concern
 - » They are not general-purpose networks, such as Ethernet)
- **Sometimes support for QoS**
 - » Want to support voice and other media
- **But there are many variants in how this functionality is supported**

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6

6

Bluetooth/802.15.1

- **IEEE 802.15.1 and**
 - » 1600 hops per second FHSS
 - » Includes synchronous, asynchronous, voice
- **IEEE 802.15.1 and Bluetooth are almost identical**
 - » Started as a IEEE 802.15.1 standard
 - » Later updated and maintained by the Bluetooth Special Interest Group
- **Range of up to 30 feet, uses FHSS**
 - » 1600 hops per second FHSS
- **Think USB, not Ethernet**
 - » Mostly used as a cable replacement technology
 - » Small, low-power, short-range, cheap, versatile radios
 - » Typically used to connect devices, e.g. phone to headset

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7

7

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.
- **The standard is very big and complicated!**

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9

9

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

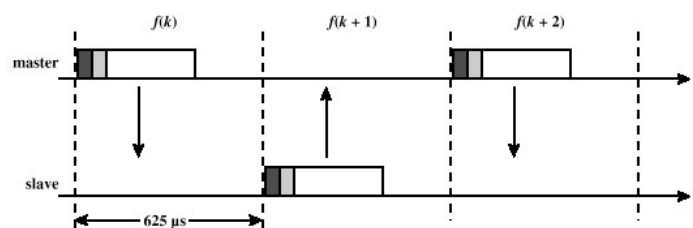
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10

10

Sharing the Channel

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



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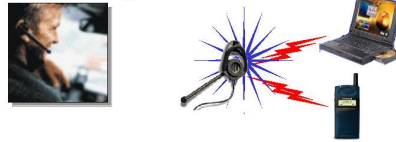
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11

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 cable attachments for connection

Usage scenarios: Headset



Usage scenarios: Synchronization



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12

12

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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13

13

Bluetooth Piconet

- **A collection of devices connected via Bluetooth technology in a master-slave network**
 - » Master functions as the piconet coordination (PNC)
 - » Can have a master and 1-7 slaves
- **All Bluetooth devices are identical, but they have a master or slave role when connecting**
- **Joining of piconet involves three steps**
 - » Master advertises its presence (basically beacons)
 - » Slave can submit a join request (typically initiated by user)
 - » Master accepts request and establishes connection
- **Example: connecting to a printer, game station, ..**

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14

14

Configuring a Piconet

- **Communication requires two parameters:**
 - » Hopping pattern of the radio it wishes to connect.
 - » Phase within the pattern i.e. the clock offset of the hops.
 - » Defines a channel that must be unique to the piconet
- **The global ID defines the hopping pattern**
 - » It is picked by the master after listening to other piconets
- **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 Hopping Synchronization) packet**

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15

15

Master and Slave Roles

- **Master and Slave roles can be reversed once the two nodes are connected**
 - » During pairing, the Master acts as a basestation and can advertise its presence to other BT devices
 - » Master typically provides a server, e.g., printer
- **The application using Bluetooth may require the “slave” to become the “master”**
 - » It must be able to initiate requests, e.g., “print”

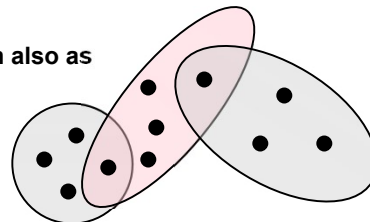
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16

16

Piconets Support a Master with Multiple Slaves

- **Master with up to 7 active slaves**
 - » Slaves only communicate with master
 - » Slaves must wait for permission from master
- **Master picks the radio parameters**
 - » Channel, hopping sequence, timing, ...
- **Scatternets can be used to build larger networks**
 - » Example: A slave in one piconet can also as a master in another piconet
 - » Basis for creating larger networks
 - » The process is complicated, e.g., addressing
 - » The level of deployment is not clear



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17

17

Bluetooth Versions

- **Some pre-standard versions (1.0, 1.0B)**
 - » Lacked interoperability
- **Bluetooth 1.1**
 - » First standard - defined by Bluetooth SIG, ~802.15.1
 - » Rates up to 0.73 Mbps
- **Bluetooth 1.2**
 - » Many improvements relative to version 1.1, e.g., speed, connection time, ...
- **Bluetooth 2 and 2.1**
 - » Enhanced Data Rate supports up to 3 Mbps
 - » V2.1 improves the security of the pairing process

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18

18

Bluetooth 3

- **Bluetooth 3**
 - » Provides data rates up to 24 Mbps – seems like magic!
- **This is possible using the “Alternative MAC/PHY media” option**
 - » The idea is that Bluetooth is used for discovery
 - » Once the devices are connected using Bluetooth, they can fall back on WiFi for fast, large data transfers
 - » One important benefit is power savings in idle mode
- **Adds several other features**
 - » Better power control during communication

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19

19

Bluetooth 4 and 5

- **Supports multiple modes**
 - » Classic, Bluetooth HS, and Bluetooth BLE
 - » New features, e.g., v5.1 has an Angle of Arrival feature enables localization
- **Bluetooth Low Energy BLE targets very low power devices**
 - » The goal is to extend the lifetime of batteries
 - Replacing batteries on a large scale is expensive!
 - » A more lightweight protocol stack
 - » Narrower channels: 40 channels of 2 MHz
 - Devices use channels adaptively based on conditions
 - » Low bit rate (1 Mbps); up to 2 Mbps in v5 (data rate is lower)
 - » Very popular: 4.9 billion BLE devices sold in 2022, predicted to increase by 0.5 billion/year