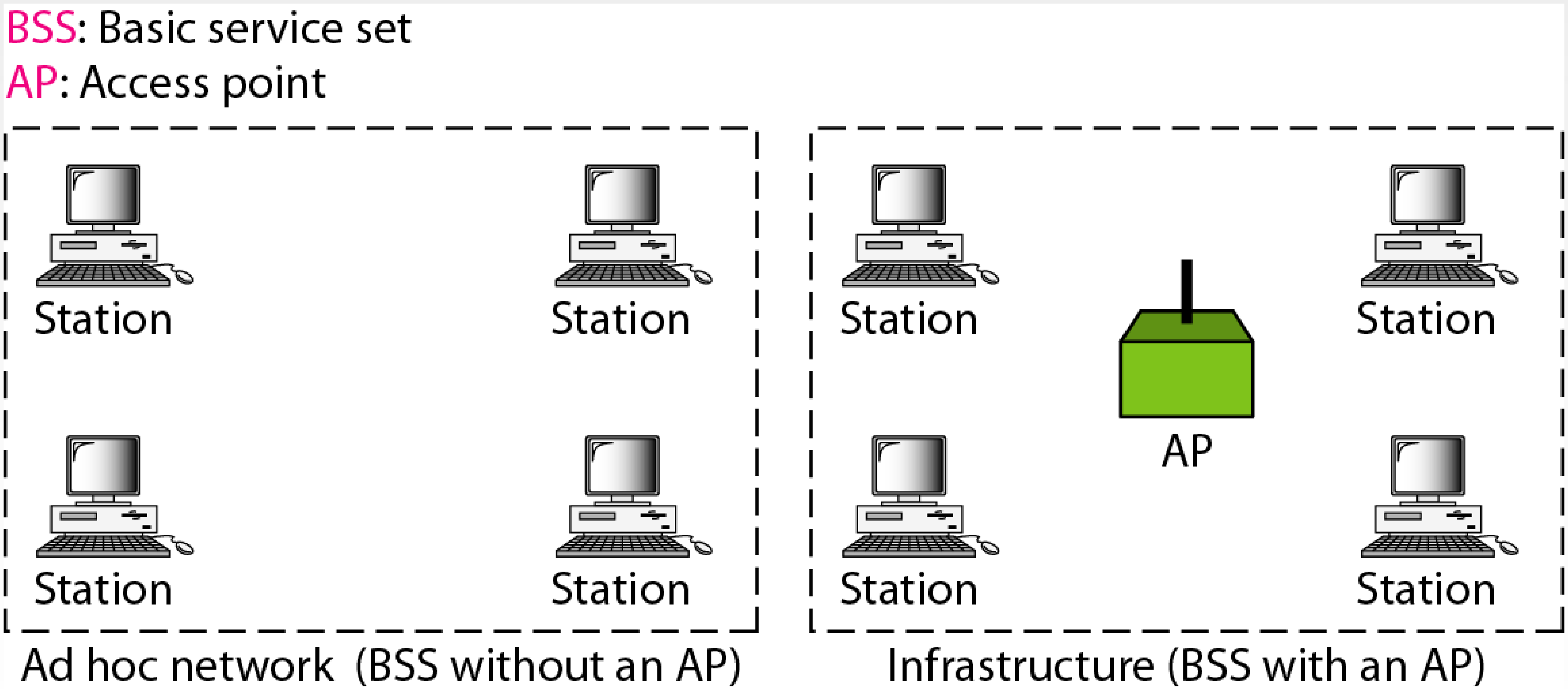
Wireless LANs: IEEE 802.11, Bluetooth
Wireless Low Power Technology: ZigBee

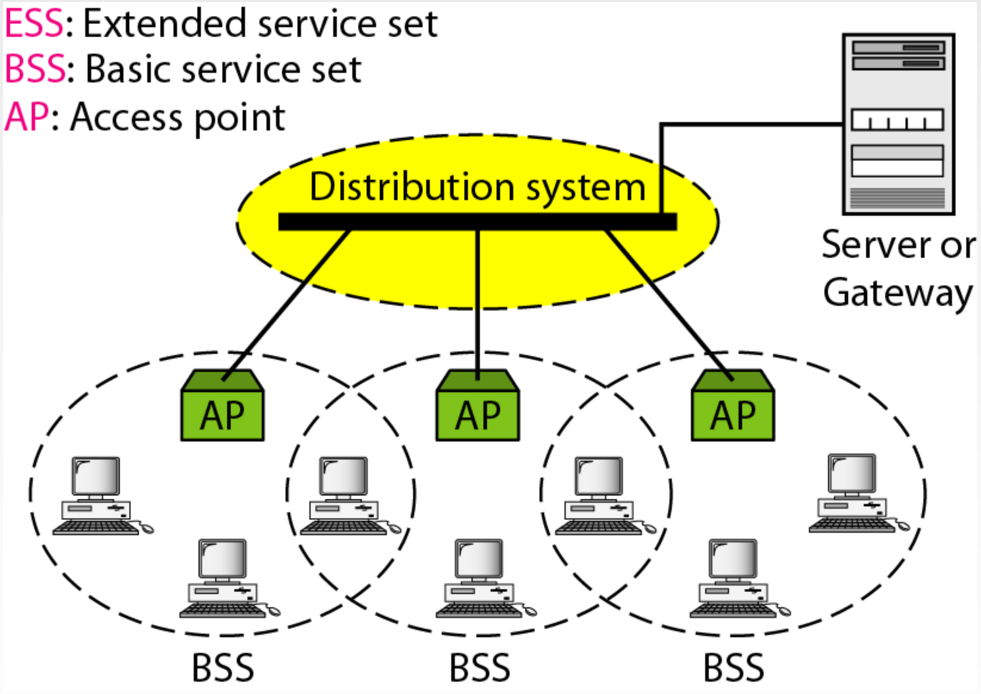
Basic Service Set (BSS)

- BSS
  - The building block of a wireless LAN
- BSS with an AP
  - Access Point (AP): central base station
  - Called an infrastructure network
- BSS without an AP
  - Stand-alone network
  - Cannot send data to other BSSs
  - *Ad hoc* architecture

BSS

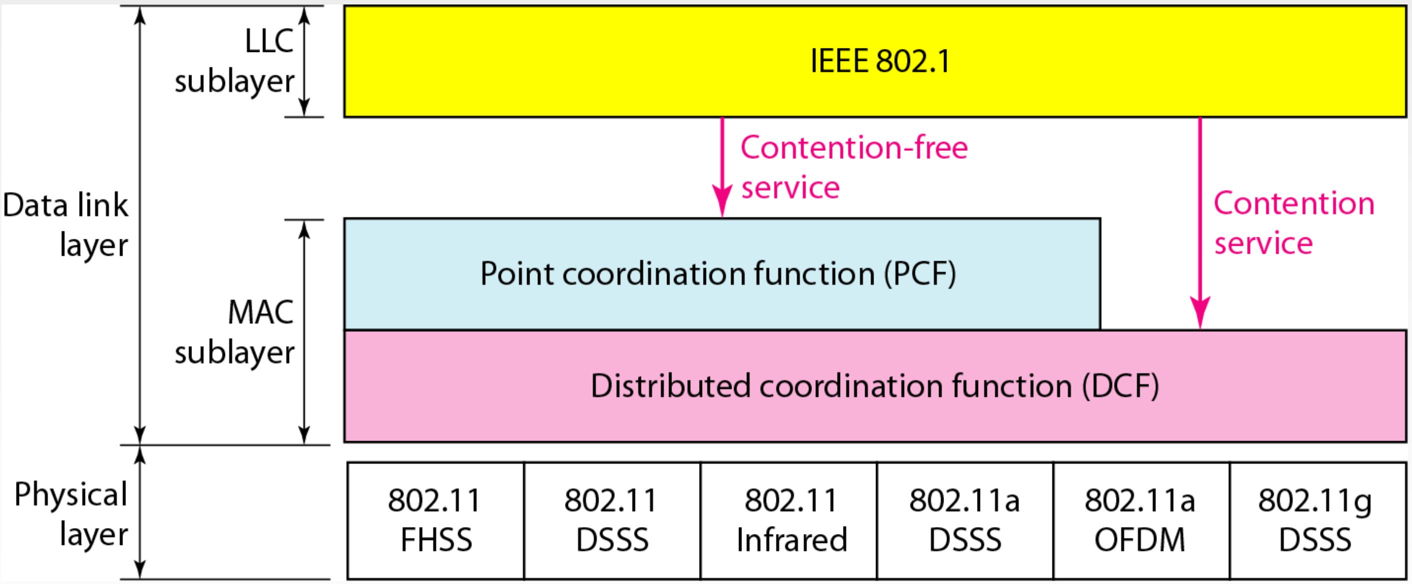

BSS: Basic service set
AP: Access point
Station
Station
Station
Station
Station
Station
AP
Station
Station
Ad hoc network (BSS without an AP)
Infrastructure (BSS with an AP)

Extended Service Set (ESS)



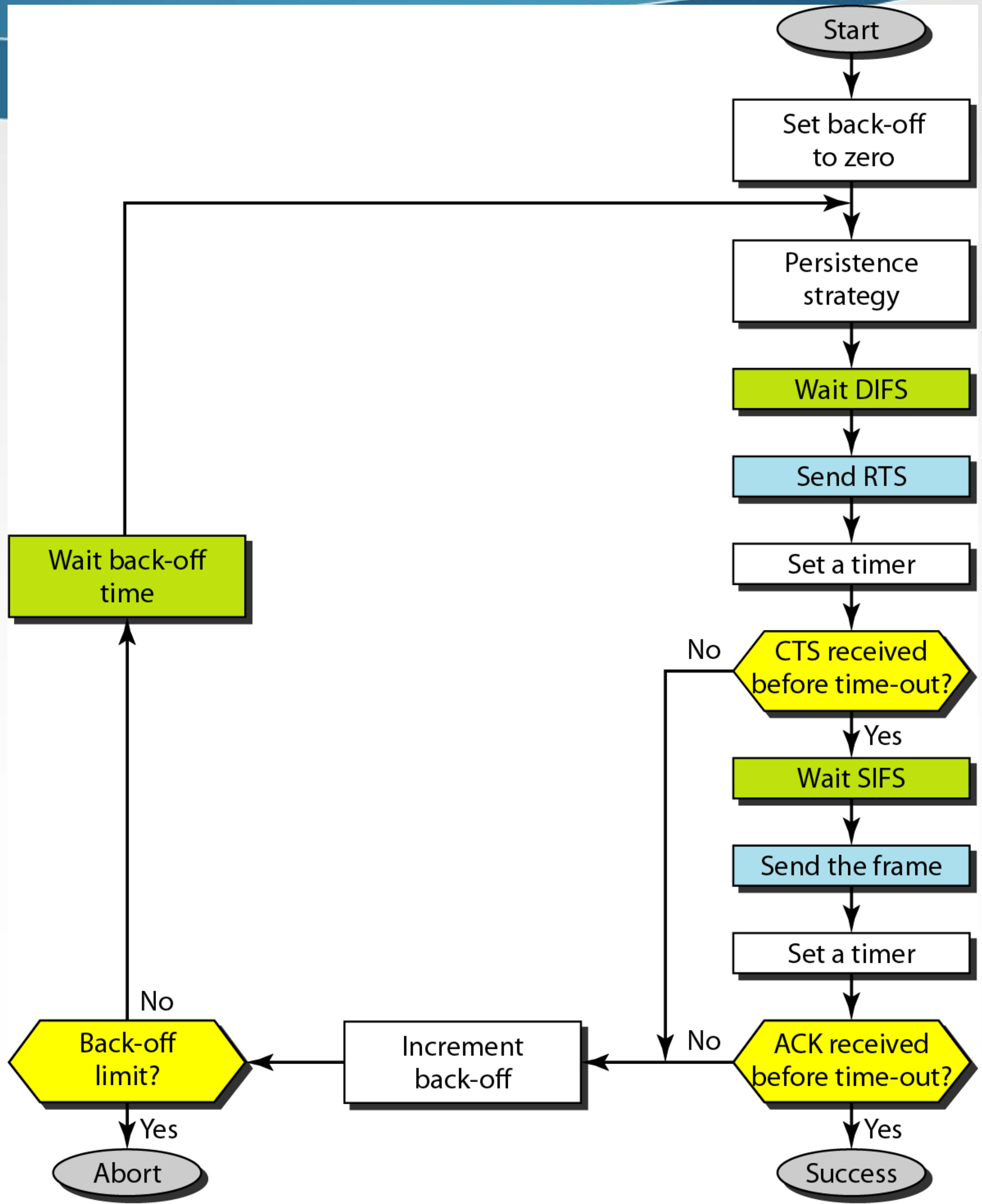
- BSSs are connected through a distribution system: *infrastructure network (usually wired LAN)*
- Station Types: No-transition, BSS-transition, and ESS-transition mobility

MAC Sublayer



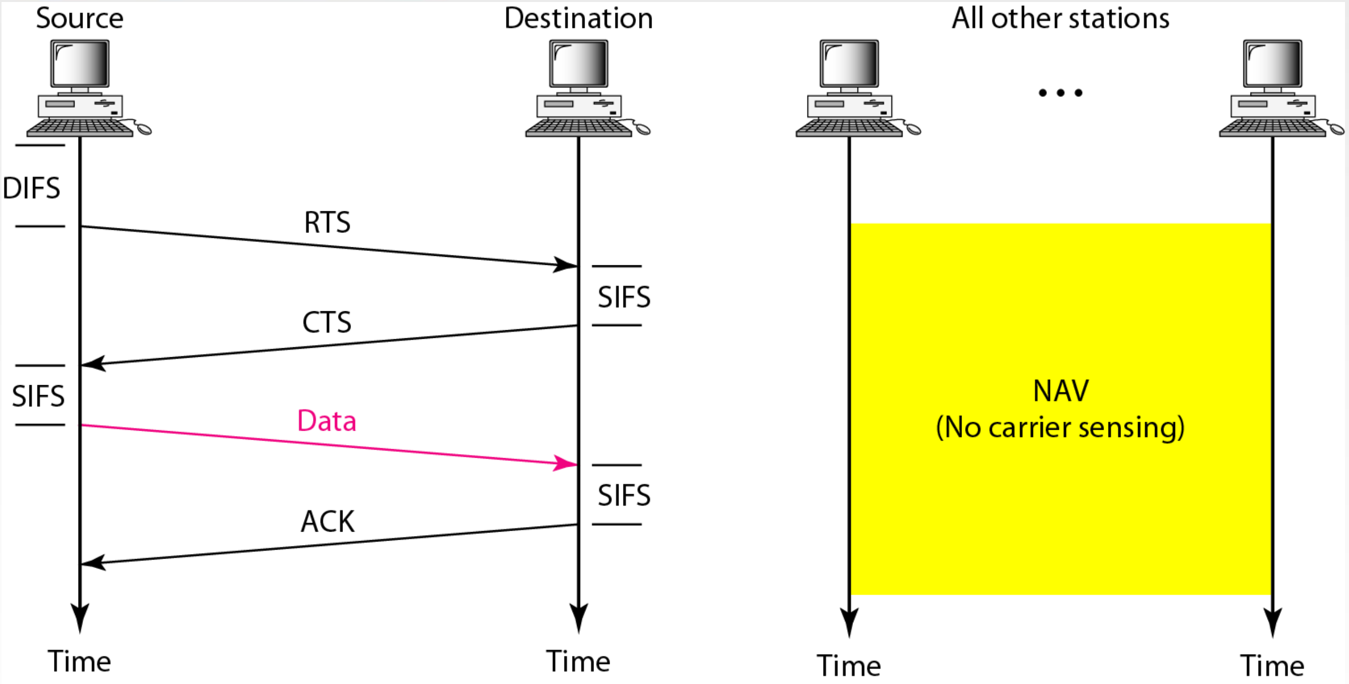
- Two MAC sublayers: DCF and PCF
- DCF uses CSMA/CA as the access method

CSMA/CA

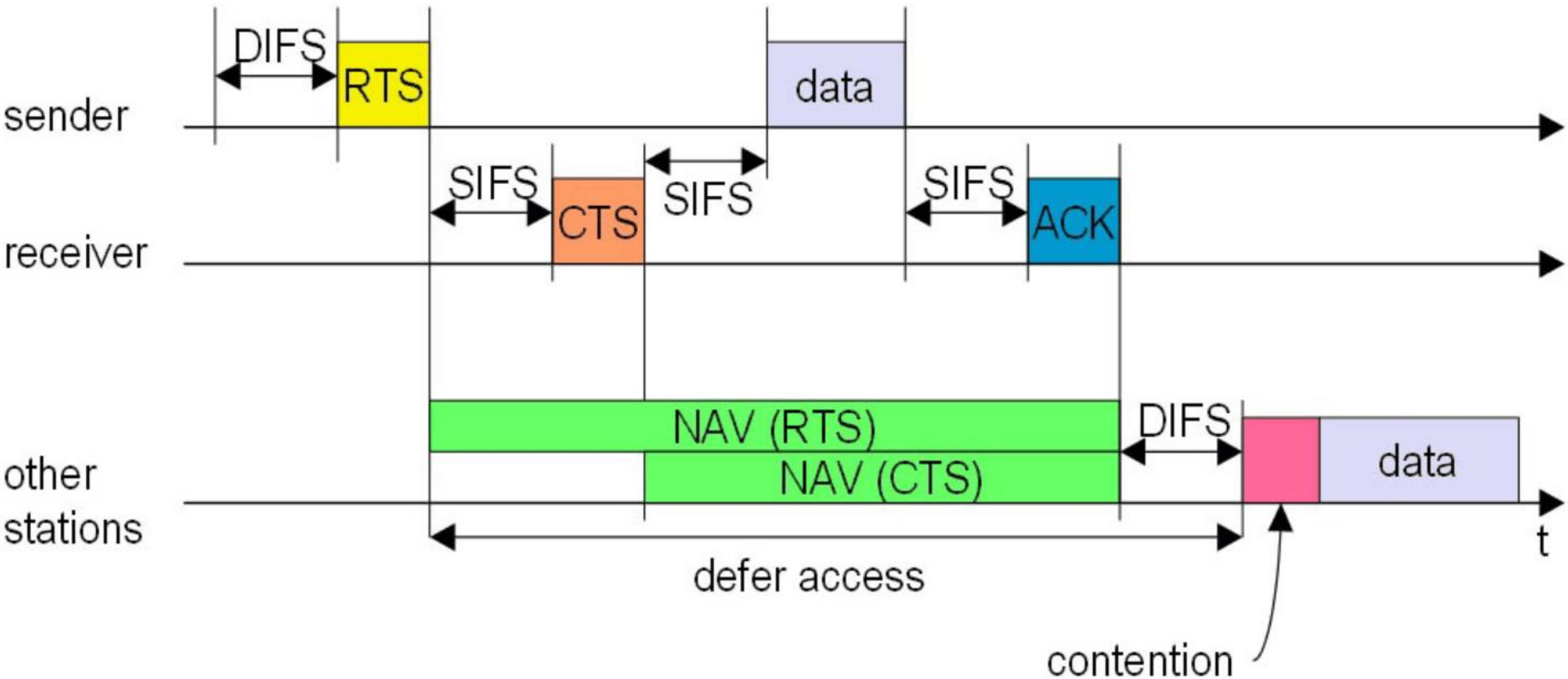


Start
Set back-off to zero
Persistence strategy
Wait DIFS
Send RTS
Set a timer
CTS received before time-out?
No
Yes
Wait SIFS
Send the frame
Set a timer
ACK received before time-out?
No
Yes
Success
Increment back-off
Back-off limit?
No
Yes
Abort
Wait back-off time

CSMA/CA and NAV

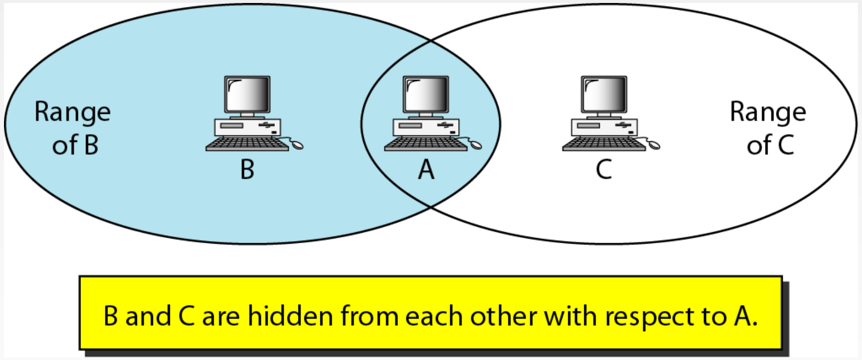


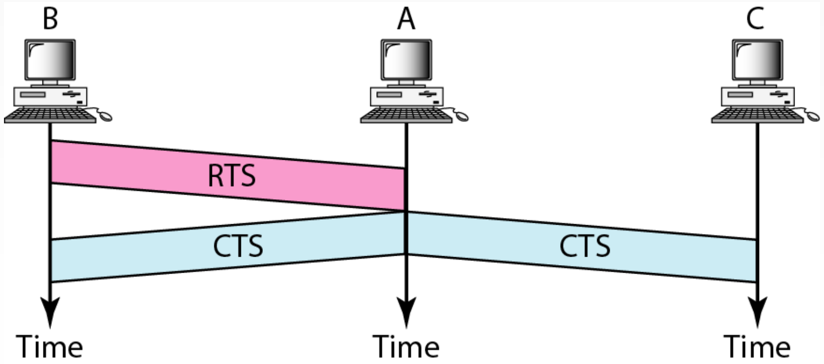
- Network allocation vector (NAV) shows how much time must pass before these stations are allowed to check the channel for idleness
- **Collision During handshaking**


DIFS
RTS
data
sender
SIFS
CTS
SIFS
SIFS
ACK
receiver
NAV (RTS)
DIFS
NAV (CTS)
data
other
stations
t
defer access
contention

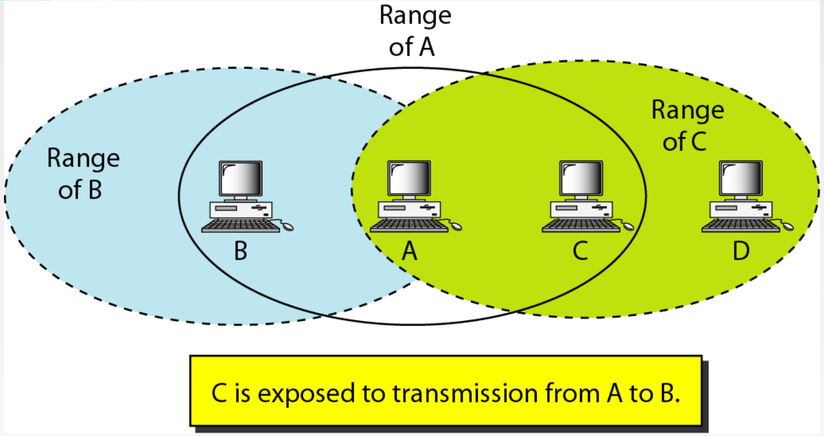
Hidden Station Problems

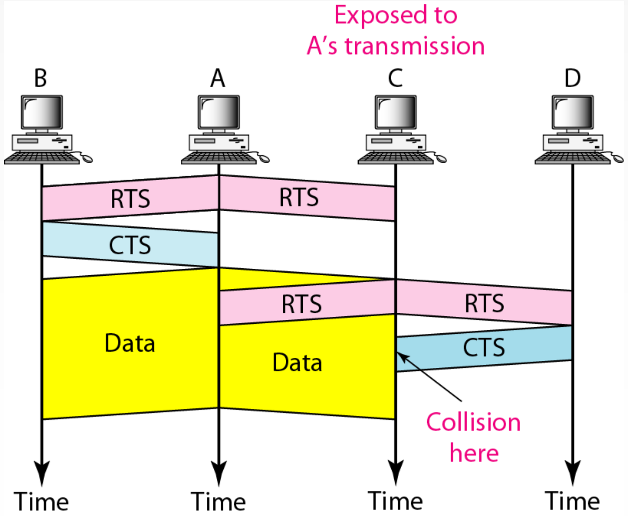
- The CTS frame in CSMA/CA handshake can prevent collision from a hidden station.





Exposed Station Problems

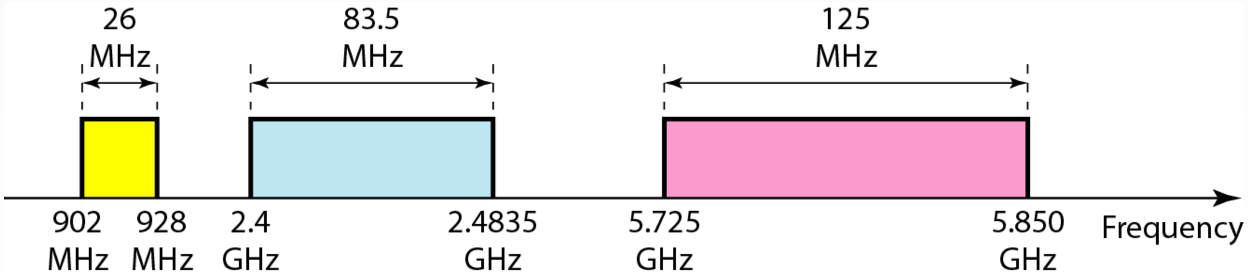




Physical Layer

IEEE	*Technique*	*Band*	*Modulation*	*Rate (Mbps)*
802.11	FHSS	2.4 GHz	FSK	1 and 2
	DSSS	2.4 GHz	PSK	1 and 2
		Infrared	PPM	1 and 2
802.11a	OFDM	5.725 GHz	PSK or QAM	6 to 54
802.11b	DSSS	2.4 GHz	PSK	5.5 and 11
802.11g	OFDM	2.4 GHz	Different	22 and 54

- Industrial, scientific, and medical (ISM) band which defines three unlicensed bands in three ranges 902-928 MHz, 2.400-2.4835 GHz, and 5.725-5.850 GHz



Bluetooth

Overview of Bluetooth History

- Bluetooth is a short-range wireless communications technology.
- Name of 10th century Danish King Harald Blatand who unified Denmark and Norway.
- 5 companies (Ericsson, Intel, IBM, Nokia & Toshiba) joined to form the Bluetooth Special Interest Group (SIG) in 1998.
- First specification (1.0A) released in July 1999.
- SIG promoter group expanded: 3Com, Lucent, Microsoft & Motorola
- IEEE 802.15.1

Technical Features

Connection Type	Spread Spectrum (Frequency Hopping) & Time Division Duplex (1600 hops/sec)
Spectrum	2.4 GHz ISM Open Band (79 MHz of spectrum = 79 channels) Bluetooth 4.0 uses 2 MHz spacing, which accommodates 40 channels
Modulation	GFSK
Transmission Power	1 mw – 100 mw
Data Rate	1 Mbps

Technical Features

Range	30 ft
Supported Stations	8 devices
Data Security –Authentication Key	128 bit key
Data Security –Encryption Key	8 -128 bits (configurable)
Module size	9 x 9 mm

Version	Data rate
1.2	1 Mbit/s
2.0 + EDR	3 Mbit/s
3.0 + HS	24 Mbit/s
4.0	24 Mbit/s

Class	Max. permitted power		Typ. range[1] (m)
	(mW)	(dBm)	
1	100	20	~100
2	2.5	4	~10
3	1	0	~1

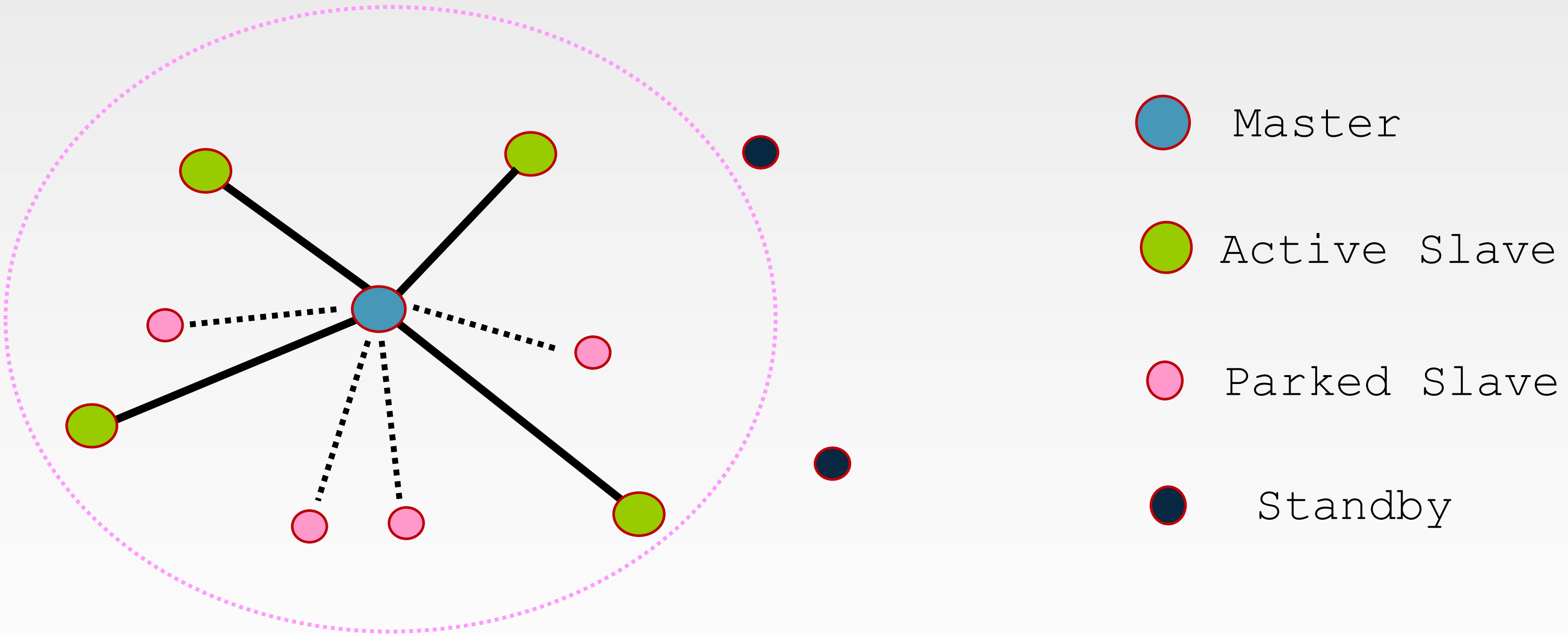
Typical Bluetooth Scenario

- Bluetooth will support wireless point-to-point and point-to-multipoint (broadcast) between devices in a piconet.

- Point to Point Link
  - Master - slave relationship

- **Piconet**
  - It is the network formed by a Master and one or more slaves (max 7)
  - Each piconet is defined by a different hopping channel to which users synchronize to
  - Each piconet has max capacity (Upto 24 Mbps)

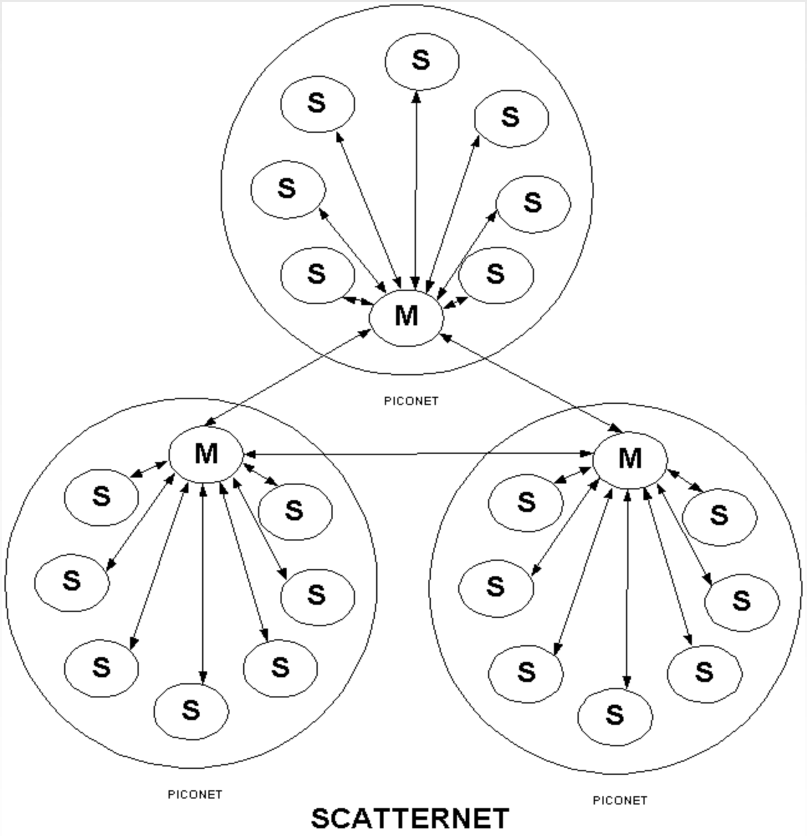
Piconet Structure



- All devices in piconet hop together.
- Master’s ID and master’s clock determines frequency hopping sequence & phase.

Ad-hoc Network - the Scatternet

- Inter-piconet communication
- Up to 10 piconets in a scatternet
- Multiple piconets can operate within same physical space
- This is an ad-hoc, peer to peer (P2P) network



Master - Slave Roles:

- The specification permits any bluetooth radio to assume either role (it may act as a master or slave)
- The role of master is it governs the synchronisation of the FHSS communication between devices.
- Each Piconet can only have one master
- Each device can be master of only one Piconet at a time
- Slaves in one Piconet can be masters in another
- Each Piconet has its own hopping pattern

Master - Slave Roles:

- A Master can communicate with up to 7 slaves (active) and up to 8 parked slaves.
- Slaves can be active or parked
- In parked state, slaves can only respond to activation from the master
- In active state,
  - all communication is between master and slave
  - direct slave-slave communication is not possible

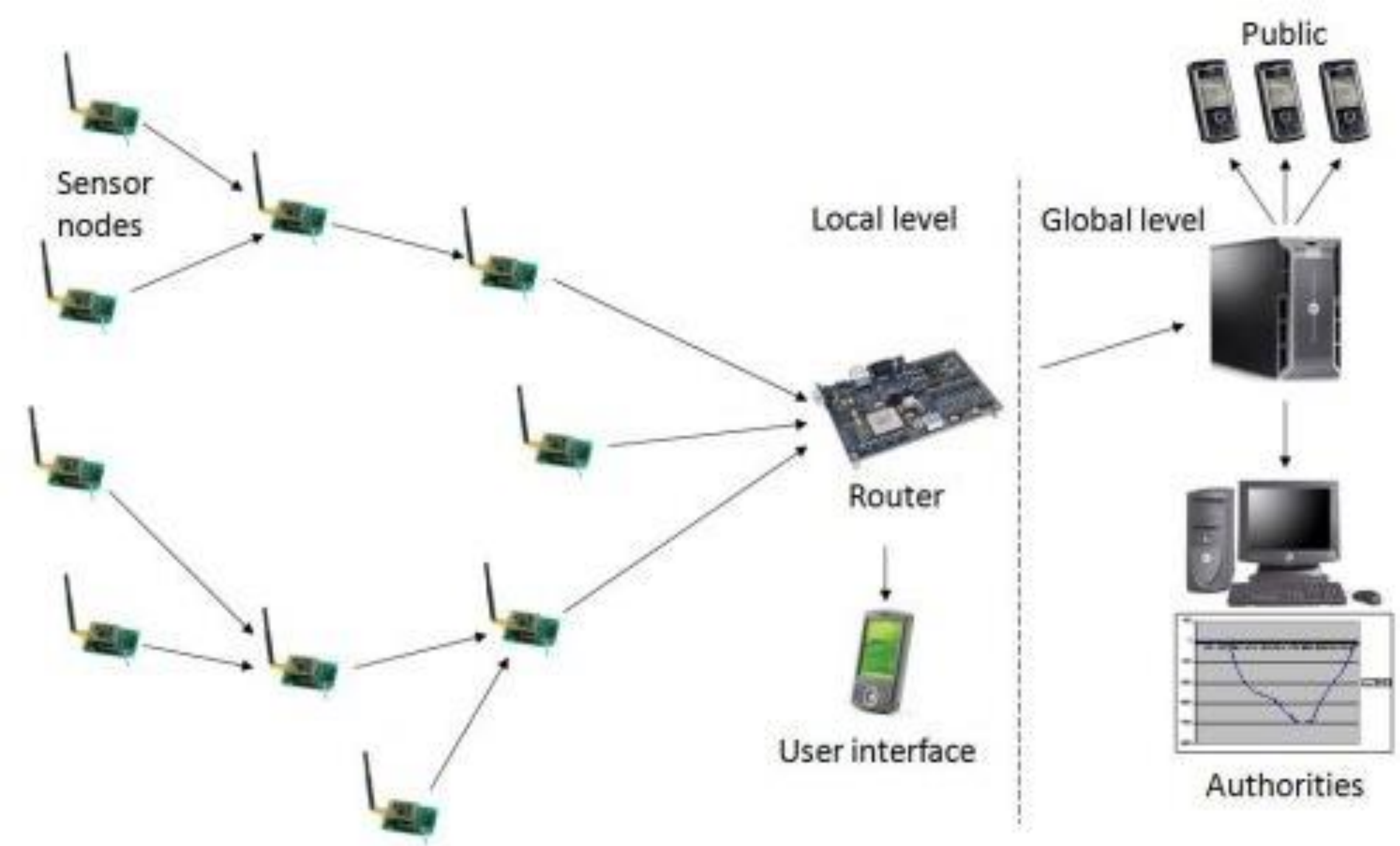
Wireless Sensor Networks:

- A network of generally low complex devices called nodes (motes) that
  - Sense any measurable parameter
  - Communicate the data through multiple hops to a sink (controller/coordinator/server)
- Combines the sensing, processing and networking over miniaturized embedded devices → sensor nodes
- The prime requirements:
  - Low Power
  - Low Cost
  - Scalable
  - Operate in ad hoc manner

Key characteristic that distinguishes WSN from other networks:

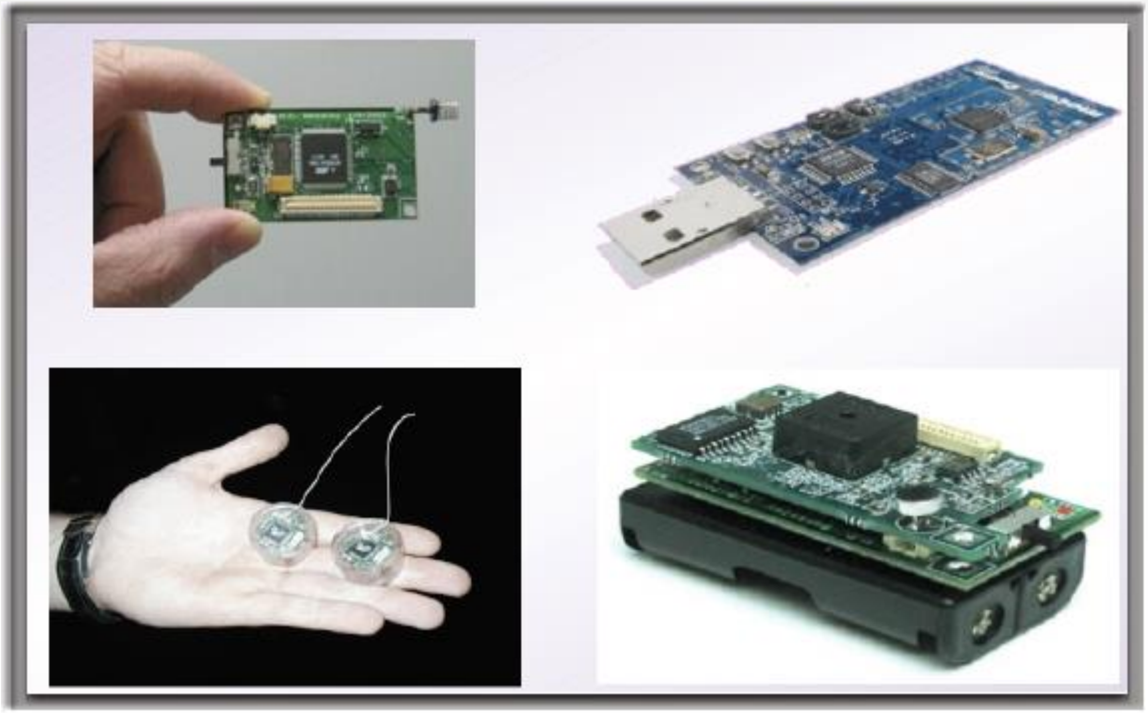
- Collect information from the physical environment
- Couple the end-users directly to the sensor measurements
- Provide information that is precisely localized (in spatio-temporal terms) according to the application demands
- Establish a bi-directional link with the physical space (remote & adaptable actuation based on the sensing stimulus)

A Multi Hop WSN:



WSN/IoT Nodes

- Node comprise of a processor, radio, storage, sensors and with embedded OS
- Connected to Servers via networks



Wireless Sensor Node Block Diagram

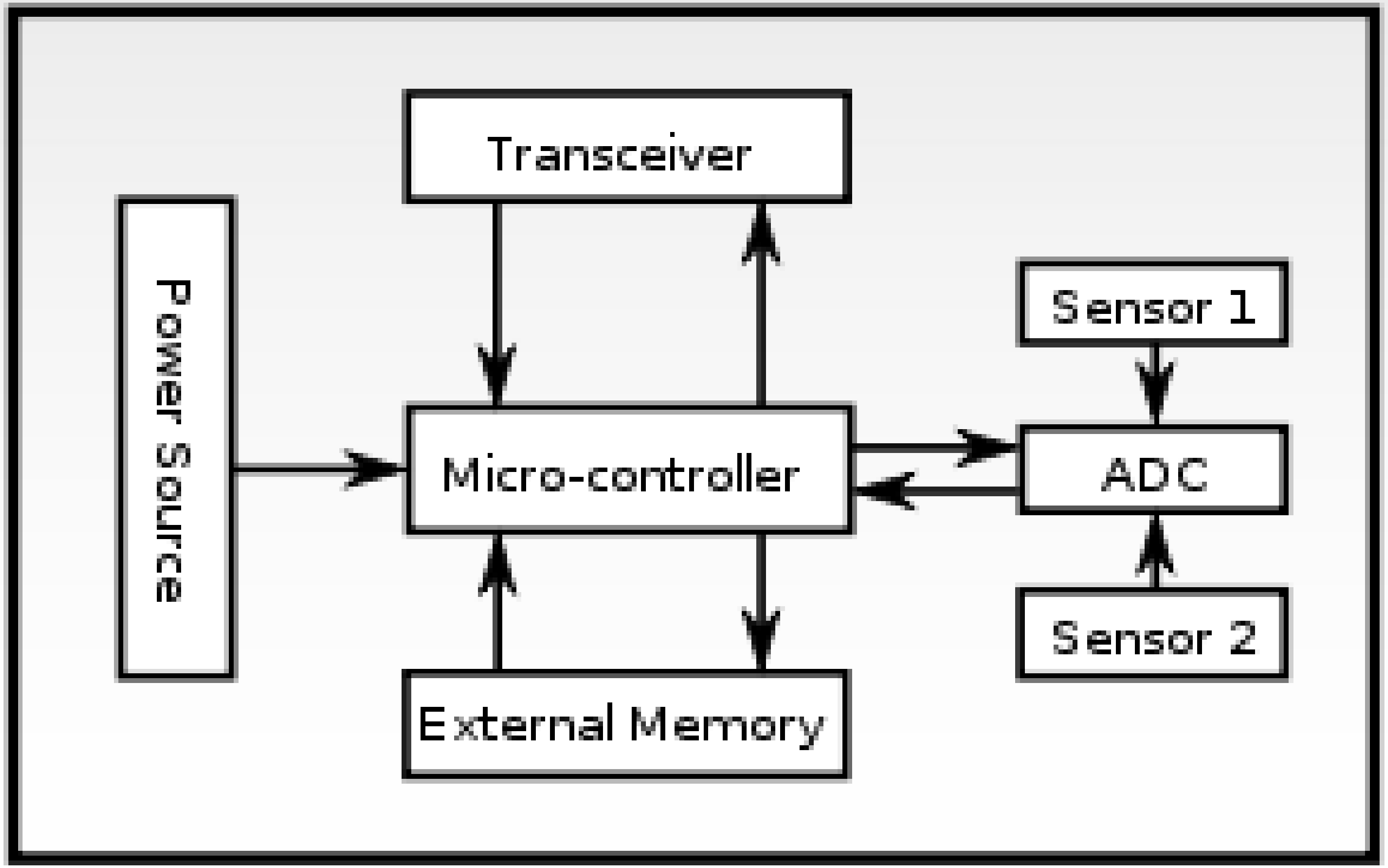


Table 1.1 Sensor and mesh nodes characteristics

		Sensor nodes	Mesh nodes
General	Target form factor	Small or tiny $O(mm^3)$	Larger $O(cm^3)$
	Antenna	Integrated	External
	Power consumption	O(mW)	O(W)
	Power	Small battery or energy harvesting	Unlimited due to external power source
	Price	Relatively cheap (a few dollars or less)	Relatively expensive ($50–$500 and up)
	RAM/ROM	Kbytes	Mbytes
	Processing power	Very limited	Relatively high
Network	Bandwidth	Low (a few Mbps and frequently less)	Relatively high (several Mbps)
	Interface(s)	Single, often proprietary	Single or multiple, often standardized
	Max packet size	Small O (bytes)	Larger O (kbytes)
	IP capabilities	Limited or none	IP capable
	Sleeping schemes	Often used	Rarely used
	Delay per hop	O (ms) to several seconds	O (ms)
	Mobility	None to highly mobile	Most often limited or none

Types of WSN:

- Terrestrial WSNs
  - Deployed on particular area
  - Two Types: Structured and Unstructured
  - ***Structured WSN:***
    - All or some of the nodes are placed in preplanned manner
    - Optimization of number of node
    - Provide full coverage
    - Lower maintenance and management cost
    - Node failures in low density deployment may create uncovered regions
  - ***Unstructured WSN:***
    - Nodes deployed in ad hoc manner
    - Once deployed the network is left unattended to perform monitoring and reporting
    - Difficult network management

Types of WSN:

- Underground WSNs
  - Consist of a number of sensor nodes buried underground or in a cave or mine used to monitor underground conditions
  - More expensive than a terrestrial WSN in terms of equipment, deployment, and maintenance
  - Challenges
    - Reliable communication through soil, rocks, water, and other mineral contents.
    - High levels of signal attenuation.
- Underwater Acoustic Sensor Networks (UASNs)
  - Provides new opportunities to explore the oceans, weather forecasting, understanding of the environmental issues such as climate change, life of ocean animals
  - Applications: Monitoring Oil rigs, Tsunami, Earthquakes, Water Salinity, Temperature, Pressure, Speed, etc
  - Agro Project: University of California, San Diego (www.argo.ucsd.edu)

Types of WSN:

- Underwater Acoustic Sensor Networks (UASNs)
  - Radio signals attenuate rapidly, hence short distance communication
  - Optical signals scatter and cannot travel far in adverse conditions
  - On the other hand, **acoustic signals** attenuate less and they are able to travel further distances than radio signals and optical signals.

  Challenges :

  - Low Bandwidth of the acoustic channel hence low data rates
  - Low link quality, because of multi-path propagation and the time-variability of the medium.
  - Speed of sound is slow (~1500 m/s) yielding large propagation delay.
  - Relative motion of transmitter/receiver may create the Doppler effect.
  - UASNs are also energy limited similar to other WSNs.

Types of WSN:

- Multimedia WSNs
  - High bandwidth demand
  - High energy consumption
  - Quality of service (QoS) provisioning
  - Data processing and compressing techniques
  - Cross-layer design
- Mobile WSNs:
  - E.g. Swarm of drones (aerial/underwater)
  - Group of soldiers in wars/surgical strikes

Sensor Network Constraints:

- Small Devices in large numbers
- Often wireless have limited power
  - Needs Ad-hoc networking approach
- Interoperability among different sensor networks and seamless integration with existing IP networks

Applications of WSN:

- Environmental Monitoring:
  - Floods, earthquakes, volcano, fire, structural integrity , etc
- Health Care:
  - Nightshift / backup assistant, acute patient monitoring, continuous care, etc
- Logistics:
  - Target tracking, Warehouse tracking, Management at departmental stores, Smart storage
- Agriculture:
  - Green Houses, Metrological Station Network , Compost, etc
  - M2M Applications, Temperature, etc
- Retails / Transportation / Home and Office / Security / Emergencies

Standards for WSN:

- IEEE 802.15.4 (ZigBee)
- IEEE 802.15.4 2006 (LR-WPANs)

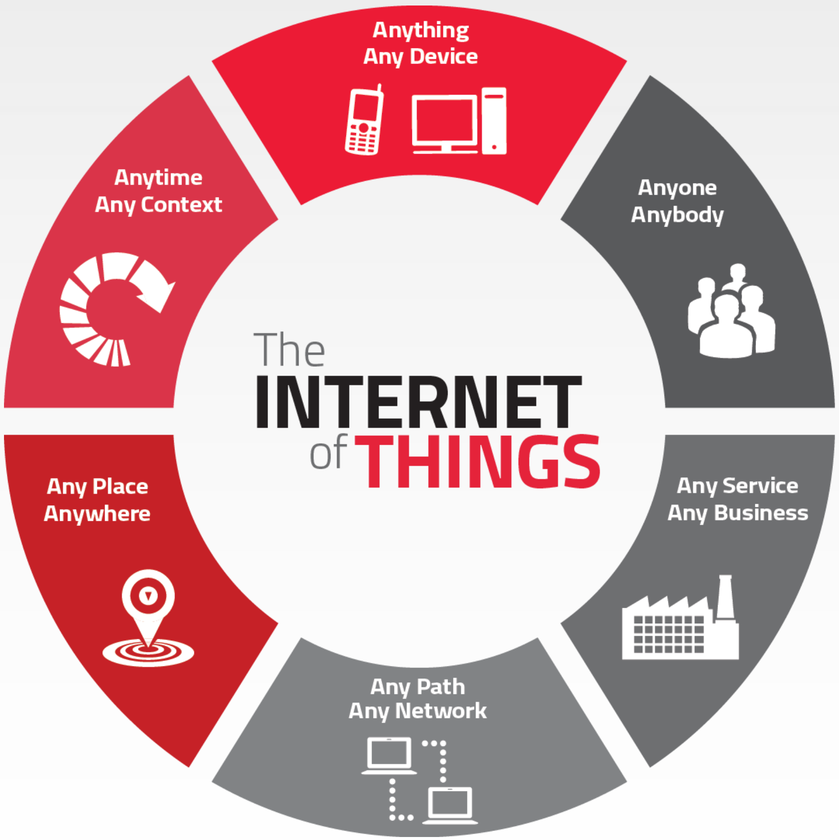
- LPWANs

- IEEE 802.11 Wireless Local Area Networks (WLANs)
- IEEE 802.15.1 (Bluetooth)

- Operated in unlicensed band (except few LPWANs Tech)
  - Interfere each other if not designed properly

Introduction to Internet of Things

Internet of Things (IoT):

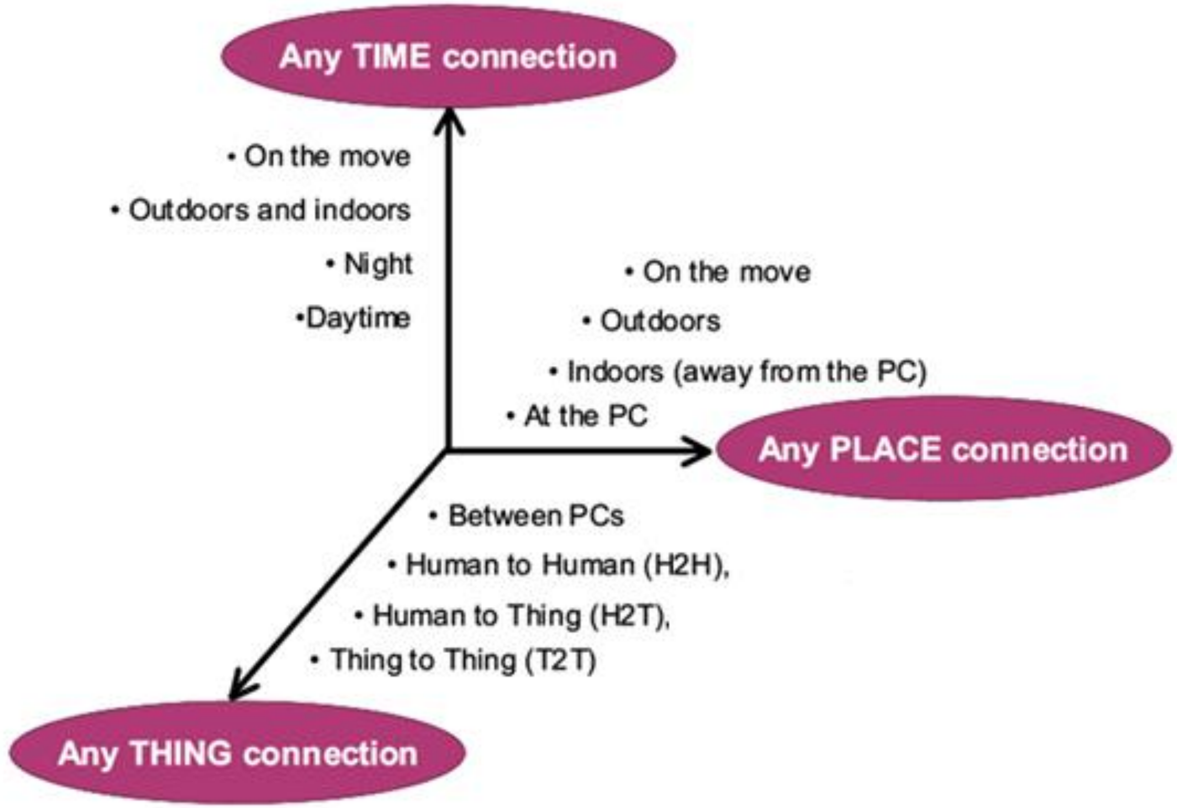


- Internet appears every where connecting people - *Internet of People*

- ***IoT connect things - Internet of Things***

Internet of Things:

- For any time, any place connectivity for anyone, we will now have connectivity for anything



Source: ITU adapted from Nomura Research Institute

Internet of Things:

- Represents the first true evolution of the Internet
  - More machines than people
  - More mobiles than fixed connections
  - Sensor based new architectures

Smart Cities:

- Smart Parking
- Structural health Monitoring
- Noise and Pollution
- Water Management
- Electromagnetic Field Levels Measurement
- Traffic Congestion Monitoring
- Smart Lighting
- Waste Management
- Smart Roads

Smart Environment:

- Forest Fire Detection
- Air Pollution Control
- Water Management
- Snow Level Monitoring
- Landslide and Avalanche Prevention Monitoring
- Earthquake Early Detection
- Wild Life Monitoring and Protection

Smart Water:

- Potable water monitoring
- Chemical leakage detection in rivers
- Swimming pool remote measurement
- Pollution levels in the sea
- Water Leakages
- River Floods

Smart Metering:

- Smart Grid
- Tank Level
- Electricity
- Photovoltaic Installations
- Water Flow
- Silos Stock Calculation

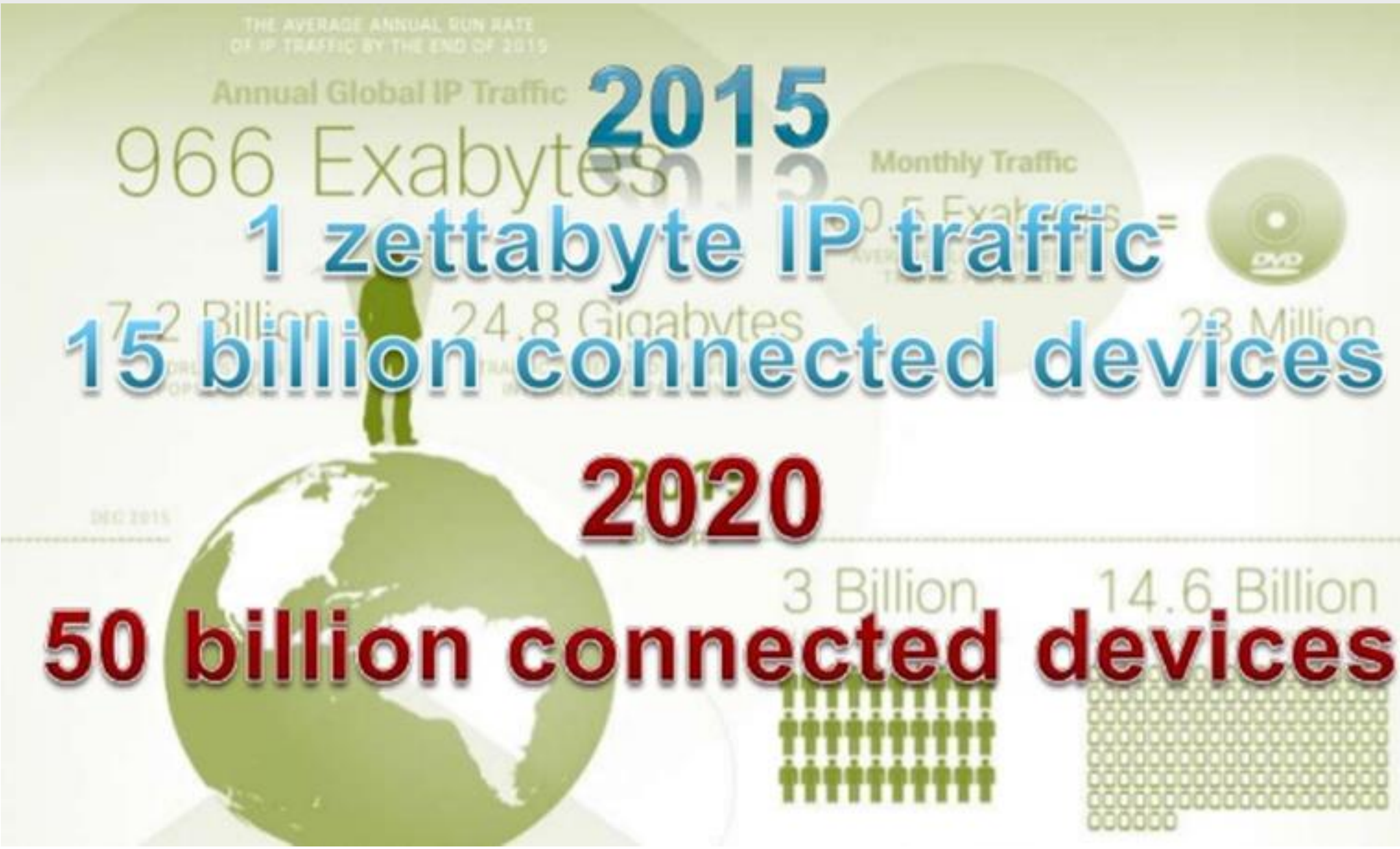
Security & Emergencies

- Perimeter Access Control
- Liquid Presence
- Radiation Levels
- Explosive and Hazardous Gases

Many More Applications…

- Retail
- Logistics
- Industrial Control
- Smart Agriculture
- Smart Animal Farming
- Domestic & Home Automation
- eHealth

Internet in 2015:



2015

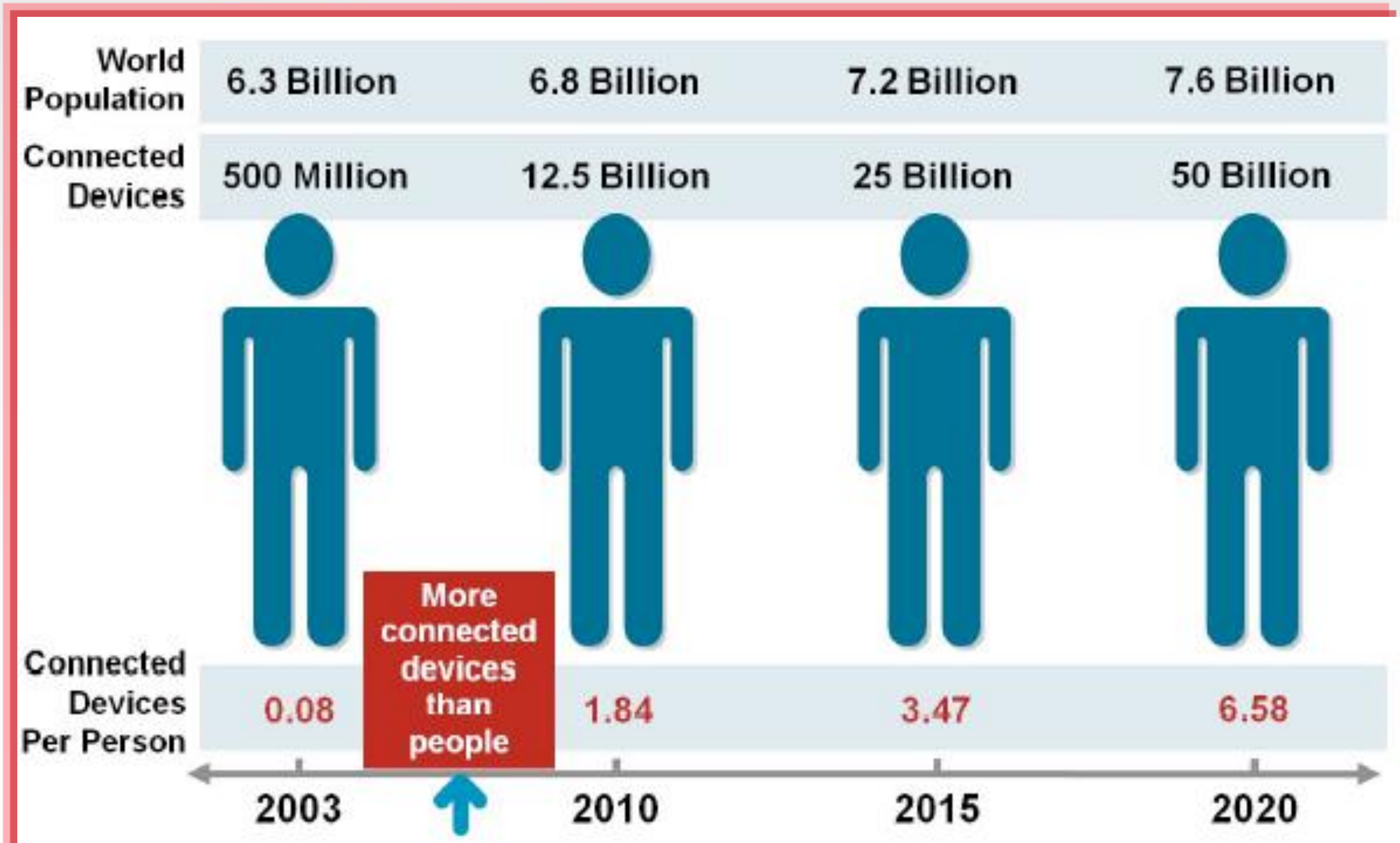
1 zettabyte IP traffic

15 billion connected devices

2020

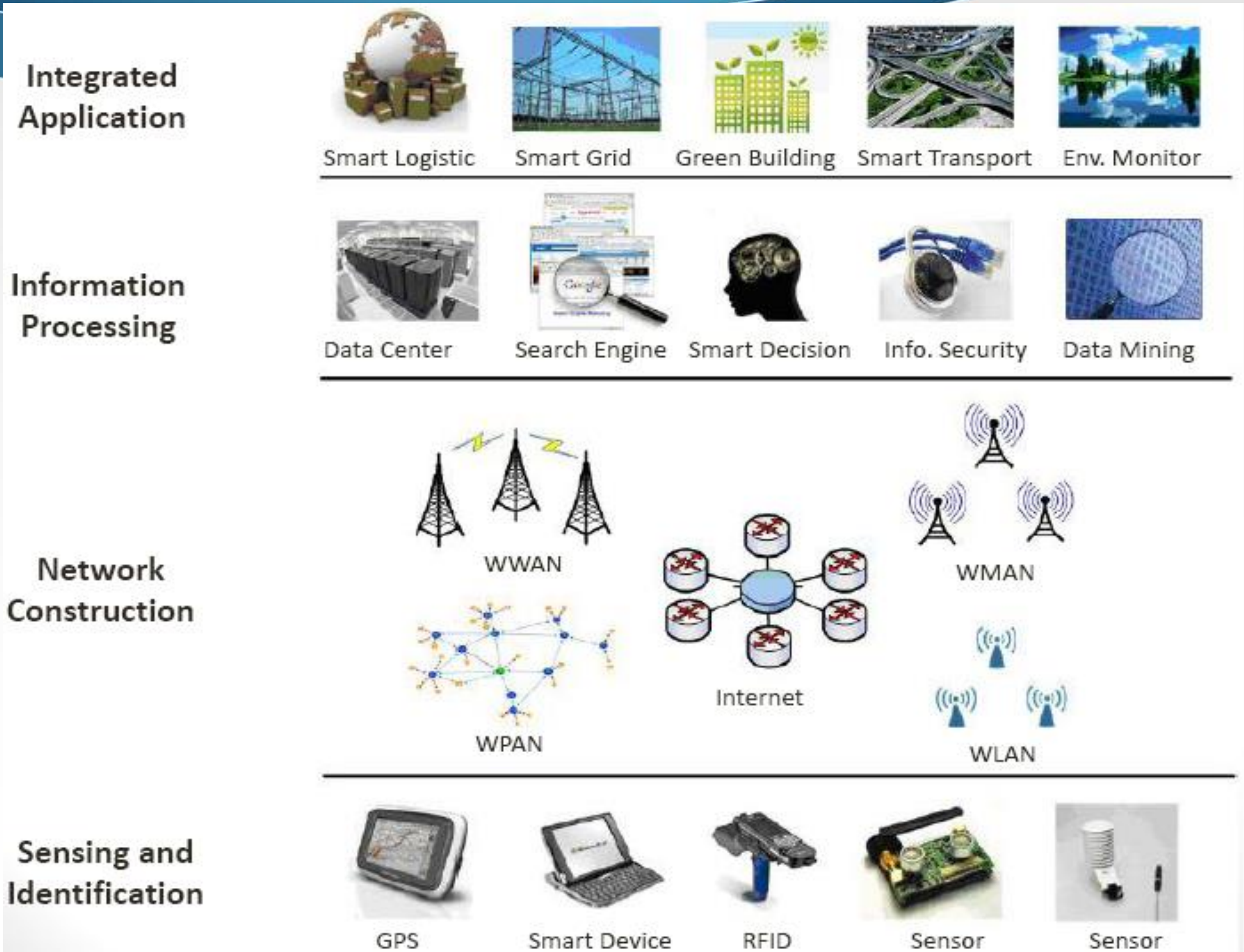
50 billion connected devices

Connected Devices Per Person:



Source: Cisco IBSG, April 2011

Four Layer Model for IoT:



IoT and Wireless Sensor Networks:

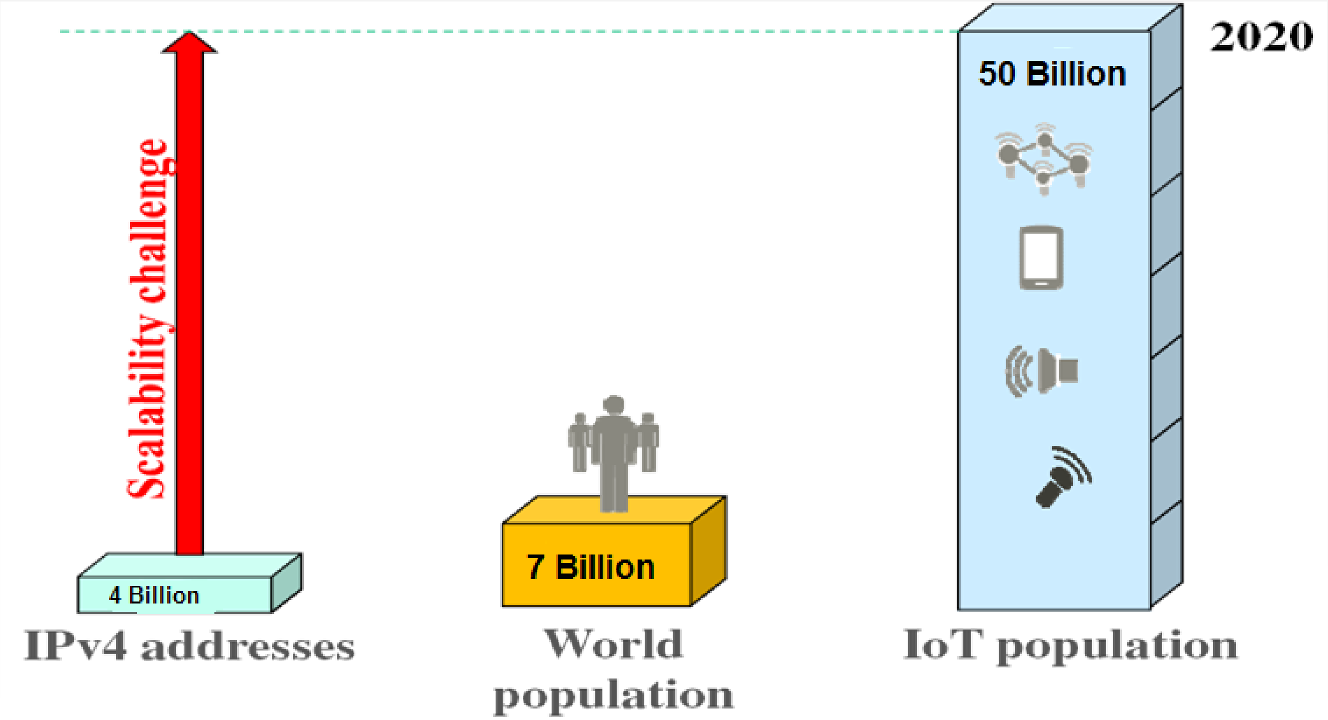
- IoT is not WSN
- IoT contains WSN
- IoT > WSN
- Things are diverse:
  - They might be individuals/entities like water, soldiers, trees…
  - They can be set of individuals/entities like ocean, battlefields, forests…

IPv4 in WSN/IoT:

- Designed for networks without considering WSN constraints
- Lack of IPv4 address space (32 bit addresses)
- Too many entries in routing tables of the routers
- Some mechanisms at Layer 3 are developed to incorporate in wireless sensor networks
  - Big packet size
  - Power consuming

Huge Demand for Addresses

- Today most users are become ‘Internet homeless’ users, unaware that they are sharing potentially temporary public IP address with others



IPv4 ⇨ IPv6

IPv4 $= 2^{32}$	IPv6 $= 2^{128}$
$= 4.3\times10^{9}$ addresses	**$= 3.4\times10^{38}$ addresses**
= 4,294,967,296	=340,282,366,920,938,463,463,374,607,431,768,211,456
Ex: 192.168.0.1	Ex: 2001:21AB:1234:1000:CDEF:0123:4567:1203

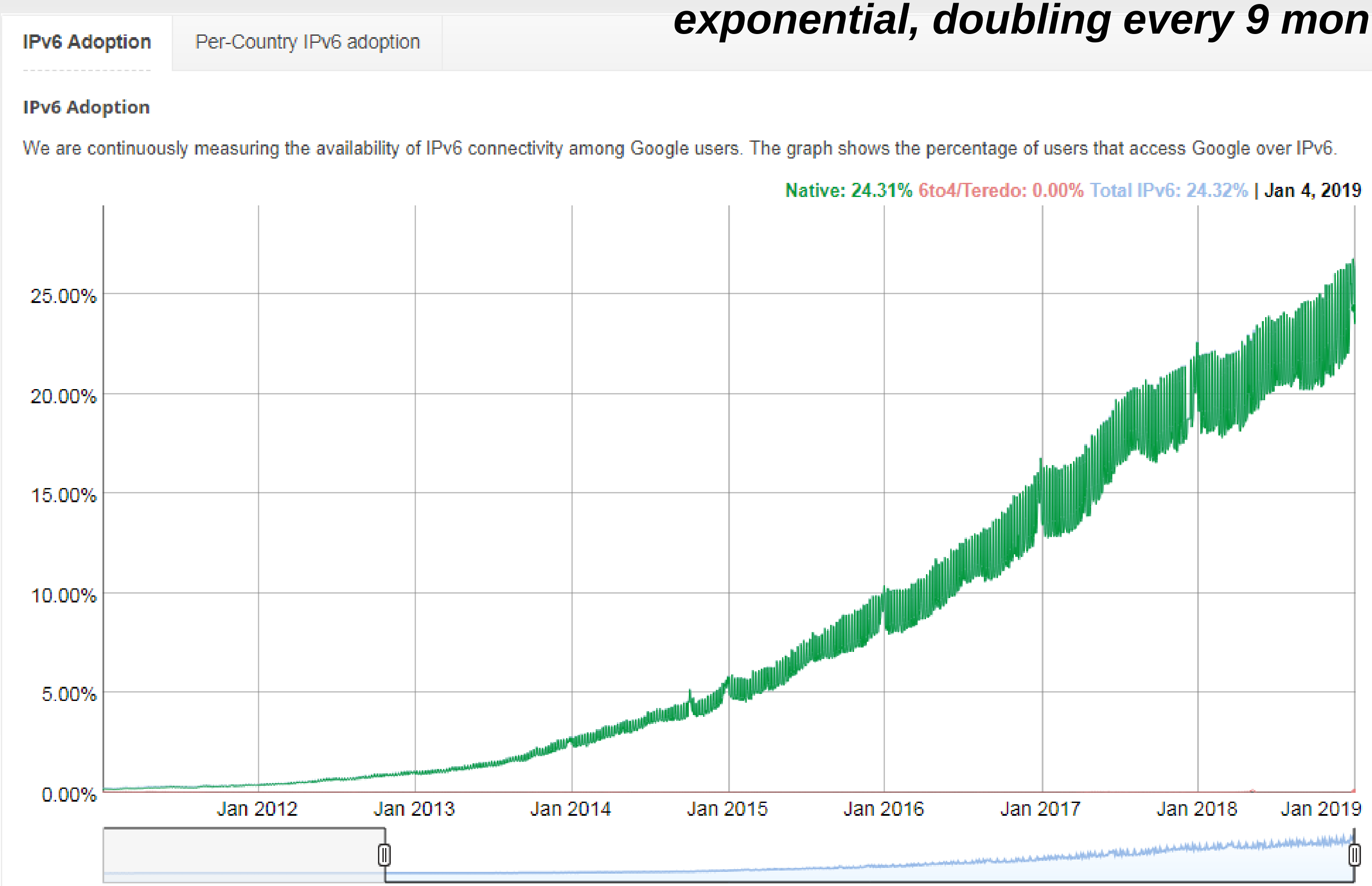
High Scalability of IPv6

- Natural Answer for emerging IoT

4.3	x	10^9	IPv4 addresses
7	x	10^9	Human beings
5	x	10^{10}	IoT devices
8.6	x	10^{11}	Neurons in a brain
5.1	x	10^{14}	Square meters on the Earth surface
		10^{15}	Synaps in a brain
5.1	x	10^{20}	Square milimeters on the Earth
7	x	10^{20}	Grains of sand on earth
~		10^{23}	Stars in the universe
7	x	10^{27}	Atoms in one human body
1.4	x	10^{37}	Atoms in all human bodies
3.4	**×**	**10^{38}**	**IPv6 addresses**

Penetration IPv6 (Google Stat):

According to Google, IPv6 adoption will be exponential, doubling every 9 months.



Moving towards IPv6:

- Extended address space to support large number of devices (with multiple interfaces) as required in IoTs
  - Solves NAT barrier
- Mobile devices with different link layers with tiny stacks
  - For example, Contiki requires not more than 11.5 Kbytes.
- Auto-configuration
- Remote Network Management
- End to End connectivity
- Strong Network Security

Emerging Protocols for IoT:

- IPv6 over WPAN (6LowPAN)
  - Lighter version of IPv6 for constrained nodes and networks
- Constrained Application Protocol (CoAP) providing a light substitute to *HTTP*
- *LPWAN Technologies*: LoRa, SIGFOX, WEIGHTLESS, NB-IoT, LTE – M Type Communication
- Newly formed IETF Work Group:
  - 6TiSCH (Time Slotted Channel Hopping)
  - 6lo (IPv6 over Networks of Resource-constrained Nodes)

ZigBee

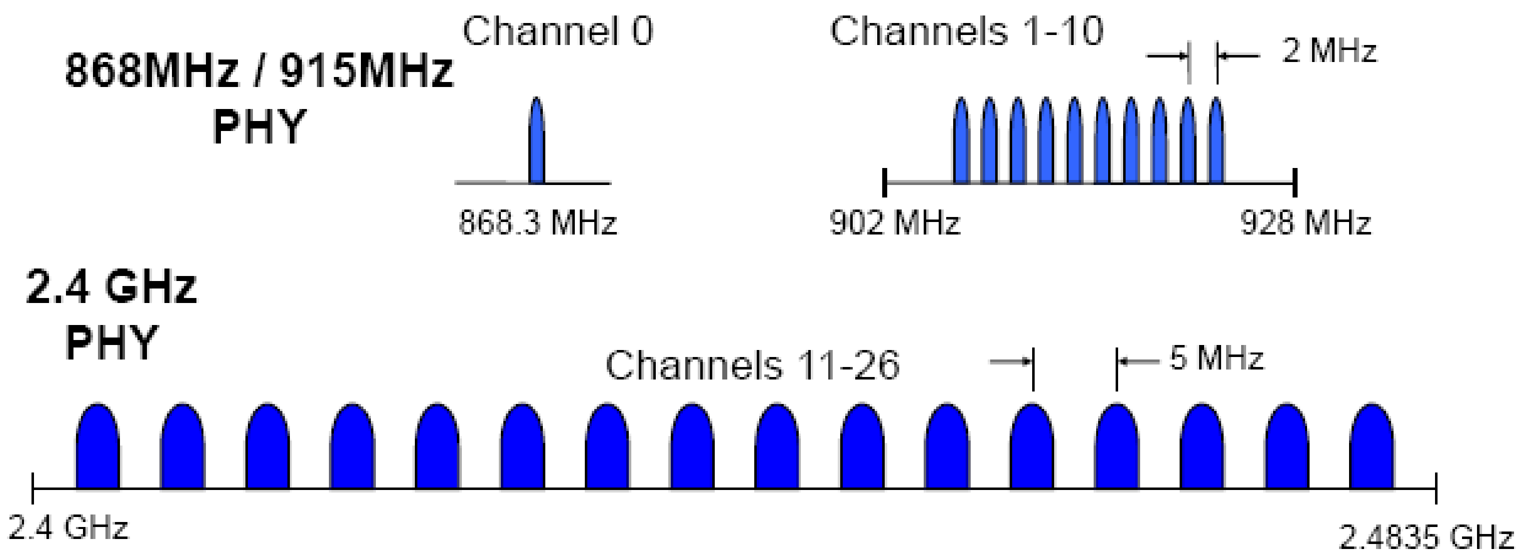
Introduction

- ZigBee is a technological standard designed for control and sensor networks
- Based on the IEEE 802.15.4 Standard
- Created by the ZigBee Alliance

Standards for WSN:

- IEEE 802.11 Wireless Local Area Networks (WLANs)
- IEEE 802.15.1 (Bluetooth)
- IEEE 802.15.4 (ZigBee)
- IEEE 802.15.4 2006 (LR-WPANs)
- All are operated in unlicensed band
  - Interfere each other if not designed properly

IEEE 802.15.4 2006:



Frequency Bands of Operation

- 16 channels in the 2.4GHz ISM band
- 10 channels in the 915MHz ISM band
- 1 channel in the European 868MHz band

Transmit Power

- Capable of at least 1 mW

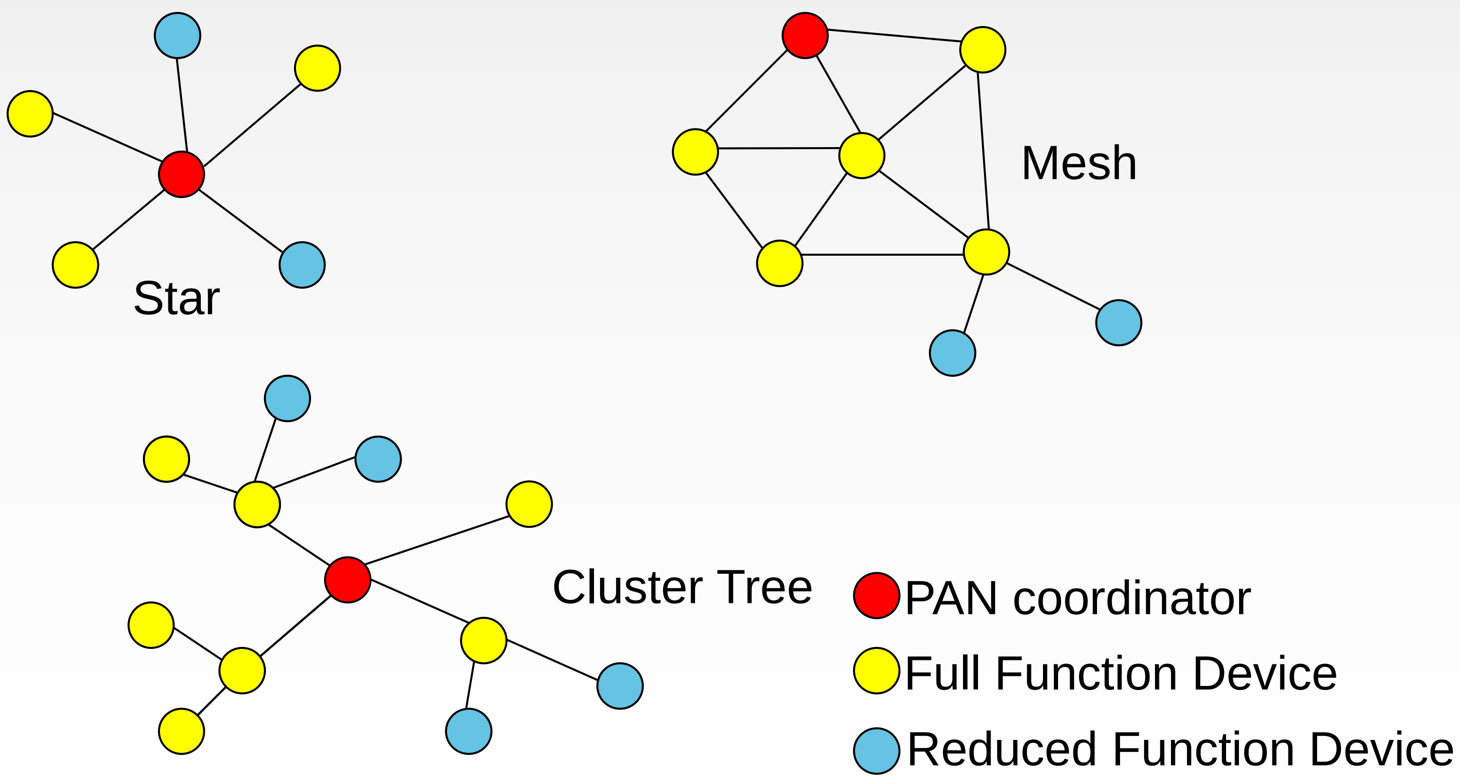
Receiver Sensitivity (Packet Error Rate <1%)

- -85 dBm @ 2.4 GHz band
- -92 dBm @ 868/915 MHz band

Important Features of IEEE 802.15.4 2006:

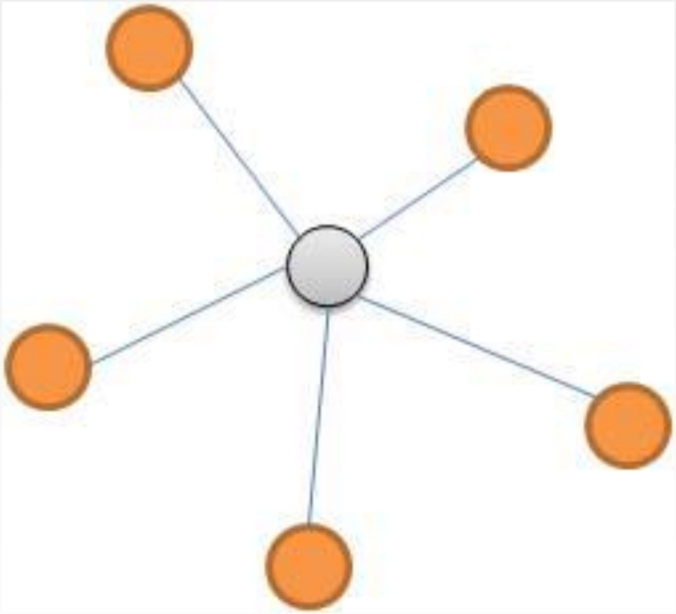
- Over-the-air data rates of 20 kbps - 250 kbps
- Star or peer-to-peer operation
- Allocated 16-bit short or 64-bit extended addresses
- CSMA/CA channel access
- Option for by reservation of guaranteed time slots (GTS)
- Integrated support for secure communications
- Power management functions such as RSSI and LQI

ZigBee Network Topologies



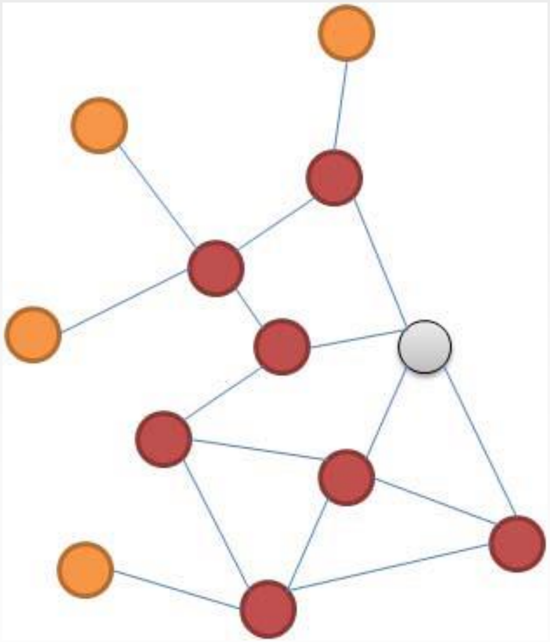
ZigBee Network Topologies

- Star Topology
  - Advantage
    - Easy to synchronize
    - Low latency
  - Disadvantage
    - Small scale



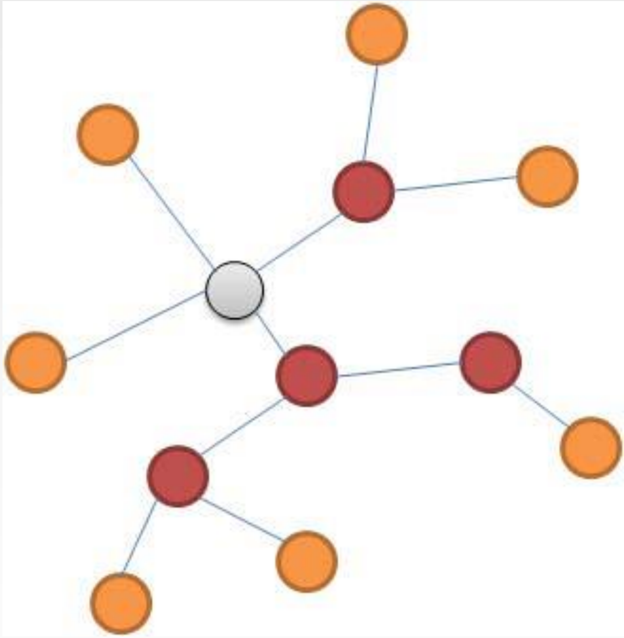
ZigBee Network Topologies

- Mesh Topology
  - Advantage
    - Robust multihop communication
    - Network is more flexible
    - Lower latency
  - Disadvantage
    - Route discovery is costly
    - Needs storage for routing table



ZigBee Network Topologies

- Cluster Tree
  - Advantage
    - Low routing cost
    - Allow multihop communication
  - Disadvantage
    - Route reconstruction is costly
    - Latency may be quite long



ZigBee and Bluetooth Comparison

- *Optimized for different applications*
  - ZigBee
    - Smaller packets over large network
    - Mostly Static networks with many, infrequently used devices
    - Home automation, toys, remote controls, industrial control etc.
  - Bluetooth
    - Larger packets over small network
    - Ad-hoc networks
    - File transfer
    - Graphics, pictures, hands free audio
    - Mobile phones, headsets, etc.

ZigBee and Bluetooth Comparison

Feature(s)	Bluetooth	ZigBee
Power Profile	days	years
Complexity	complex	Simple
Nodes/Master	8	64K
Latency	Low	High
Range	10m	70m ~ 300m
Extendibility	no	Yes
Data Rate	1 Mbps	250 Kbps
Security	64bit, 128bit	128bit AES and Application Layer