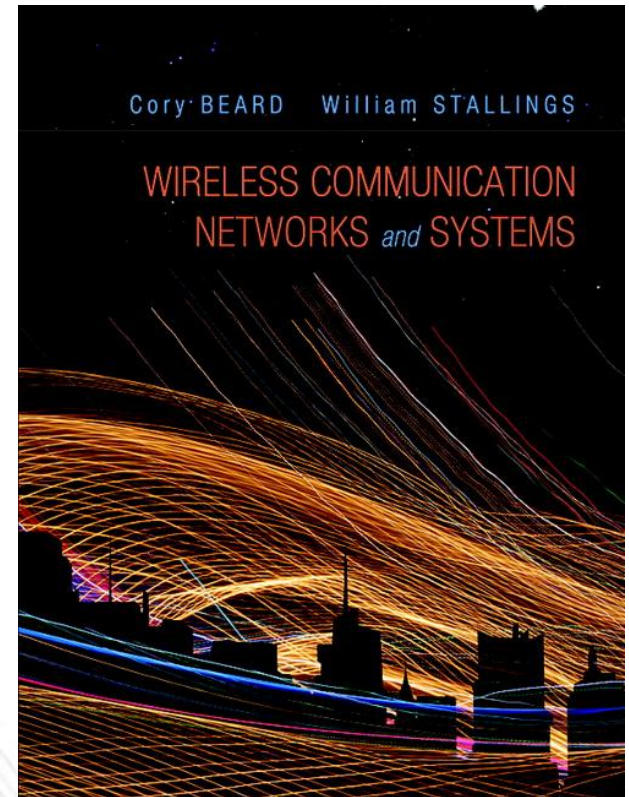


CHAPTER 3

BLUETOOTH AND

IEEE 802.15



Wireless Communication Networks and Systems

1st edition

Cory Beard, William Stallings

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IEEE 802.15

- **Wireless Personal Area Networks**
 - Short-range communication
 - Low-cost, low-energy to provide long battery life
- **Several standards have been provided**
- **We focus on 802.15 technologies**
 - Other viable WPAN alternatives exist

INTERNET OF THINGS

- Key application area for short-range communications
- Future Internet
 - Large numbers of wirelessly connected objects
 - Interactions between the physical world and computing, digital content, analysis, and services.
 - Called the Internet of Things
 - And many other “Internet of ...” titles
 - Useful for health and fitness, healthcare, home monitoring and automation, energy savings, farming, environmental monitoring, security, surveillance, education, and many others.
- Machine-to-machine communications (MTM, M2M, D2D, etc.), also machine-type communications (MTC)
 - Devices working together for data analysis and automated control

BLUETOOTH

- Universal short-range wireless capability
- Uses 2.4-GHz band
- Available globally for unlicensed users
- Devices within 10 m can share up to 2.1 Mbps or 24 Mbps of capacity
- Supports open-ended list of applications
 - Data, audio, graphics, video
- Started as IEEE 802.15.1
 - New standards come from the Bluetooth Special Interest Group (Bluetooth SIG)
 - Industry consortium
 - Bluetooth 2.0, 2.1, 3.0, and 4.0

BLUETOOTH APPLICATION AREAS

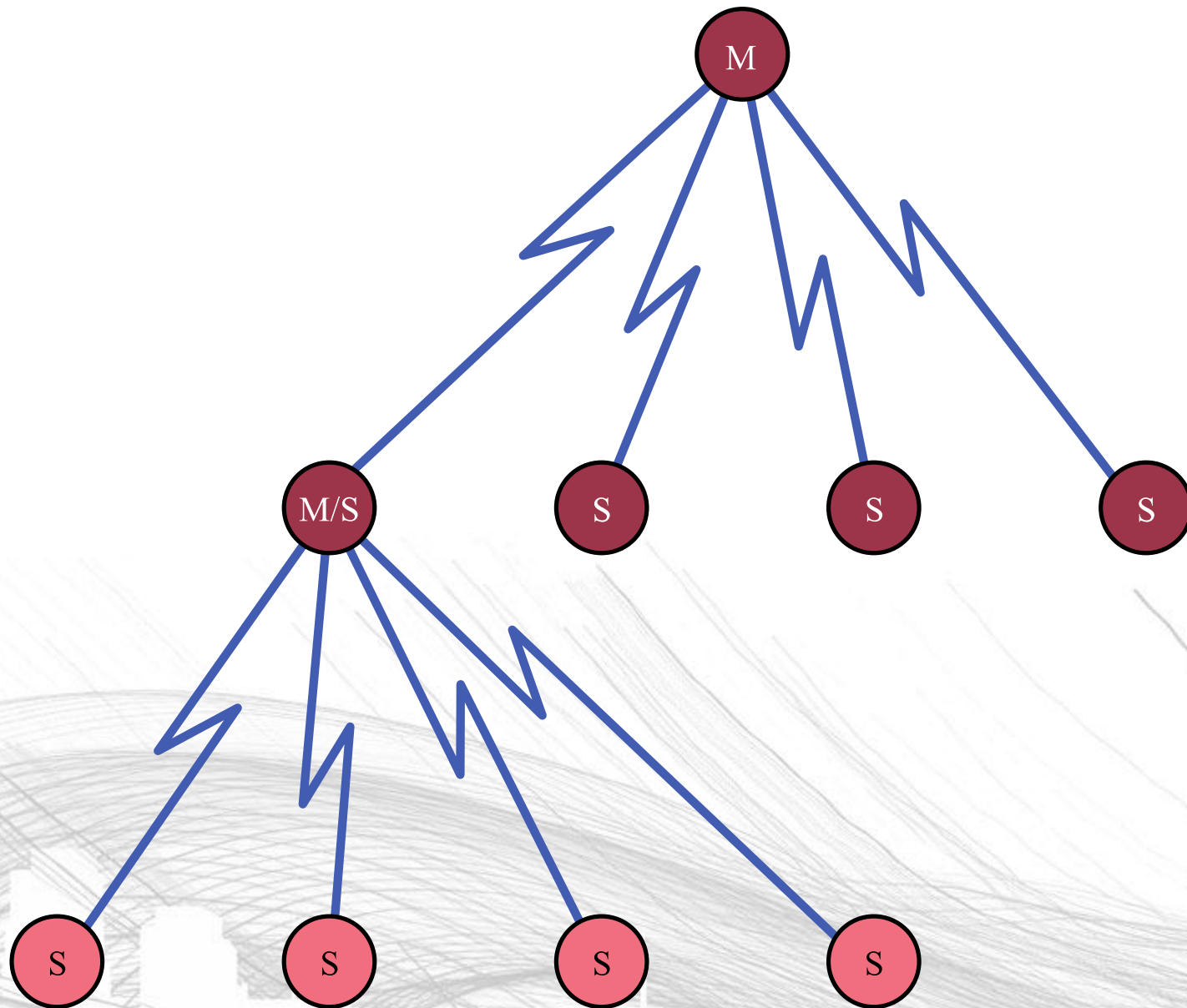
- Data and voice access points
 - Real-time voice and data transmissions
- Cable replacement
 - Eliminates need for numerous cable attachments for connection
- Ad hoc networking
 - Device with Bluetooth radio can establish connection with another when in range

TOP USES OF BLUETOOTH

- Mobile handsets
- Voice handsets
- Stereo headsets and speakers
- PCs and tablets
- Human interface devices, such as mice and keyboards
- Wireless controllers for video game consoles
- Cars
- Machine-to-machine applications: credit-card readers, industrial automation, etc.

PICONETS AND SCATTERNETS

- Piconet
 - Basic unit of Bluetooth networking
 - Master and one to seven slave devices
 - Master determines channel and phase
- Scatternet
 - Device in one piconet may exist as master or slave in another piconet
 - Allows many devices to share same area
 - Makes efficient use of bandwidth



12.2 MASTER/SLAVE RELATIONSHIPS



RADIO SPECIFICATION

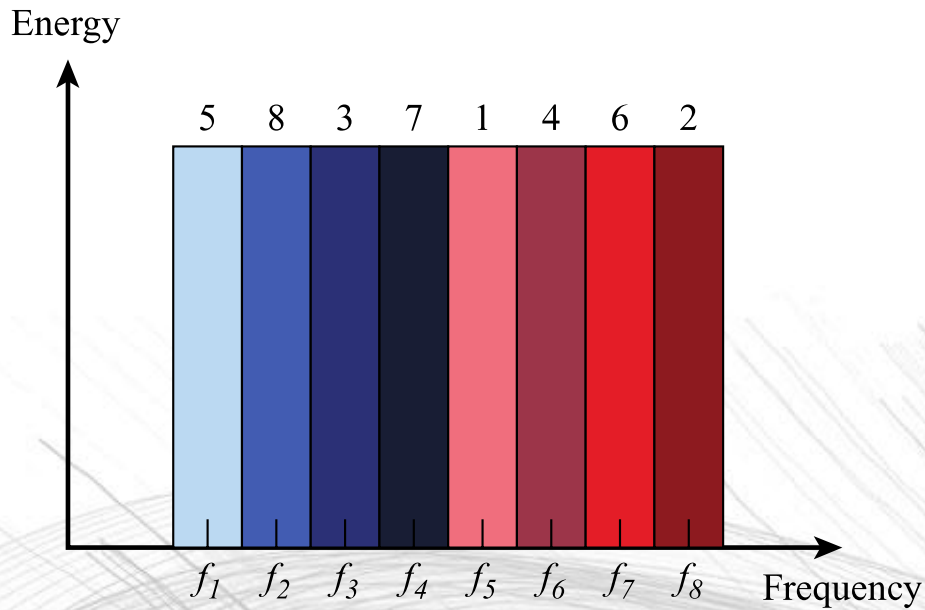
- Classes of transmitters
 - Class 1: Outputs 100 mW for maximum range
 - Power control mandatory
 - Provides greatest distance
 - Class 2: Outputs 2.4 mW at maximum
 - Power control optional
 - Class 3: Nominal output is 1 mW
 - Lowest power

FREQUENCY HOPPING IN BLUETOOTH

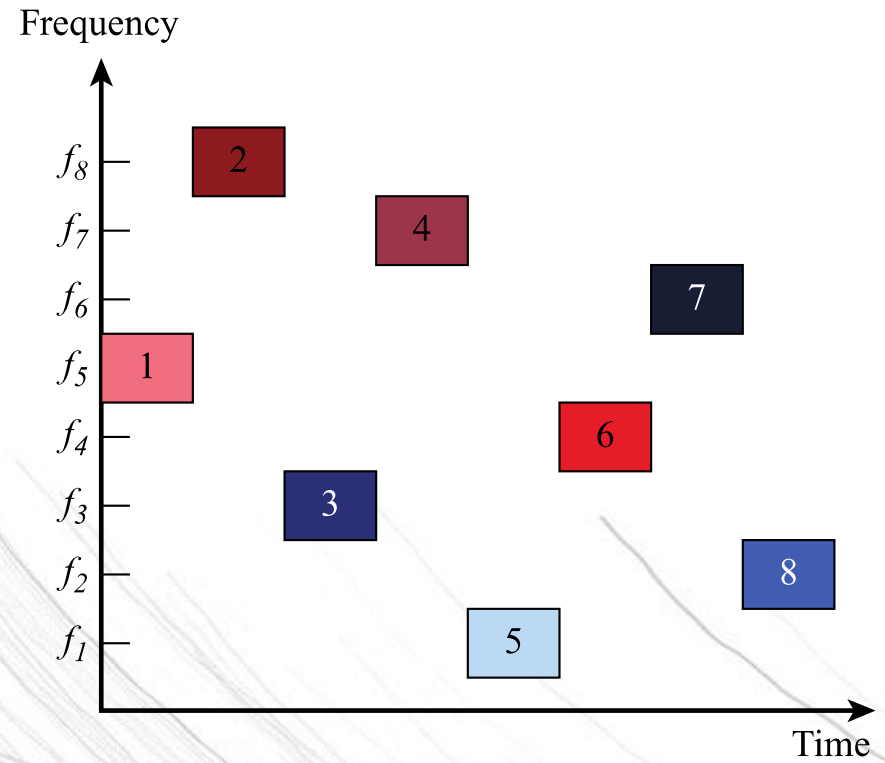
- Provides resistance to interference and multipath effects
- Provides a form of multiple access among co-located devices in different piconets

FREQUENCY HOPPING

- Total bandwidth divided into 1MHz physical channels
- FH occurs by jumping from one channel to another in pseudorandom sequence
- Hopping sequence shared with all devices on piconet
- Piconet access:
 - Bluetooth devices use time division duplex (TDD)
 - Access technique is TDMA
 - FH-TDD-TDMA



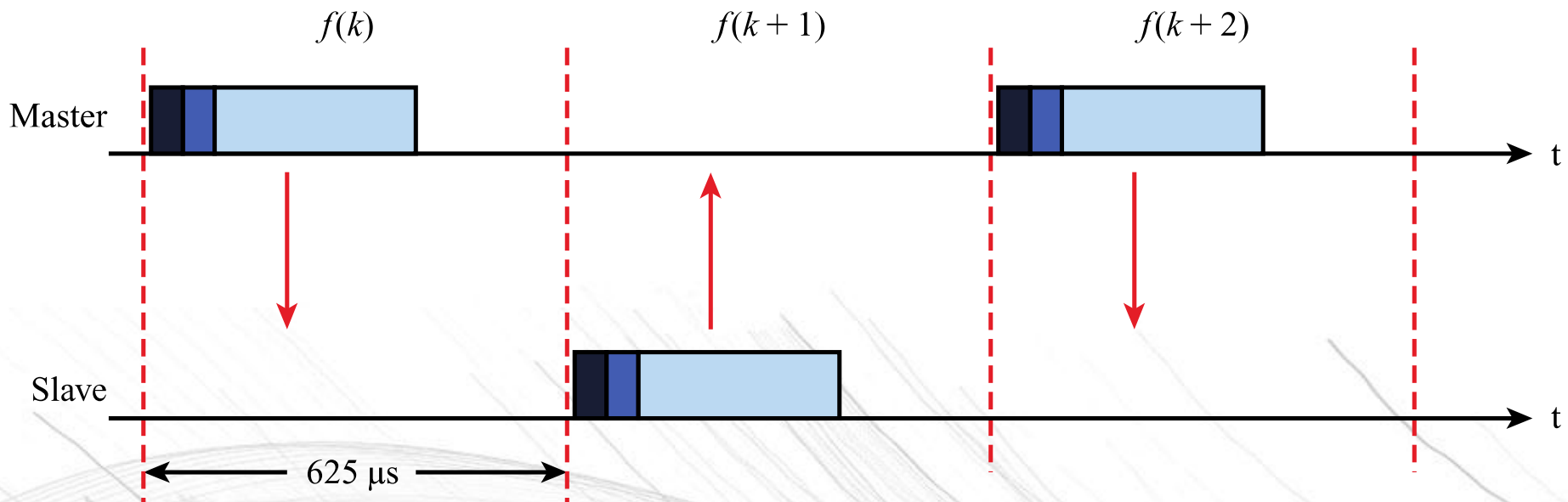
(a) Channel assignment



(b) Channel use

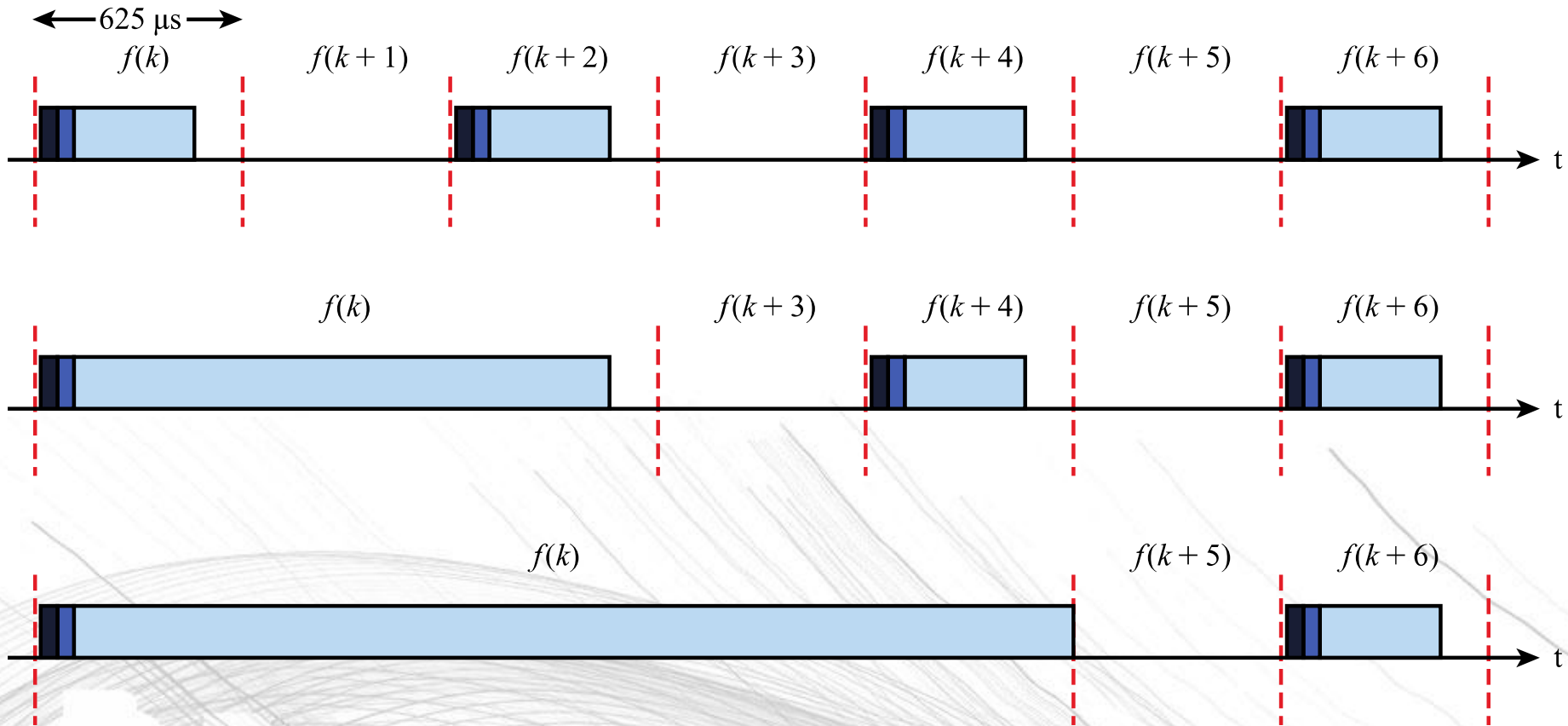
9.2 FREQUENCY HOPPING EXAMPLE





12.4 FREQUENCY-HOP TIME-DIVISION DUPLEX





12.5 EXAMPLES OF MULTISLOT PACKETS



BLUETOOTH HIGH SPEED

- Bluetooth 3.0+HS
- Up to 24 Mbps
- New controller compliant with 2007 version of IEEE 802.11
- Known as Alternative MAC/PHY (AMP)
 - Optional capability
- Bluetooth radio still used for device discovery, association, setup, etc.
- Allows more power efficient Bluetooth modes to be used, except when higher data rates are needed

BLUETOOTH SMART

- Bluetooth 4.0
- Previously known as Bluetooth Low Energy
- An intelligent, power-friendly version of Bluetooth
- Can run long periods of time on a single battery
 - Or scavenge for energy
- Also communicates with other Bluetooth-enabled devices
 - Legacy Bluetooth devices or Bluetooth-enabled smartphones
 - Great feature
- Possible successful technology for the Internet of Things
 - For example, health monitoring devices can easily integrate with existing smartphones

BLUETOOTH SMART

- Same 2.4 GHz ISM bands as Bluetooth BR/EDR
 - But uses 40 channels spaced 2 MHz apart instead of 79 channels spaced 1 MHz apart
- Devices can implement a transmitter, a receiver, or both
- Implementation
 - Single-mode Bluetooth Smart functionality
 - Reduced cost chips that can be integrated into compact devices.
 - Dual-mode functionality to also have the Bluetooth BR/EDR capability
- 10 mW output power
- 150 m range in an open field

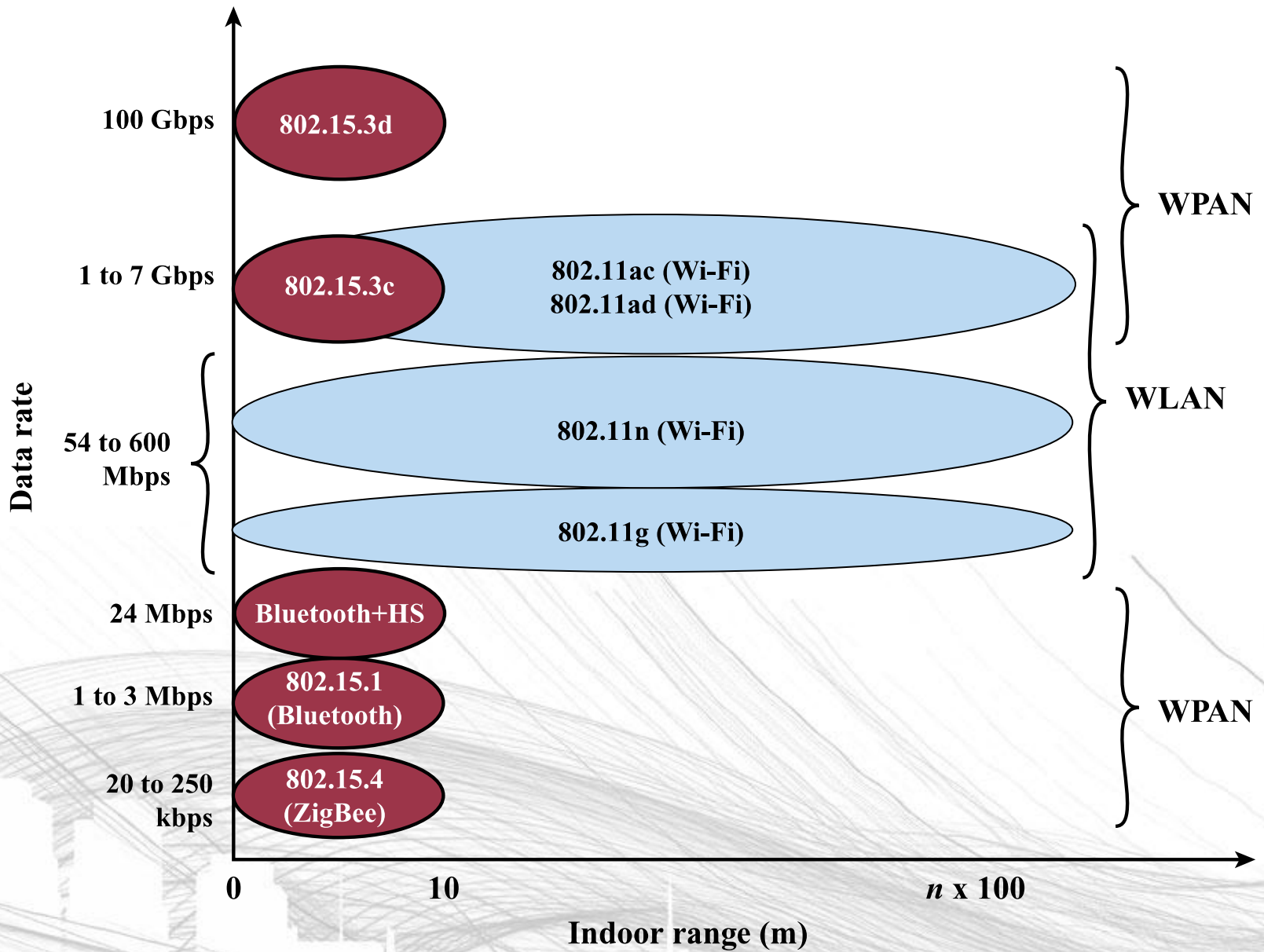
IEEE 802.15

- After 802.15.1, work went two directions
- 802.15.3
 - Higher data rates than 802.15.1
 - But still low cost, low power compared to 802.11
- 802.15.4
 - Very low cost, very low power compared to 802.15.1
- Figure 12.9 shows different options
- Figure 12.10 shows relative distances and rates

Logical link control (LLC)

<p>802.15.1 Bluetooth MAC</p>	<p>802.15.3 MAC</p>		<p>802.15.4, 802.15.4e MAC</p>
<p>802.15.1 2.4 GHz 1, 2, or 3 Mbps 24 Mbps HS</p>	<p>802.15.3c 60 GHz 1 to 6 Gbps</p>	<p>802.15.3d 60 GHz 100 Gbps</p>	<p>802.15.4, 802.15.4a 868/915 MHz, 2.4 GHz DSSS: 20, 40, 100, 250 kbps UWB: 110 kbps to 27 Mbps CSS: 250 kbps, 1 Mbps</p>

12.9 IEEE 802.15 PROTOCOL ARCHITECTURE



12.10 WIRELESS LOCAL NETWORKS

IEEE 802.15.3

- High data rate WPANs
 - Digital cameras, speakers, video, music
- Piconet coordinator (PNC)
 - Sends beacons to devices to connect to the network
 - Uses superframes like 802.11
 - QoS based on TDMA
 - Controls time resources but does not exchange data
- 802.15.3c
 - Latest standard
 - Uses 60 GHz band, with same benefits as 802.11ad
 - Single-carrier and OFDM PHY modes

IEEE 802.15.4

- Low data rate, low complexity
 - Competitor to Bluetooth Smart
- PHY options in 802.15.4 and 802.15.4a
 - 868/915 MHz for 20, 40, 100, and 250 kbps
 - 2.4 GHz for 250 kbps
 - Ultrawideband (UWB)
 - Uses very short pulses with wide bandwidth
 - Low energy density for low interference with others
 - 851 kbps and optionally 110 kbps, 6.81 Mbps, or 27.234 Mbps
 - 2.4 GHz chirp spread spectrum for 1 Mbps and optionally 250 kbps
 - Sinusoidal signals that change frequency with time

IEEE 802.15.4

- Many other creative and practical activities
- IEEE 802.15.4f – Active Radio Frequency Identification Tags (RFIDs)
 - Attached to an asset or person with a unique identification
 - An Active RFID tag must employ some source of power
- IEEE 802.15.4g – Smart Utility Networks (SUN)
 - Facilitates very large scale process control applications such as the utility smart-grid network
- IEEE 802.15.4j – Medical Body Area Networks
- IEEE 802.15.4k – Low Energy Critical Infrastructure Networks (LECI)
 - To facilitate point to multi-thousands of points communications for critical infrastructure monitoring devices with multi-year battery life.
- IEEE 802.15.4p – Positive Train Control
 - Sensor, control and information transfer applications for rail transit

OTHER IEEE 802.15 STANDARDS

- 802.15.2 – Coexistence between 802.11 and 802.15
- 802.15.5 – Mesh networks
 - Multihop networking
- 802.15.6 – Body area networks
- 802.15.7 – Visible light communication

ZIGBEE

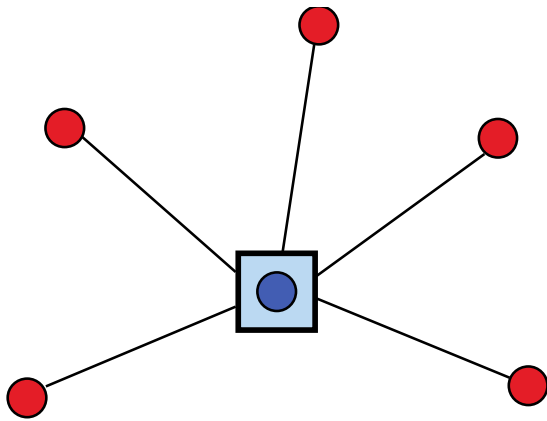
- Extends IEEE 802.15.4 standards
- Low data rate, long battery life, secure networking
- Data rates 20 to 250 kbps
- Operates in ISM bands
 - 868 MHz (Europe), 915 MHz (USA and Australia), 2.4 GHz (worldwide)
- Quick wake from sleep
 - 30 ms or less compared to Bluetooth which can be up to 3 sec.
 - ZigBee nodes can sleep most of the time

ZIGBEE

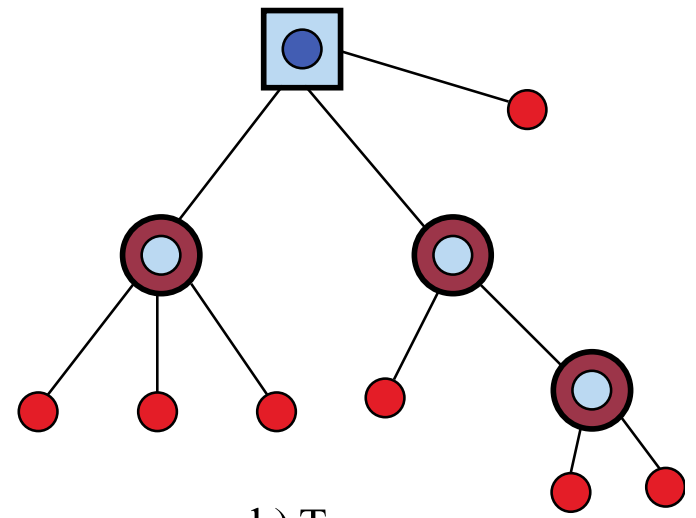
- ZigBee complements the IEEE 802.15.4 standard by adding four main components
 - Network layer provides routing
 - Application support sublayer supports specialized services.
 - ZigBee device objects (ZDOs) are the most significant improvement
 - Keep device roles, manage requests to join the network, discover devices, and manage security.
 - Manufacturer-defined application objects allow customization.

ZIGBEE

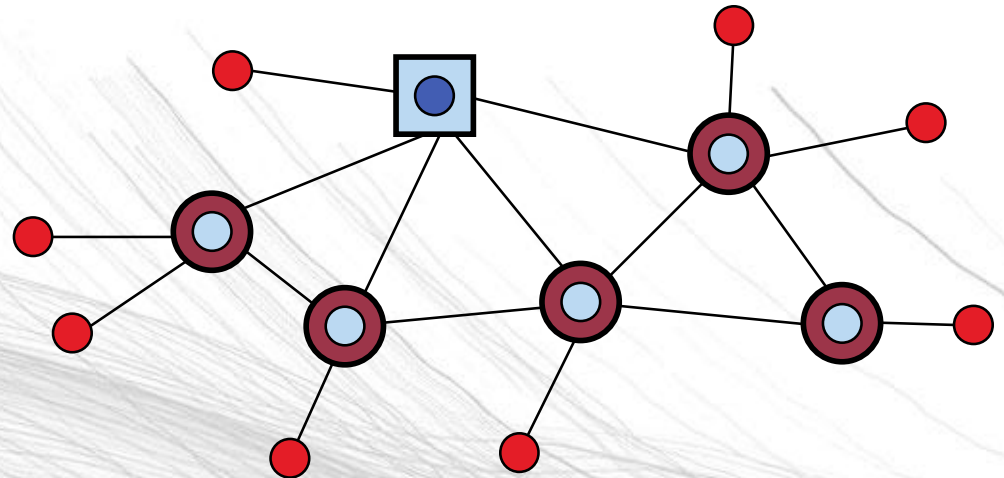
- Star, tree, or general mesh network structures
- ZigBee Coordinator
 - Creates, controls, and maintains the network
 - Only one coordinator in the network
 - Maintains network information, such as security keys
- ZigBee Router
 - Can pass data to other ZigBee devices
- ZigBee End Device
 - Only enough functionality to talk to a router or coordinator
 - Cannot relay information
 - Sleeps most of the time
 - Less expensive to manufacture






a) Star



b) Tree



c) Mesh

-  ZigBee Coordinator
-  ZigBee Router
-  ZigBee End Device

12.12 ZIGBEE NETWORK

ZIGBEE ALLIANCE

- Industry consortium
- Maintains and publishes the ZigBee standard
 - ZigBee specifications in 2004
 - ZigBee PRO completed in 2007
 - Enhanced ZigBee
 - Profile 1 – home and light commercial use
 - Profile 2 – more features such as multicasting and higher security
- Application profiles
 - Allow vendors to create interoperable products if they implement the same profile

ZIGBEE APPLICATION PROFILES

- ZigBee Building Automation (Efficient commercial spaces)
- ZigBee Health Care (Health and fitness monitoring)
- ZigBee Home Automation (Smart homes)
- ZigBee Input Device (Easy-to-use touchpads, mice, keyboards, wands)
- ZigBee Light Link (LED lighting control)
- ZigBee Network Devices (Assist and expand ZigBee networks)
- ZigBee Retail Services (Smarter shopping)
- ZigBee Remote Control (Advanced remote controls)
- ZigBee Smart Energy 1.1 (Home energy savings)
- ZigBee Smart Energy Profile 2 (IP-based home energy management)
- ZigBee Telecom Services (Value-added services)