WIRELESS TECHNOLOGIES

Bluetooth, ZigBee and ANT

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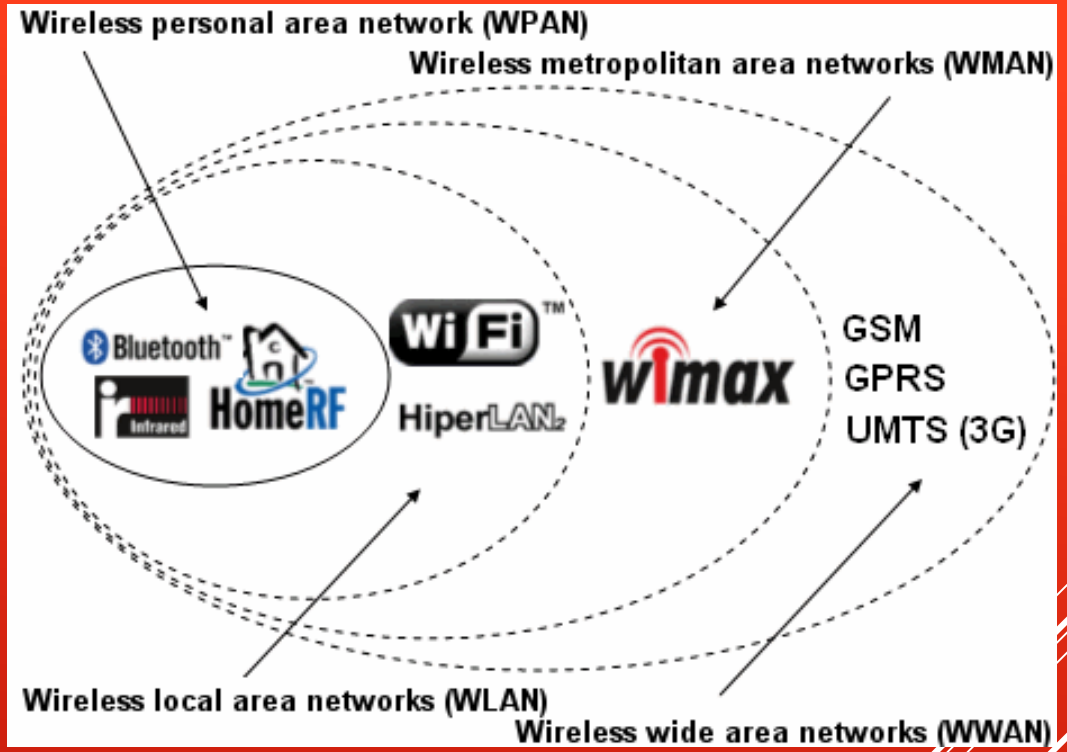
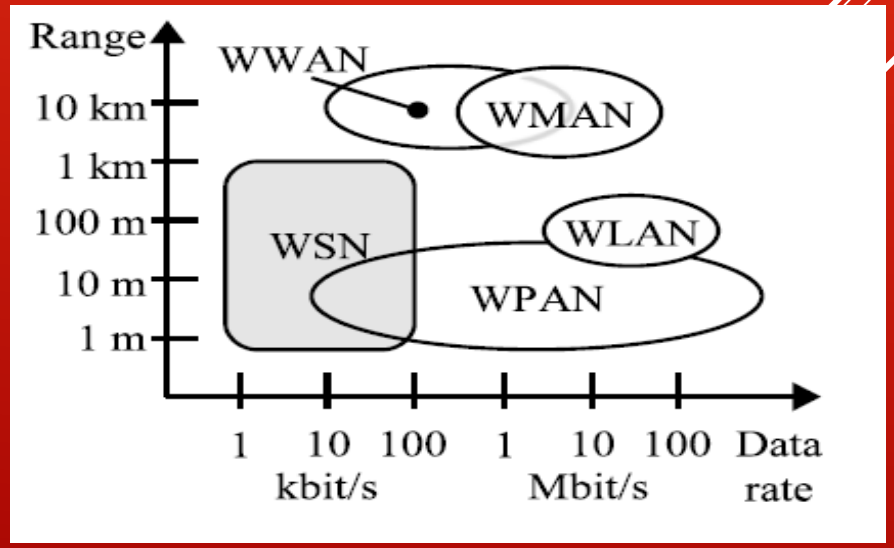
OVERVIEW

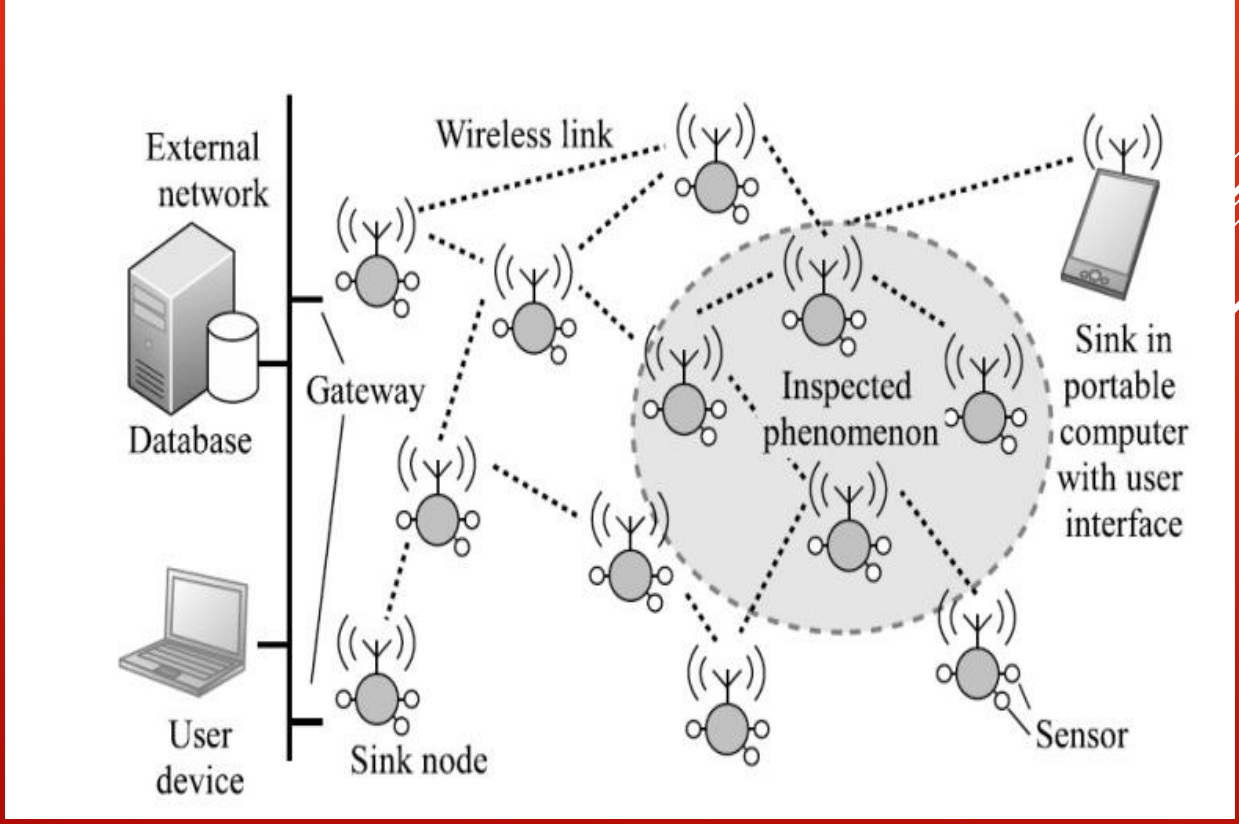
- What are **wireless sensor networks**?
- What are **personal area networks**?
- What are these networks **typically used for**?
- Bluetooth, ZigBee and ANT





WIRELESS SENSOR NETWORKS

- What is a **sensor node**?
- What is a **sensor network**?
- Potential **applications**?
- What are low-power WSNs, and what are their **characteristics**?
- Examples

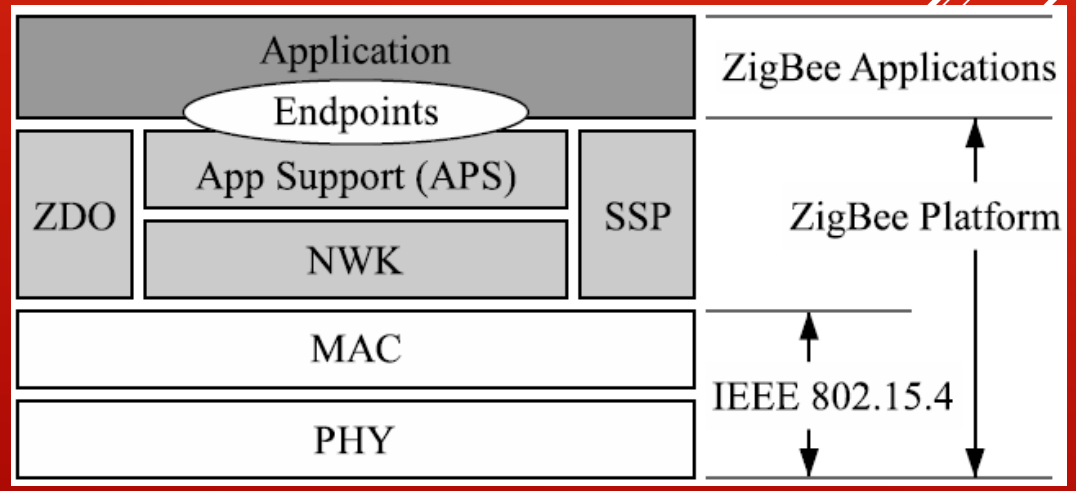


WIRELESS PERSONAL AREA NETWORKS

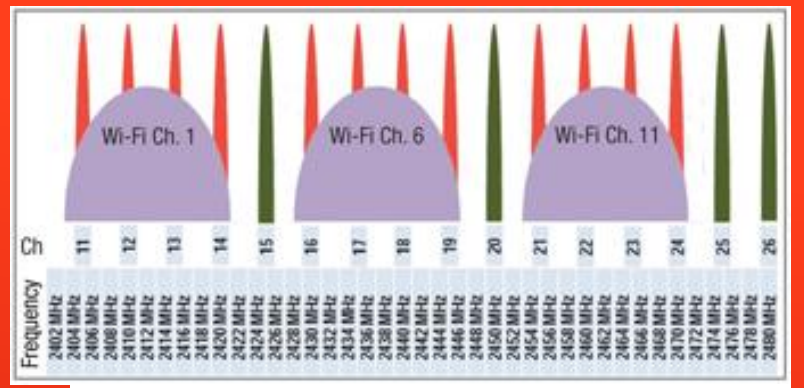
- What is a **Personal Area Network**?
- **Potential applications**?
- Examples

ZIGBEE - INTRODUCTION

- What is **ZigBee**?
- Who **created** it? Who **owns** the technology?
- Why the strange **name**?
- What is it primarily **used** for?



CHARACTERISTICS



BAND	COVERAGE	DATA RATE	CHANNEL NUMBERS
2.4 GHz	ISM Worldwide	250 kbps	11-26
868 MHz	Europe	20 kbps	0
915 MHz	ISM Americas	40 kbps	1-10

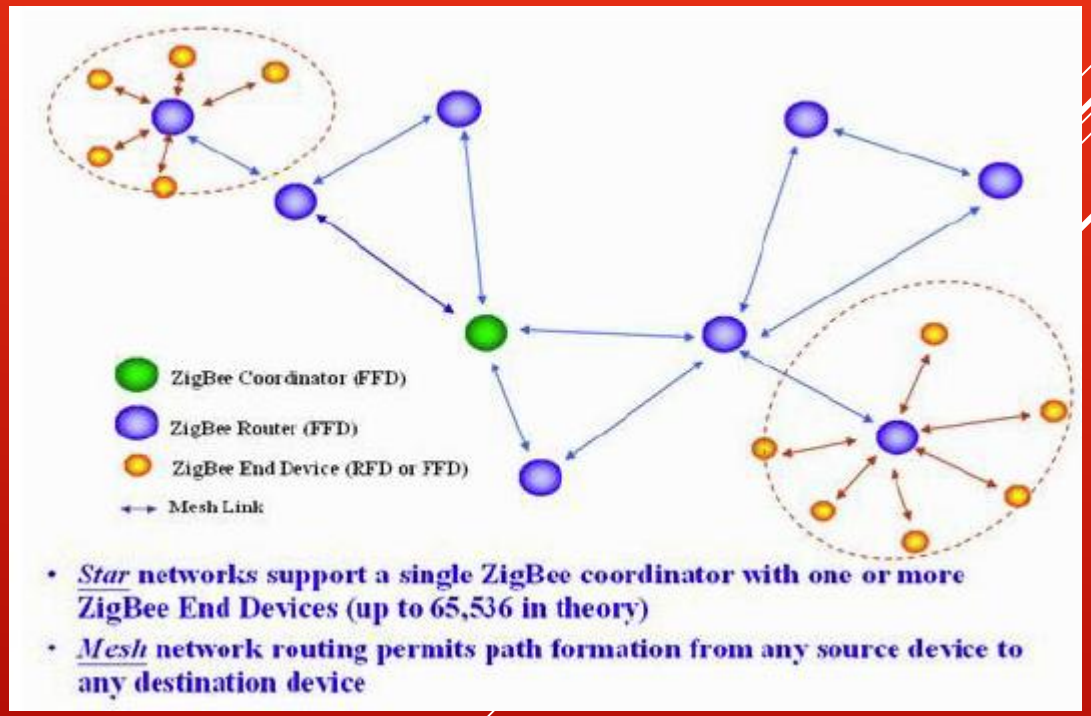
- To provide flexibility, **three** unlicensed **bands** are used depending on location – 2.4 GHz, 915 MHz and 868 MHz.
- **Sixteen channels** are allocated in the 2.4 GHz band, each channel being **2 MHz wide** and requiring ***5 MHz of spacing***.
- The 2.4 GHz band provides up to **250 kbit/s**, 915 MHz provides up to **40 kbit/s** and 868 MHz provides a data rate up to 20 **kbit/s**.
  - **Throughput** is expected to be around **10 to 115.2 kbit/s.**
- **Direct-sequence spread spectrum**(DSSS) **coding** is utilized.
  - In the 868 and 915 MHz bands, **binary phase-shift keying** (BPSK) is used.
  - **Offset quadrature phase-shift keying** (OQPSK) that transmits two bits per symbol is used in the 2.4 GHz band.

TRANSMITTER OUTPUT POWERS

- **Output power** is minimum 0.5 mW (**-3dBm**) and can be increased to approximately **10 dBm** depending on regulation.
  - Mostly used with 0 dBm.
  - Typical range between **10-100m**, depending on power and usecase.
- Receiver sensitivity is around **-92 dBm** for 868/915 MHz and **-85 dBm** for 2.4 GHz.

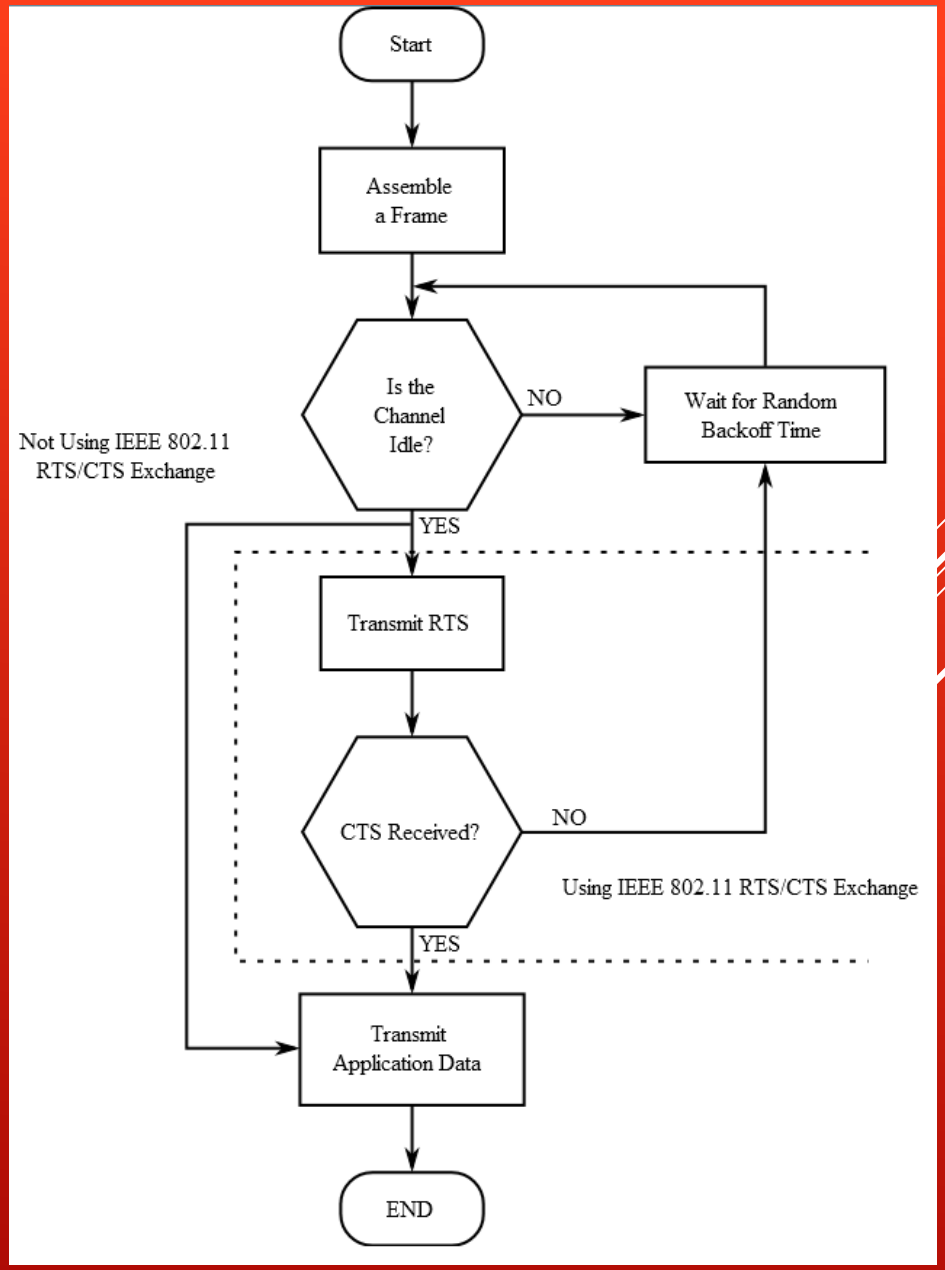
NODE TYPES AND TOPOLOGIES

- Full Function Device
  - FFD contains the entire protocol and can be the **network coordinator**
- Reduced Function Device
  - RFD contains only the **bare minimum** of the protocol. Typically used as **switches or as sensors**. Objective is to **reduce** cost and power consumption.
- Supports star and mesh topologies (or a combination of both)
  - A network can contain up to **255 members**, where one is the coordinator.
  - The coordinator initiates, terminates and routes communication.
- In a star network, all the nodes communicate directly with a coordinator.
- In a mesh network, only FFDs can participate. There is still only one coordinator.



INTERFERENCE

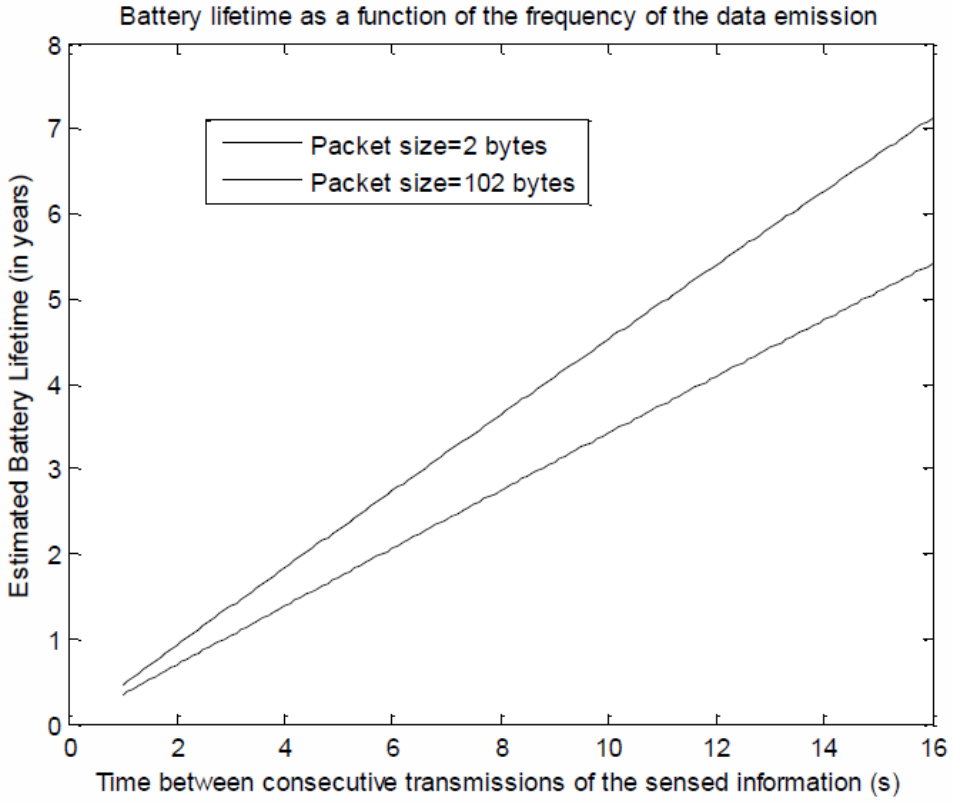
- Uses **carrier sense multiple access with collision avoidance** – CDMA/CA.
  - ACK messages are transmitted without this mechanism.
- ZigBee PRO Nodes can request that the coordinator change frequencies due to interference (**frequency agility**).
  - This, however, obviously only works if the request gets through.



POWER CONSUMPTION

- Typically uses one or two AA batteries, peak current consumption can be up to **40 mA**.
- For most uses, batteries will last several **years**. This depends on frequency of transmission, and packet size.

Expected Battery lifetime (in optimal conditions) of a mote as a function of the frequency of data emission for two different sizes of sensed data (battery capacity is assumed to be 1,200 mAh).



ZIGBEE PRO

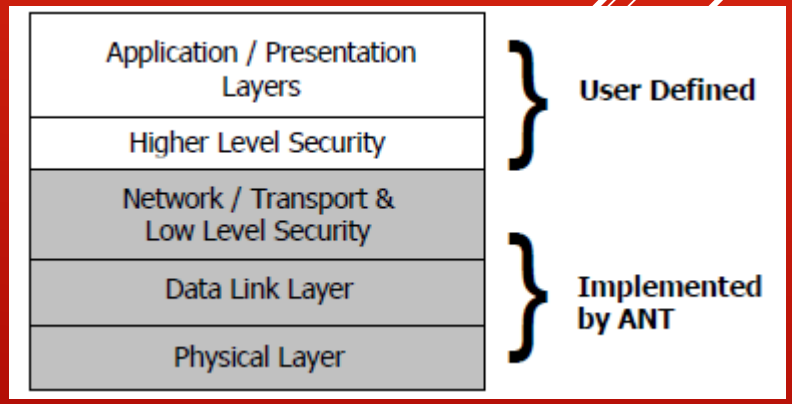
- ZigBee has two stack profiles, ZigBee and ZigBee Pro.
- ZigBee Pro is optimized for **larger networks**, but may require more memory and be more expensive.

Feature	ZigBee Feature Set	ZigBee PRO Feature Set
Network Scalability	Easily supports networks of hundreds of devices	Advanced support for networks of thousands of devices
Fragmentation	O	X
Frequency Agility	O	X
Channel Selection	X	X
Automated Device Address Management	X	X+
Group Addressing	X	X+
Wireless Commissioning	X	X+
Centralized Data Collection	X	X+
Device Maintenance & Network Recovery	X	X
Group Broadcasts	X	X
Compatibility	Devices can participate in ZigBee and ZigBee PRO networks	Devices can participate in ZigBee and ZigBee PRO networks
AES128 Encryption/ Authentication/ Trust Centers	X	X
IEEE 802.15.4 Physical Radio	X	X
Global Operation in 2.4 GHz plus 915MHz Americas / 868 MHz Europe	X	X
Single-hop Extended Range - up to Hundreds of Meters	X	X
Reliable Self-Healing Mesh Network	X	X
Ultra Low-Power, Long Battery Life	X	X
Low Cost	X	X
Network Traffic Load	Average	Increased

Legend:
X – Standard
+ – Optimized
O – Optional

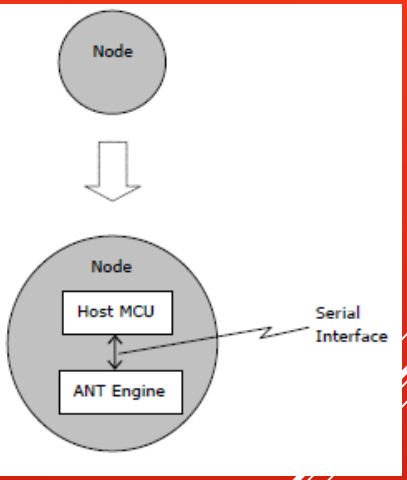
ANT - INTRODUCTION

- What is **ANT**?
- Who **created** it? Who **owns** the technology?
- Why the **name** ANT?
- What is it primarily **used** for?



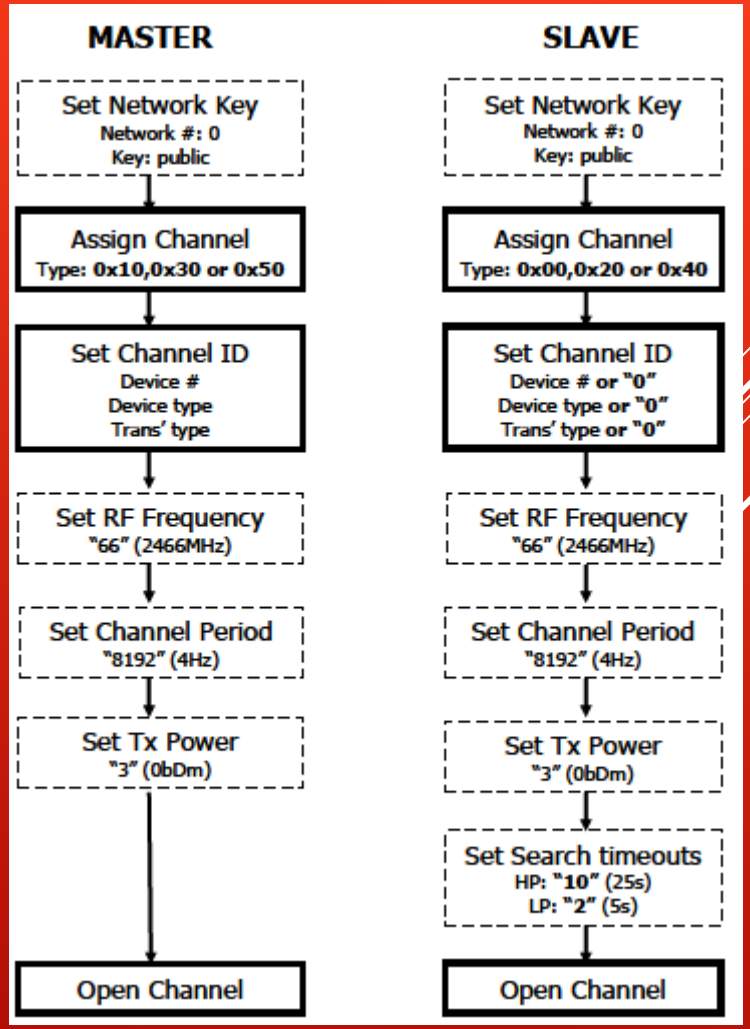
CHARACTERISTICS

- Operates in the **2.4 GHz band.**
- ANT uses **virtual channels**, and the RF frequency is an 8 bit variable which accepts numbers from 0 to 124. This gives us a range from **2400 MHz to 2524 MHz**, with the physical channels being **1 MHz wide**.
  - **Multiple** virtual channels can coexist on a single RF frequency, depending on the frequency of transmission.
  - The channels will adapt their transmission timeslots **automatically.**
    - There is **no central clock**, each node just starts transmitting and adjusts if needed.
- Supports data rate of **1 Mbp/s**.
  - Actual throughput usually around **20kbp/s**.
- Has a function called **SensRcore**, where an application can be stored on the chip itself – making it require **no external resources** but power.
- Modulation: **GFSK**.



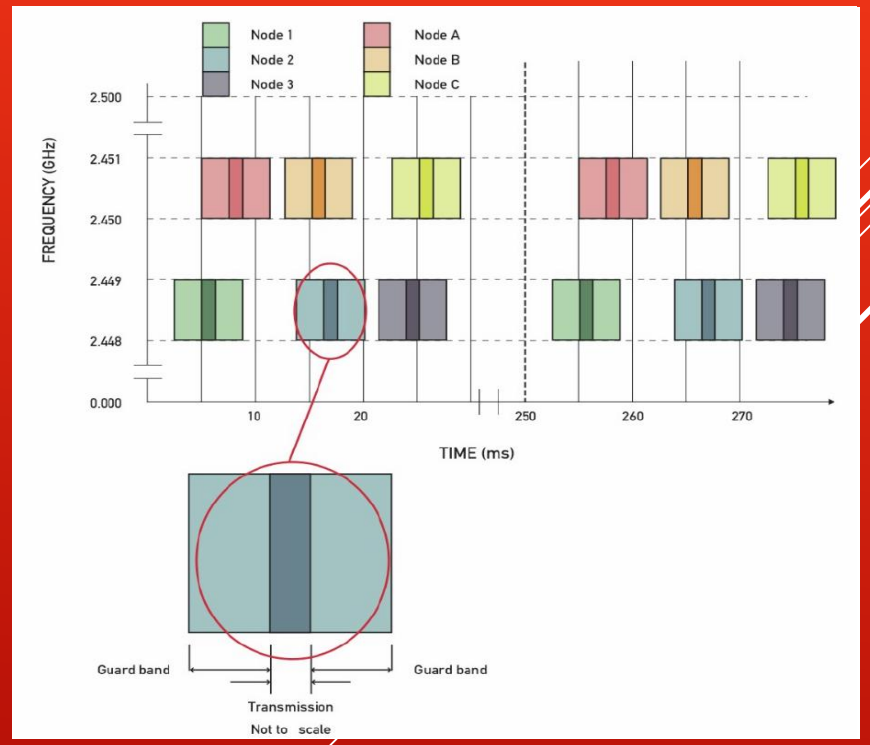
ANT CHANNELS

- The use and configuration of ANT is based on **channels**, and each ANT node connects to other nodes through dedicated channels. Each node can participate in up to **8 channels**.
- There are usually two nodes per channel, but you can configure it to be a **shared channel** with **multiple** participants.
- Every channel needs **at least** one **slave** and one **master**.
  - The master **transmits** data, and the slave **receives**.
  - A node can be configured to be both a slave and a master **simultaneously**, but this has to be on different channels.



INTERFERENCE

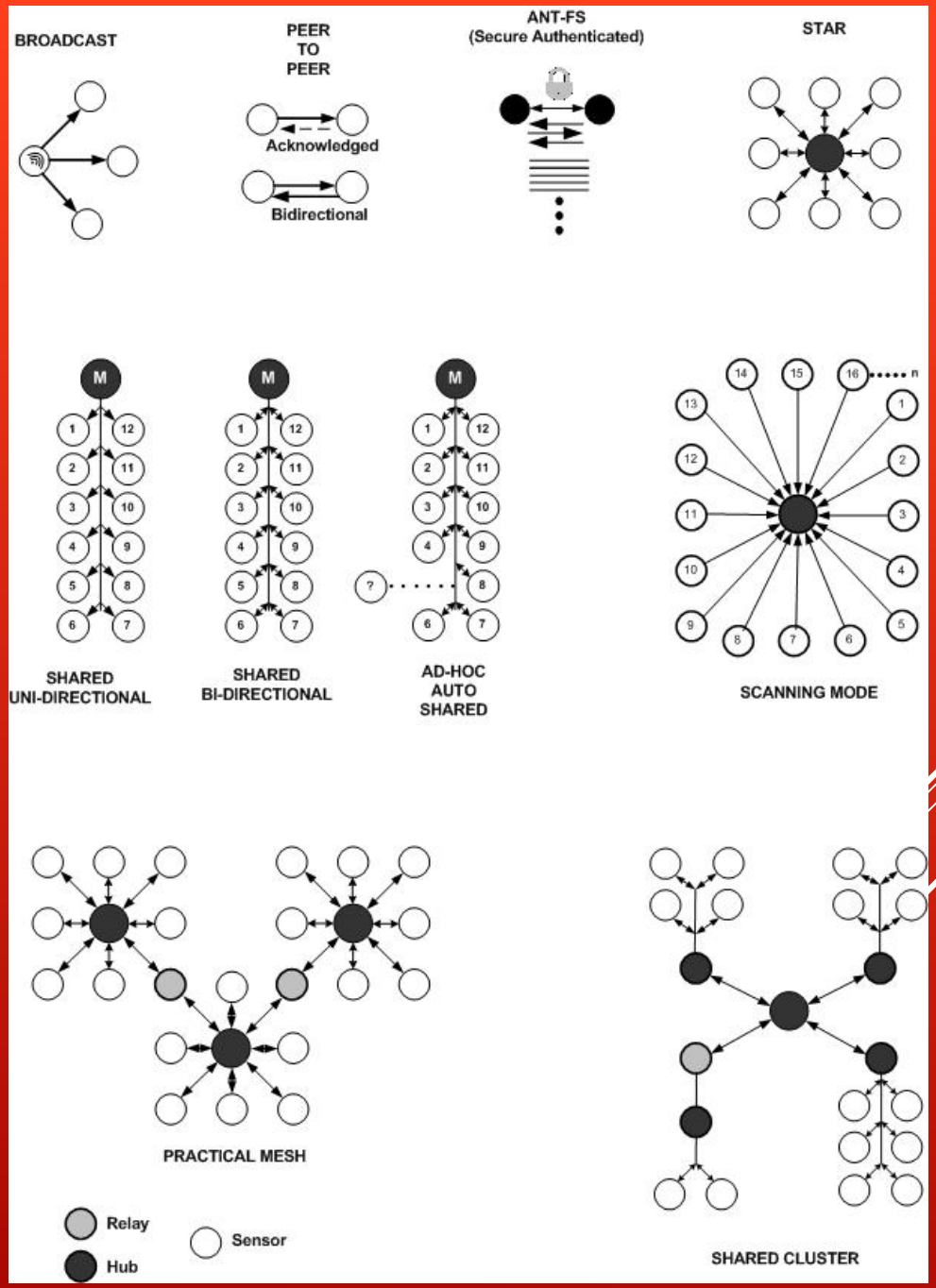
- ANT uses a selfadjusting **isochronous TDMA** technology in order to avoid collisions from other radios in the 2.4 GHz band.
- ANT nodes will begin to transmit at the chosen interval, but will adjust their timeslots if interference is discovered.
- Since each radio only transmits for less than **150 µs**, each 1 MHz frequency can be divided into **several hundred** timeslots depending on message frequency.
- ANT has frequency agilitity as well, and will change frequencies if too much interference is detected.
- Example: number of available timeslots in a channel with 1Hz message frequency and 3ms guard bands, assuming 150 µs transmit time.



$$\frac{1000\text{ms}}{(3\text{ms}+0.150\text{ms}+3\text{ms})}=162{,}6$$

TOPOLOGIES

- ANT supports from basic and peer to peer to complex practical mesh network topologies.
- **No coordinator** or network level master is required to accomplish complex topologies.
- An ANT shared channel is able to operate **65533** nodes.



ANT DATATYPES

- ANT supports three datatypes:
  - Broadcast – sent every timeslot, no ACK
  - Acknowledged
  - Burst – bursting data at max speed until it's all transmitted.
- Datatypes are **application controlled**, and any type can be used at will.
  - Exception: one-way channels.

Data Type	Channel Direction	Description
Broadcast	Forward	Default Data Type. Broadcast messages sent every timeslot (unless otherwise requested) and will be retransmitted if ANT has not received any new data from the master's host MCU
	Reverse	Broadcast messages optionally sent each channel timeslot. Only sent if specifically requested by the slave's host MCU. Sent only once, there is no retransmission
Acknowledged	Forward	If requested, sent on the next channel timeslot If the data type isn't specified as Acknowledged or if no new data is provided before the next transmit time slot, the message is resent as Broadcast data type on the next channel time slot
	Reverse	Acknowledged data types only sent when specifically requested by the slave's host MCU. Not re-transmitted
Burst	Forward	A burst transfer will commence at start of the next timeslot. Bursts packets synchronize off each other
	Reverse	Burst data types only sent when specifically requested by the slave's host MCU. Not re-transmitted

TRANSMITTER OUTPUT POWERS

- Transmitters can be configured with output powers between **-20 and 0 dBm**.
- Typical range at 0 dBm is around **30 meters** under ideal conditions.
- The percentage of payload data in a package is given by the developer to be **47%**.

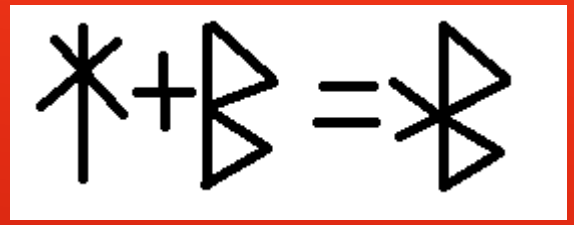
POWER CONSUMPTION

- Power consumption is directly proportional to message frequency.
  - Message frequency can be adjusted from 0.5 to 200 Hz.
- Usually runs on **coin cell batteries**. Expected lifetime is measured in **years**.

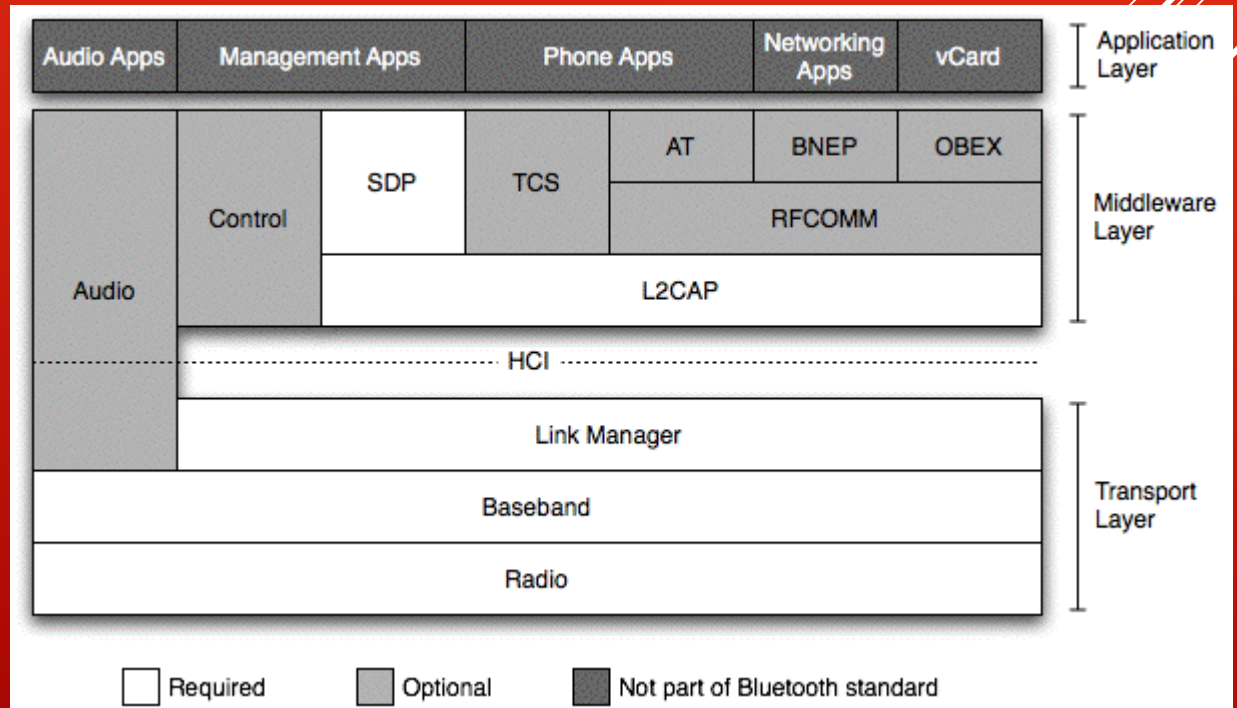
Quick Reference Data		
Message rate	0,5 – 200	Hz
Idle current consumption, no communications	2	µA
Peak current consumption RX mode	22	mA
Peak current consumption TX @ 0 dBm	16	mA
Average system current consumption per TX message [1]	39,4	µA
Average system current consumption per RX message [1]	43,1	µA
Max # of simultaneous connections [2]	>65000	connections
Maximum sustained transfer rate (all data – no overhead) [3]	20	kbps
CR2032 Battery life in typical sensor application [4]	15	years

[1] 8 bytes payload data – no additional overhead required. Message interval of 2s
[2] Using shared channel network
[3] Transfer rates refers to data rate of the end application's message payload
[4] Message interval of 2s, 1 hour/day usage (Unidirectional communication)

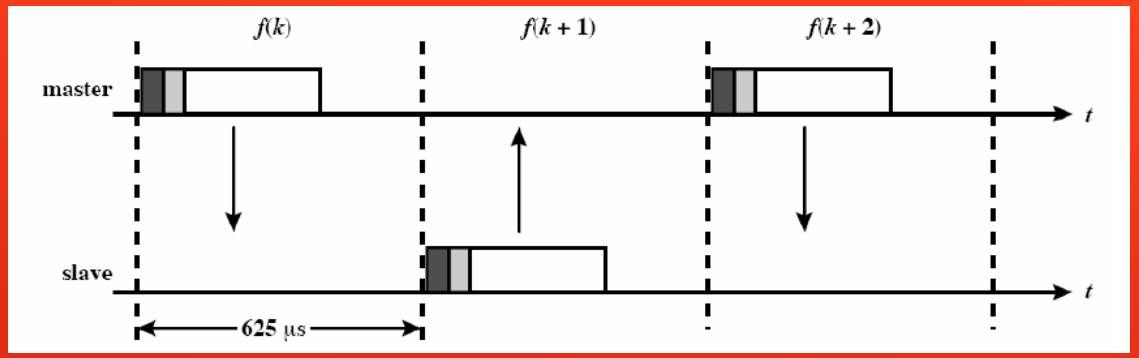
BLUETOOTH - INTRODUCTION



- What is **Bluetooth**?
- Who **created** it? Who owns the **technology**?
- Why the strange **name** and **logo**?
- What is it primarily **used** for?



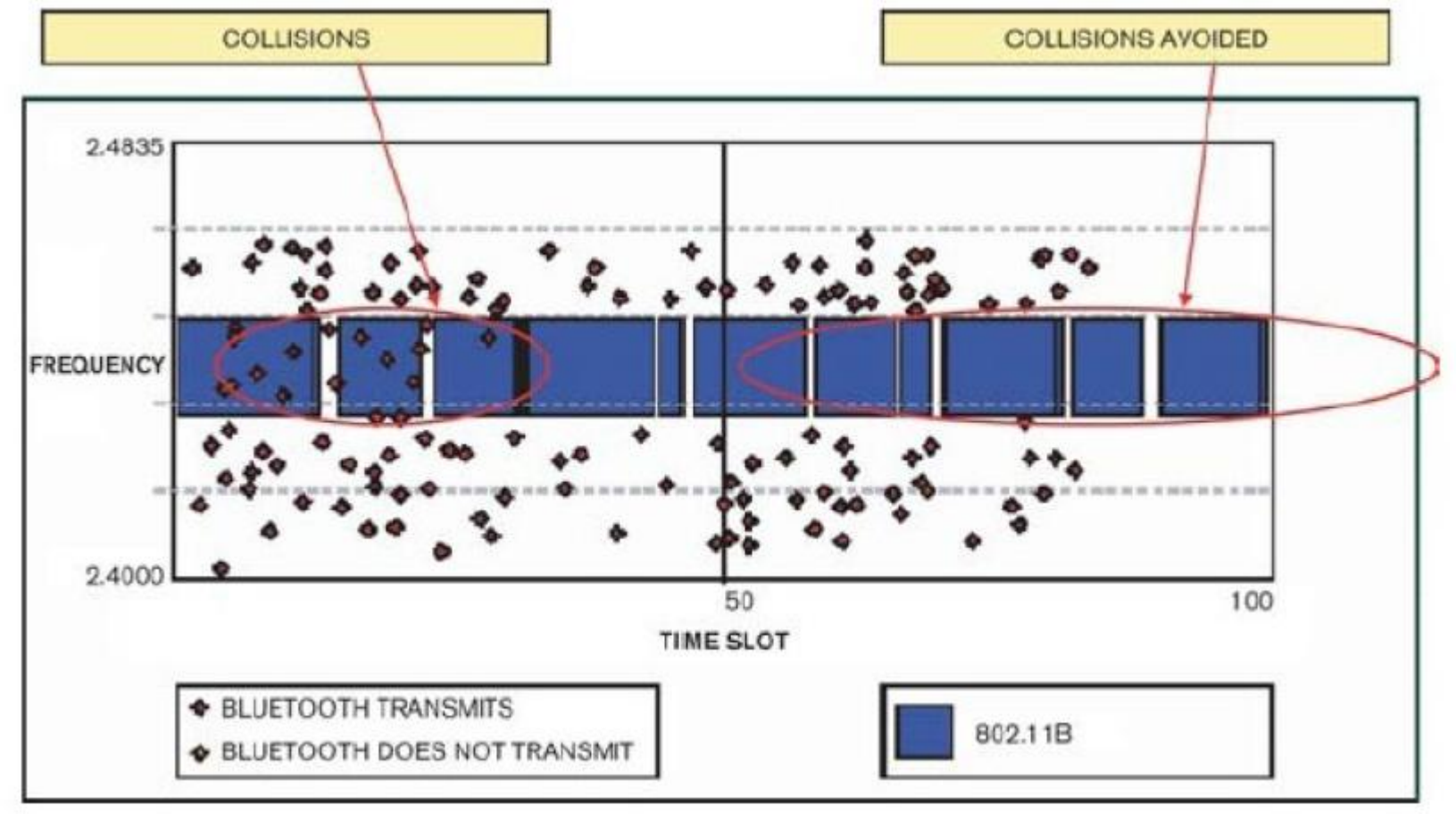
CHARACTERISTICS



- Operates in the **2.4 GHz** band
- Supports data rates up to 3 Mbps
  - Version 3.0 and up can run 24 Mbps over a collocated 802.11 link
- Uses **Frequency Hopping spread spectrum (FHSS)**, which divides the frequency band into a number of channels (2.402 - 2.480 GHz yielding 79 channels – 1 MHz wide).
  - 32 advertising channels
- Radio transceivers **hop** from one channel to another in a **pseudo-random fashion, determined by the master**
- Supports up to **8 devices in a piconet** (1 master and 7 slaves).
  - **Piconets** can combine to form **scatternets**

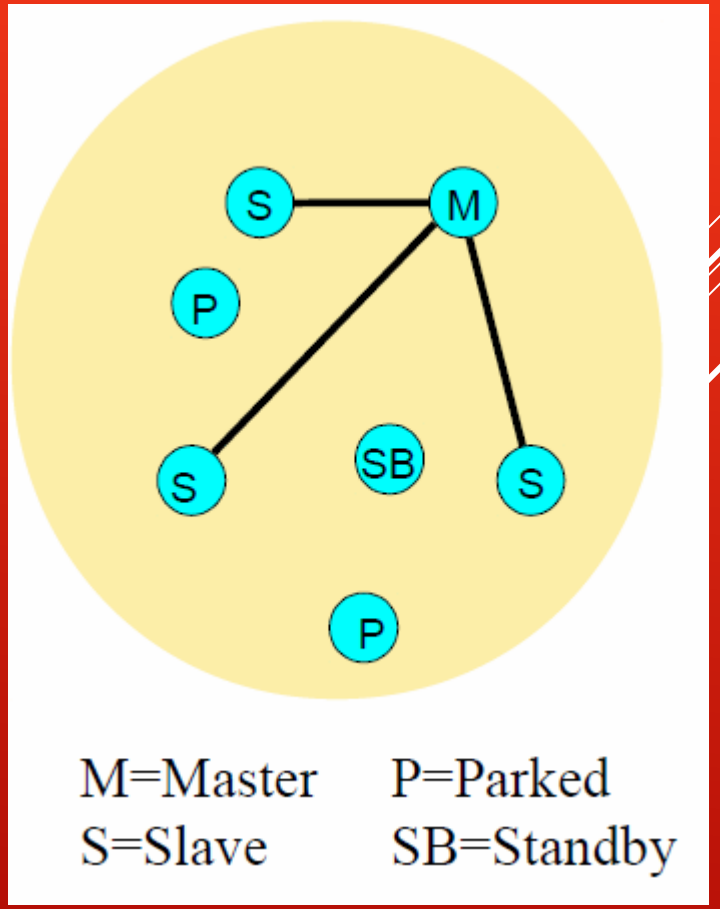
INTERFERENCE

- **Adaptive frequency hopping**
- Bluetooth will record which channels are busy, avoiding them in the future



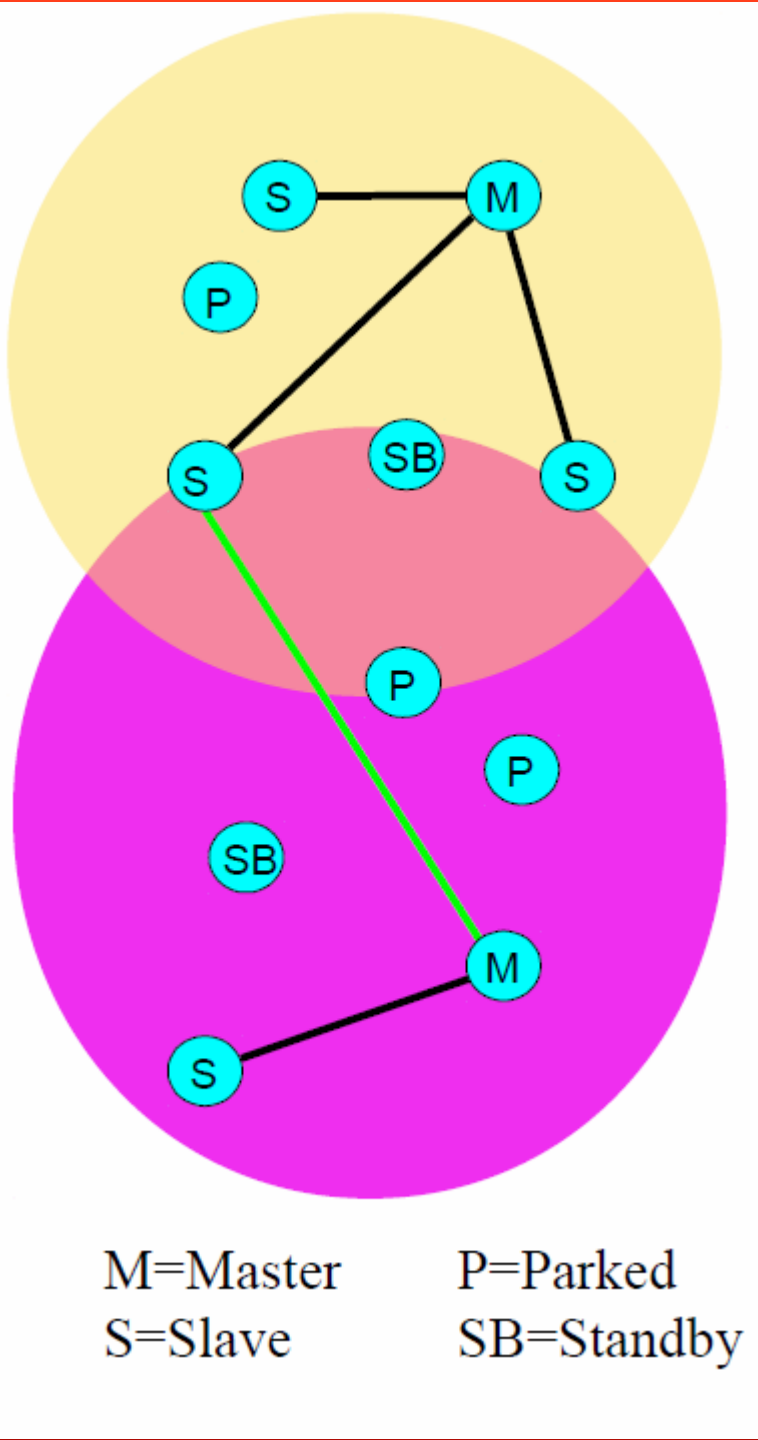
PICONETS

- A **collection** of devices that share a channel
- One unit will act as a **master** and the others as **slaves** for the duration of the piconet connection.
- **Master** sets the **clock** and **hopping** pattern (**TDMA + TDD**).
- Each piconet has a **unique hopping pattern/ID.**
- Each **master** can connect to **7 simultaneous** or **200+ inactive (parked) slaves** per piconet.



SCATTERNETS

- A **Scatternet** is the **linking** of multiple **collocated piconets** through the sharing of common master or slave devices.
- A device can be both a **master** and a **slave.**
- Radios are **symmetric** (same radio can be master or slave)
- Each piconet runs an **individual instance** of **FHSS**, making the chance of **interference** between overlapping piconets **low.** This combination gives a scatternet a form of **CDMA** with **FHSS**.

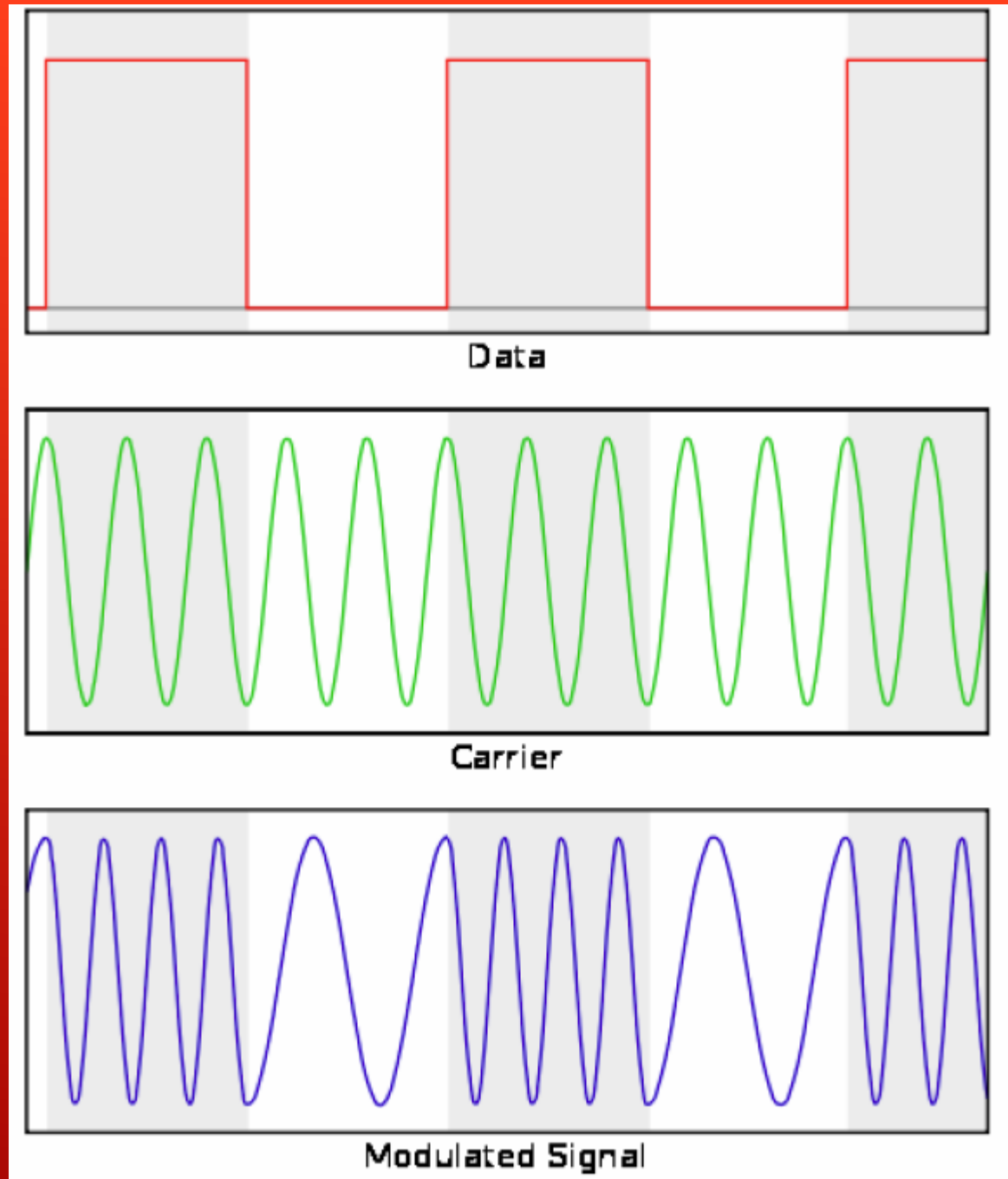


TRANSMITTER OUTPUT POWERS

- Class 1: greatest distance (**100m**)
  - 1 mW (0dBm) to 100mW (+20dBm)
  - power control mandatory
- Class 2: (**10m**)
  - 0.25 (-6dBm) ~ 2.4mW (+4dBm)
  - power control optional
- Class 3: (**1m**)
  - lowest power, 1mW

MODULATION

- Gaussian frequency-shift keying
  - Uses **two separate frequencies** to transfer -1 and 1 (1 and 0).
  - Minimum **deviation** is 115 kHz.



POWER CONSUMPTION - ESTIMATES

- Power varies with implementation – numbers based on 600 mAh battery and internal amplifier
  - Standby current < 0.3 mA
    - →3 months
  - Voice mode 8-30 mA
    - →75 hours
  - Data mode average 5 mA
    - (0.3-30mA, 20 kbit/s, 25%)
    - →120 hours
- May enter sleep mode with approximately **60 µA** power consumption.

BLUETOOTH LOW ENERGY

- Implemented in Bluetooth v4.0
  - Single mode/dual mode
  - **Not** backwards compatible
- FHSS over 39 channels instead of 79
  - 3 advertising channels
- Peak current draw around **12.5 mA**
  - Can operate on **coin cell** battery
- Efficiency: $\frac{Payload}{Total\ Length} = \frac{31}{47} = 0{,}66$
  - **66 percent** efficient.

Classic Bluetooth vs. Bluetooth low energy

The table below shows a high level comparison between classic *Bluetooth (also known as Bluetooth* BR/EDR) and *Bluetooth* low energy technologies.

Technical specification	Classic *Bluetooth* technology	*Bluetooth* low energy technology
Radio frequency	2.4GHz	2.4GHz
Distance/Range	~10-100 meters	~10-100 meters
Symbol rate	1-3Mbps	1Mbps
Application throughput	0.7 – 2.1Mbps	305kbps
Nodes/Active slaves	7	Unlimited
Security	56 to 128 bit	128-bit AES
Robustness	FHSS	FHSS
Latency (from not connected state to send data)	100+ ms	<6ms
Government regulation	Worldwide	Worldwide
Certification body	Bluetooth SIG	Bluetooth SIG
Voice capable	Yes	No
Network topology	Point-to-point, scatternet	Point-to-point, star
Power consumption	1 (reference value)	0.01 to 0.5 (use case dependent)
Service discover	Yes	Yes
Profile concept	Yes	Yes
Primary use cases	Mobile phones, headsets, stereo audio, automotive, PCs etc.	Mobile phones, gaming, PCs, sport & fitness, medical, automotive, industrial, automation, home electronics etc.