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)

Outline

- 802.15 protocol overview
- Bluetooth
- Personal Area Networks – 802.15
  - Applications and positioning
  - Bluetooth
  - High speed 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 – Positioning

Wireless Positioning

- Bluetooth
  - Person Space: Office, Room, Briefcase, Pocket, Car
  - Short Range/Low Power
  - Voice AND Data
  - Low-cost
  - Small form factor
  - Many co-located neuts
  - Universal Bridge

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
Wireless Network Configurations

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

Sharing the Channel

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

![Frequency-Hop Time-Division Duplex](image)

Physical Links between Master and Slave

- Synchronous connection oriented (SCO)
  » Allocates fixed bandwidth between point-to-point connection of master and slave
  » Master maintains link using reserved slots
  » Master can support three simultaneous links
- Asynchronous connectionless (ACL)
  » Point-to-multipoint link between master and all slaves
  » Only single ACL link can exist

Bluetooth Packet Fields

- Access code – used for timing synchronization, offset compensation, paging, and inquiry
  » Channel access code (CAC) – identifies a piconet
  » Device access code (DAC) – used for paging and subsequent responses
  » Inquiry access code (IAC) – used for inquiry purposes
- Header – used to identify packet type and carry protocol control information
  » Packet type, slave address, flow control, ARQ, HEC, seqn
- Payload – data and payload header, if present
  » Channel information, L2CAP information
ARQ Scheme Elements

- Error detection – destination detects errors, discards packets
- Positive acknowledgment – destination returns positive acknowledgment
- Retransmission after timeout – source retransmits if packet unacknowledged
- Negative acknowledgment and retransmission – destination returns negative acknowledgement for packets with errors, source retransmits

Channel Control

- States of operation of a piconet during link establishment and maintenance
- Major states
  - Standby – default state
  - Connection – device connected
- Inquiry: master identifies nearby slaves
- Paging: establishing a connection between a master and a slave

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.
Steps in Joining a Piconet

- Devices not connected to a piconet are in **STANDBY** mode, using low power.
- A connection is made by either a **PAGE** command if the address is known or by the **INQUIRY** command followed by a **PAGE**
  - An **INQUIRY** is a discovery command to identify nearby radios
  - **PAGE** is used to connect to a known device
- When a radio sends an **INQUIRE** command, all the listening radios respond with their FHS packets, which tells the inquiring radio of all the radios in the area.
- All listening radios perform a **page scan** and/or an **inquiry scan** every 1.25 seconds.
- The master radio sends an FHS to the paged radio.

Inquiry Procedure

- Potential master identifies devices in range that wish to participate
  - Transmits ID packet with inquiry access code (IAC)
  - Occurs in Inquiry state
  - On 32 wake-up carriers (out of 79)
- Device receives inquiry
  - Enter Inquiry Response state
  - Returns FHS packet with address and timing information
  - Moves to page scan state

Page Procedure

- Master uses device address to calculate a page frequency-hopping sequence
- Master pages with ID packet and device access code (DAC) of specific slave
- Slave responds with DAC ID packet
- Master responds with its FHS packet
- Slave confirms receipt with DAC ID
- Slaves moves to Connection state
Logical Link Control and Adaptation Protocol - L2CAP

- Provides a link-layer protocol between entities with a number of services
- Relies on lower layer for flow and error control
- Makes use of ACL links, does not support SCO links
- Provides two alternative services to upper-layer protocols
  » Connectionless service
  » Connection-mode service

L2CAP Logical Channels

- Connectionless
  » Supports connectionless service
  » Each channel is unidirectional
  » Used from master to multiple slaves
- Connection-oriented
  » Supports connection-oriented service
  » Each channel is bidirectional with QoS on each direction
- Signaling
  » Provides for exchange of signaling messages between L2CAP entities

Flow Specification Parameters

- Service type
- Token rate (bytes/second)
- Token bucket size (bytes)
- Peak bandwidth (bytes/second)
- Latency (microseconds)
- Delay variation (microseconds)

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.
Outline

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

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

802.15.4 applications

- ZigBee
- LOW DATA-RATE RADIO DEVICES
- INDUSTRIAL & COMMERCIAL
- CONSUMER ELECTRONICS
- PC & PERIPHERALS
- PERSONAL HEALTHCARE
- TOYS & GAMES
- SECURITY
- HOME AUTOMATION
- Remote control
- TV VCR
- DVD/CD
- mouse
- keyboard
- joystick
- security
- HVAC
- lighting
- closures

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

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
IEEE 802.15.4 – Peer-to-Peer

- **Active period**
- **Inactive period**

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.

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