Guide to Wireless Communications, Third Edition

Chapter 6

High Rate Wireless Personal Area Networks

Objectives

- Define a high rate wireless personal area network (HR WPAN)
- List the different HR WPAN standards and their applications
- Explain how WHDI, WiGig, WirelessHD and UWB work
- Outline the issues facing WPAN technologies
- Describe the security features of each HR WPAN technology

High Rate WPAN Standards

- IEEE discontinued work on the original 802.15.3 standard
  - IEEE 802.15.3b and 802.15.3c were ratified in 2005 and 2009 respectively
  - 802.15.5 for mesh networking was also ratified in 2009
- IEEE 802.15.3c standard
  - Enables multimedia connectivity between mobile and stationary consumer devices in the home

High Rate WPAN Standards

- IEEE 802.15.3c (cont'd)
  - WirelessHD Consortium created a spec based on this standard for combining the transmission of HD video, multichannel audio, and data for multimedia streaming in the 60 GHz band
- Two other standards that don't use 802.15.3c:
  - WirelessHD from Wireless Home Digital Interface (WHDI) Consortium
  - WiGig specification, designed to work with 802.11ac (Gigabit WLAN) standard

High Rate WPAN Standards

- HR WPAN applications
  - Connecting digital cameras to printers and kiosks
  - Connecting laptops to multimedia projectors and sound systems
  - Connecting camera-equipped cell phones and tablets to laptops and printers
  - Connecting speakers in a surround system to amps and receivers
  - Linking multiple display monitors
  - And others

High Rate WPAN Standards

- Application characteristics
  - Require high throughput; 20 Mbps or more
  - Low-power transceivers
  - Low cost
  - Require quality-of-service (QOS) capabilities
  - Connections should be simple and automatic
  - Simple and automatic connections
  - Security features should be included
  - Internet access and use of digital TVs as wireless displays

Networking Audio, Video, and Other I/O Devices

- Wireless Home Digital Interface (WHDI)
  - Developed primarily for delivery of uncompressed video and audio with cable-connection quality
  - Used to mirror screens of multiple devices
  - Works in 5 GHz frequency band; coexists with 802.11a and 802.11n and cordless phones
  - Max range of 100 ft.
  - No special adapters needed; supports HDMI

Networking Audio, Video, and Other I/O Devices

- Wireless Gigabit (WiGig) Architecture
  - Designed for 802.11n and 802.11ac compatibility; will support 802.11ad in 60 GHz band
  - Defines **protocol adaptation layers (PALs)**: enables direct AV display standard support
  - Figure 6-1 shows WiGig protocol stack
  - WiGig uses beamforming to maintain reliable connections at higher frequencies
  - Supports two modulation types in 60 GHz band:
    - Single-carrier modulation
    - Orthogonal frequency-division multiplexing (OFDM)

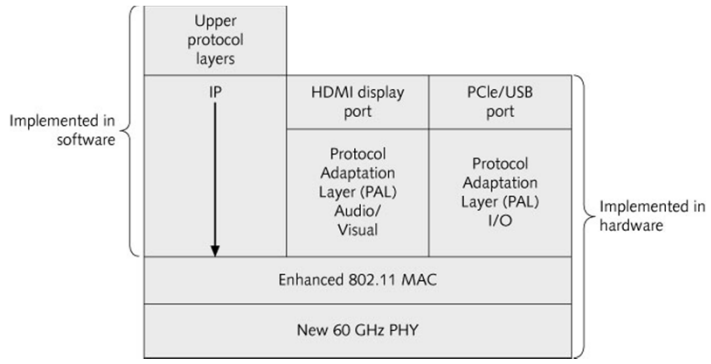

Figure 6-1 WiGig protocol stack

Networking Audio, Video, and Other I/O Devices

- WirelessHD and IEEE 802.15.3c
  - Consumer products already available
  - 802.15.3c amendment only refers to 60 GHz band
  - Supports devices transmitting at different speeds to allow mobile devices to conserver battery power
  - Table 6-1 shows speeds and applications supported by WirelessHD

Source	Sink	Data Rate(s)	Number of Streams Transmitted
HD A/V	HD A/V	3.0 Gbps	1
HD A/V	HD Video Audio	3.0 Gbps 40 Mbps	2
HD A/V Compressed A/V	HD A/V Compressed A/V	3.0 Gbps 24 Mbps	2
HD A/V HD A/V	HD A/V HD A/V	1.5 Gbps 1.5 Gbps	2
HD A/V Compressed A/V	HD Video Compressed A/V Audio	1.5 Gbps 24 Mbps 40 Mbps	3
Audio	Audio	30 Mbps	1
HD A/V	HD A/V HD A/V	1.5 Gbps 1.5 Gbps	2
Data Source	Data Sink	1.0 Gbps	1
HD A/V HD A/V	HD A/V HD A/V Audio	0.5 Gbps 0.5 Gbps 40 Mbps	3
HD A/V HD A/V	HD A/V Audio Audio	1.5 Gbps 40 Mbps 40 Mbps	3
HD A/V Audio	HD A/V Audio	3.0 Gbps 40 Mbps	2

Table 6-1 Speeds supported in WirelessHD

Networking Audio, Video, and Other I/O Devices

- WirelessHD and IEEE 802.15.3c
  - Source device: transmitter
  - Sink device: receiver
  - Divides PHY layer into three sections:
    - Low-Rate PHY (LRP) – data rates 2.5 to 40 Mbps
    - High-Rate PHY (HRP) – data rates to 7 Gbps and up to 25 Gbps using **spatial multiplexing**
    - High-or-Medium-Rate PHY (HMRP) – data rates of 476 Mbps to 2 Gbps
  - Also supports USB 2.0, 2.0 and HDMI
  - Uses beamforming for line-of-sight/non-line-of-sight transmissions

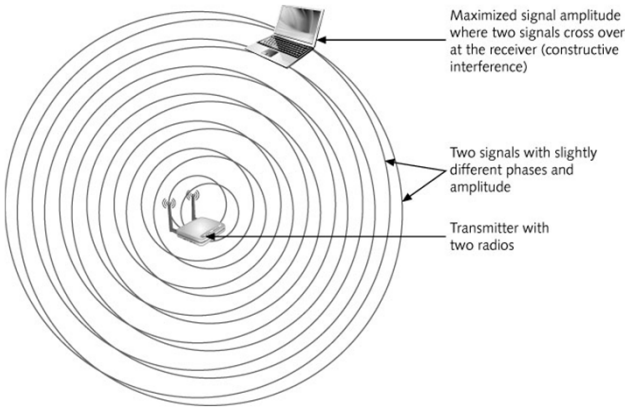

Figure 6-2 Beamforming

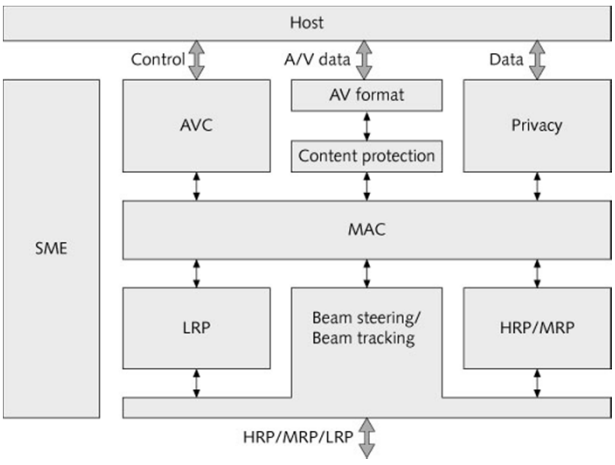

Figure 6-3 Recommended WirelessHD protocol-layer implementation

WirelessHD and 802.15.3 MAC layer

- Devices associate with the piconet coordinator (PNC)
  - PNCs are usually a sink device such as HD TV
  - Coordinator acts as a station on the **wireless video area network (WVAN)**
  - The first sink devices assumes the role of PNC
  - PNC responsible for QoS

WirelessHD and 802.15.3 MAC layer

- Piconet coordinator (PNC)
  - Role assumed by the first device in the area
  - Provides all of the basic communications timing in a piconet
  - PNC sends a beacon
- The piconet is peer-to-peer
  - Devices can transmit data directly to each other
- The PNC is also responsible for managing QoS
- Devices can form a dependent piconet

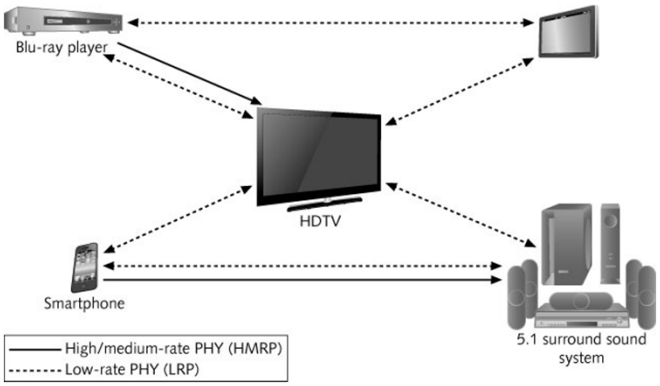

Figure 6-4 Wireless video area network (WVAN) topology example

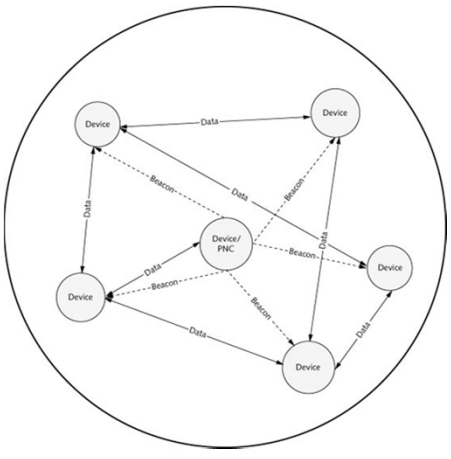

Figure 6-5 802.15.3 piconet topology

WirelessHD and 802.15.3 MAC layer

- Two types of dependent piconets – dependent on the PNC of another (parent) piconet
  - Child piconets
    - Has its own piconet ID but child PNC is a member of the original (parent) piconet
  - Neighbor piconets
    - Separate piconet but depends on original piconet's PNC to allocate time for transmitting

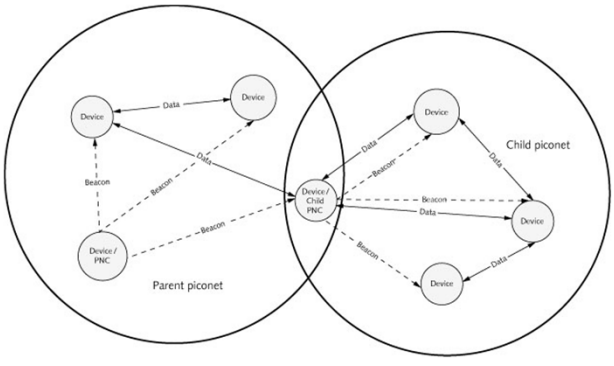

Figure 6-6 Child piconet

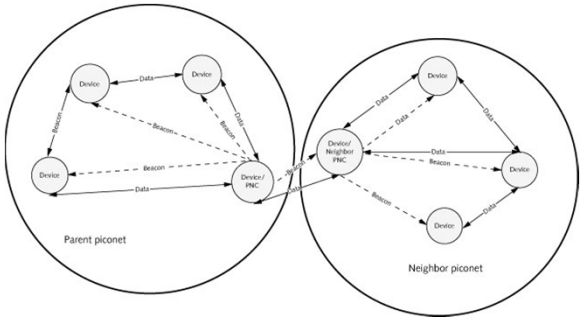

Figure 6-7 Neighbor piconet

WirelessHD and 802.15.3 MAC layer

- The IEEE 802.15.3 MAC layer designed to support these features:
  - Connection time (association) is fast
  - Devices associated with the piconet can use a short, one-octet device ID
  - Devices can obtain information about the capabilities of other devices
  - Peer-to-peer (ad hoc) networking
  - Data transport with QoS
  - Security
  - Efficient data transfer using superframes (Figure 6-8)

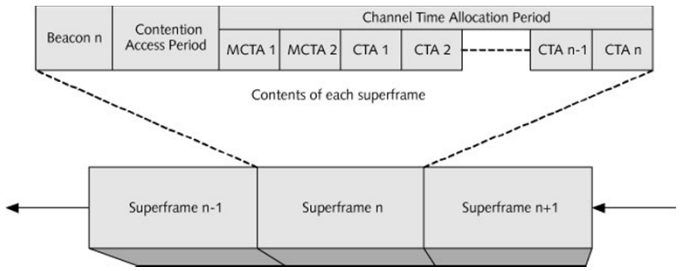

Figure 6-8 802.15.3 superframe

WirelessHD and 802.15.3 MAC layer

- IEEE 802.15.3 superframe structure
  - A beacon – used to set time allocations and communicate management information
  - An optional **contention access period (CAP)** – used for association, command communication, or asynchronous data
  - The **channel time allocation period (CTAP)** – includes **channel time allocations** and may include **management channel time allocation** periods

WirelessHD and 802.15.3 MAC layer

- Communication in an 802.15.3 piconet
- Communication in an 802.15.3 piconet
  - Beacon frame sent by the PNC includes a variable indicating the end of the CAP
  - Devices can send asynchronous data in the CAP
  - Devices can request channel time on a regular basis
    - Requested channel time is called isochronous time
  - Devices can also request channel time for asynchronous communications in the CTAP
    - Communications use a time division multiple access (TDMA) scheme

WirelessHD and 802.15.3 MAC layer

- D-WVAN establishment process:
  - An originator device sends a request to a target to form a D-WVAN.
  - D-WVAN PNC notifies the H-WVAN PCN that it will enter into a power-save mode and then begins searching for an available frequency channel.
  - the target device sends a request to enter into drone mode to the H-WVAN PNC.
  - the D-WVAN PNC switches to the new frequency channel and begins sending beacons as the D-WVAN coordinator.
  - the H-WVAN coordinator grants the request and attempts to associate with it.

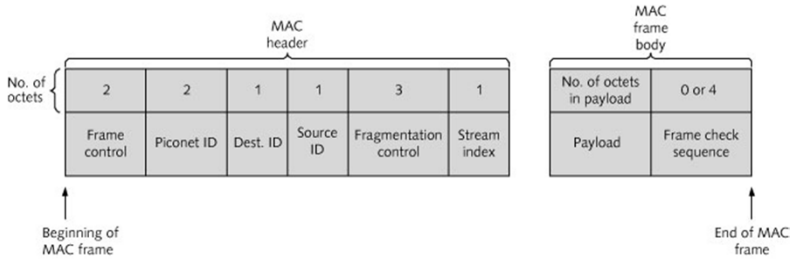

Figure 6-9 General MAC frame format

WirelessHD and 802.15.3 MAC layer

- Power management
  - 802.15.3 power-saving methods
    - Device synchronized power save (DSPS) mode
    - Piconet synchronized power save (PSPS) mode
    - Asynchronous power save (APS) mode
  - Wake superframe
    - Superframe designated by the PNC
    - Devices that are in power save mode wake up and listen for frames addressed to them

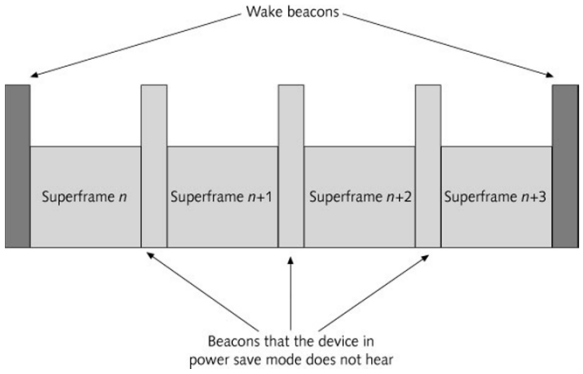

Figure 6-10 Wake beacons

802.15.3c PHY Layer

- Uses 60 GHz band and supports the channel plan
  - Four 2 GHz wide channels
  - Channel aggregation is supported

Channel ID	Start Frequency GHz	Center Frequency GHz	Stop Frequency GHz
1	57.240	58.320	59.400
2	59.400	60.480	61.560
3	61.560	62.640	63.720
4	63.720	64.800	65.880

Table 6-2 channel plan

802.15.3c PHY Layer

- Contains a number of optional enhancements
  - Passive scanning
  - Channel energy detection
  - Channel quality requests
  - Link quality indication
  - Transmit power control
  - Neighbor and child piconets
  - Two superframe transmission modes
  - Max data frame length of 8,388,608 octets

802.15.3c PHY Layer

- Modulation
  - Variations of BPSK and QPSK
  - Required to transmit headers using LRP
  - Single carrier for LRP and OFDM encoding for HRP and MRP

Mesh Networking (802.15.5)

- Mesh networking
  - Each device connects to all other devices within range
  - Effectively creating multiple paths for transmission
  - Enable WPANs to cover an entire building

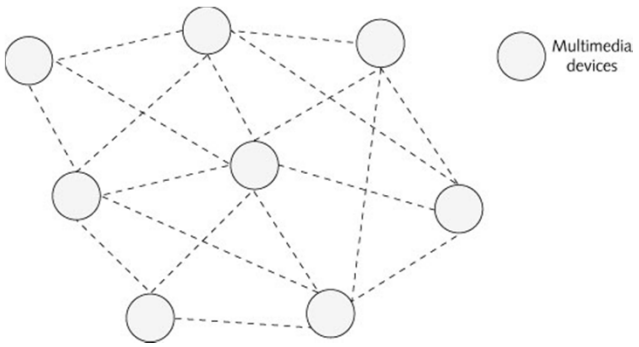

Figure 6-11 Mesh network

Ultra Wide Band (UWB)

- Allows new transmission techniques based on UWB to coexist with other RF systems
  - With minimal or no interference
- Characteristics
  - It transmits low-power, short-range signals
  - It transmits using extremely short low-power pulses lasting only about 1 nanosecond
  - It transmits over a band that is at least 500 MHz wide

How UWB Works

- MAC layer is unchanged; only PHY layer is different
- UWB PHY
  - Digital signals need to be spread over a wide band
    - Using techniques such as FHSS or DSSS
  - UWB uses short analog pulses for signaling
    - Does not rely on traditional modulation methods
    - This technique is called **impulse modulation**
  - Biphase modulation
    - Most common modulation technique used by UWB
    - Uses a half-cycle positive analog pulse to represent a 1

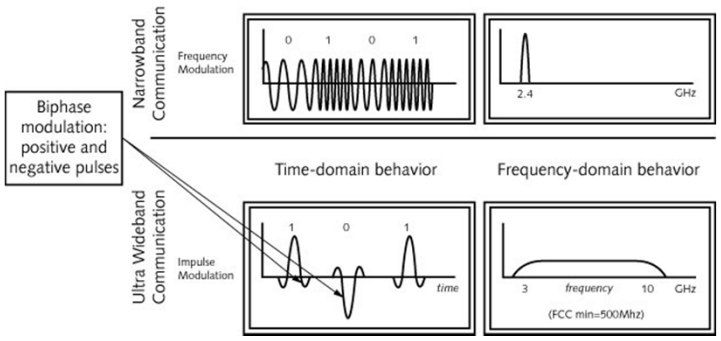

Figure 6-12 UWB impulse modulation

How UWB Works

- UWB PHY
  - Direct-sequence UWB (DS-UWB)
    - When transmitting pulses that are a nanosecond long
      - Signal spreads over a very wide frequency band
    - In the UWB case, the signal spreads over a band that is at least 500 MHz wide
  - Multiband orthogonal frequency division multiplexing (MB-OFDM)
    - Based on technique used for 802.11g and 802.11a
    - Frequency band is divided into five groups containing a total of 14 frequency bands

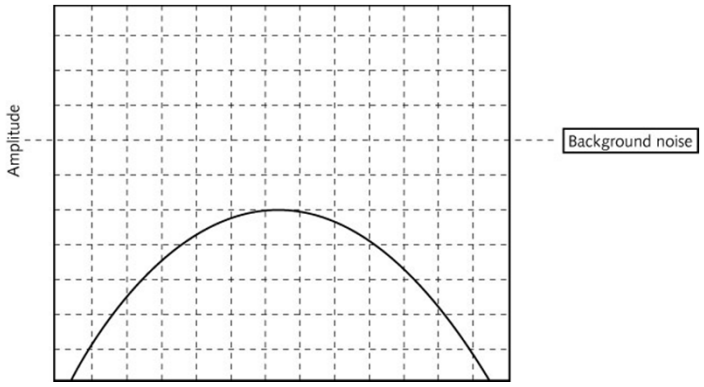

Figure 6-13 Effect of a direct-sequence 1-nanosecond pulse (frequency domain)

Band Group	Band ID	Center Frequency (MHz)
1	1	3,432
	2	3,960
	3	4,488
2	4	5,016
	5	5,544
	6	6,072
3	7	6,600
	8	7,128
	9	7,656
4	10	8,184
	11	8,712
	12	9,240
5	13	9,768
	14	10,296

Table 6-4 MB-OFDM frequency band allocations

How UWB Works

- UWB PHY
  - Orthogonal frequency division multiplexing (OFDM)
    - Each frequency band is 528 MHz wide
      - Further divided into 128 frequency channels
    - Channels are orthogonal
      - They do not interfere with each another
    - Data bits are sent simultaneously (in parallel)

WPAN Challenges

- Challenges
  - Competition Among WPAN Standards
  - WPAN Security
  - Security for Bluetooth
  - Security for ZigBee WPANs
  - Security for IEEE 802.15.3 HR WPANs
  - Cost of WPAN Components
  - Industry Support for WPAN Technologies
  - Protocol Functionality Limitations
  - Spectrum Conflict

Competition Among WPAN Standards

- IEEE 802.15.1 and 802.15.3 are positioned to compete with Bluetooth for market share
  - It will take a few years before 802.15.3 products begin to ship in volume
- WirelessHD, WiGig, and WHDI have the potential to quickly outpace Bluetooth

WPAN Security

- Bluetooth security
  - Bluejacking
    - Exploits a Bluetooth device's ability to discover nearby devices and send unsolicited messages
  - Bluesnarfing
    - Accesses contact lists and other information without the user's knowledge
  - Denial-of-service (DoS) attacks
    - Flood a Bluetooth device with so many frames that it is unable to communicate

WPAN Security

- Security for ZigBee WPANs
  - Uses the concept of a trust center
  - Uses a symmetric encryption key
    - Preprogrammed on each ZigBee node
    - Any two devices in a piconet can request a link key to set up secure communications
  - Uses a message integrity check and sequential freshness

WPAN Security

- IEEE 802.15.3 HR WPAN security
  - Based on Advanced Encryption Standard (AES)
  - Uses a 128-bit key
  - Two security modes:
    - Mode 0: does not encrypt or protect the data
    - Mode 1: strong cryptography based on AES

Cost of WPAN Components

- Bluetooth currently supports more devices than other WPAN technologies
  - Industry experts believe that price must be reduced to reach competitive advantage
- Does not make economic sense to use a chip that costs $5 to replace a higher-data rate cable that costs < $10

Industry Support for WPAN Technologies

- Industry experts predict that new technologies will be more quickly embraced by manufacturers
  - Such as WirelessHD and ZigBee

Protocol Functionality Limitations

- Bluetooth protocol suffers from its lack of hand-off capability between piconets
- Hand-off
  - Ability to move from one master or PNC to another
    - Without getting disconnected from the network
- ZigBee and WirelessHD have the advantage over Bluetooth in this area

Spectrum Conflict

- Spectrum conflict
  - Potential for technologies using the same frequency bands to interfere with each other
- Applying UWB technology may significantly reduce or eliminate this issue
- ZigBee and WiMedia products should be able to coexist with 802.11b/g without any serious problems

Summary

- HR WPANs are optimized for multimedia transmissions
  - Optimized for multimedia voice and video signals
- WHDI defines wireless connectivity using the 5 GHz band
- WiGig defined a set of specs that include protocol adaptation layers to support wireless HDMI, USB, PCIe, data, video, and audio

Summary

- The 60 GHz band can only support short-range connections
- WiGig supports the same modulation and coding schemes in the ISM and U-NII bands as 802.11
- WirelessHD is the only spec that uses IEEE 802.15.3c standard
- WirelessHD defines three PHY layers: LRP, HRP, and MRP

Summary

- WiGig and WirelessHD support beamforming
- 802.15.3c supports peer-to-peer networking
- 802.15.3 piconets support child and neighbor piconets
- Piconet association is implemented in hardware
- Efficient data transmission is accomplished using a superframe
- Devices can send asynchronous data in the CAP or request channel time for async during CTAP
- 802.15.3 devices support three power-saving modes: DSPS, PSPS, and APS

Summary

- UWB transmits using very short pulses
- UWB transmissions occupy at least 500 MHz bandwidth; use impulse modulation or multiband OFDM
- Challenges for WPANs include speed, security, cost, industry support, interference, and protocol limitations
- WPAN devices that are designed to be small and consume very little power have limited processing capabilities and storage; security is difficult