COMP90018 Mobile Networks

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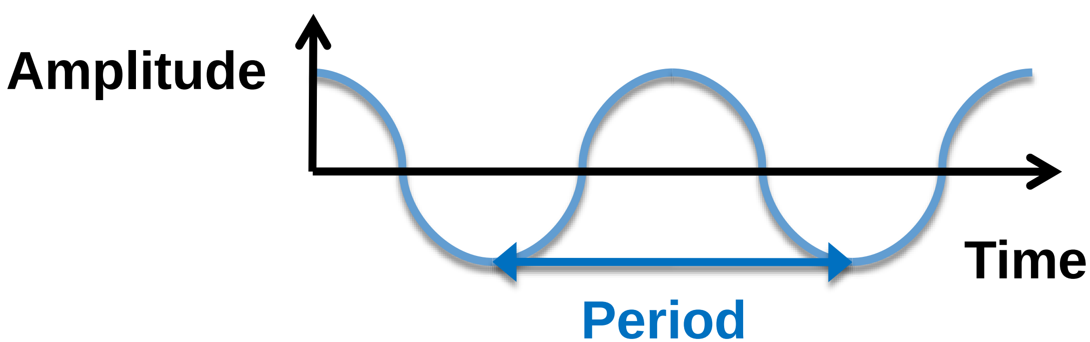
Wireless Wide Area Networks

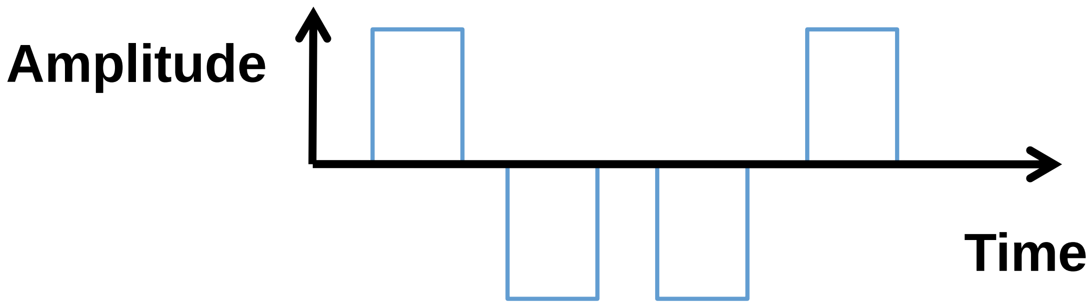
Fundamentals I

- **Analog signals**
  - Continuous electrical signals varying in time
  - Usually analog signals are not smooth waveforms
  - Voice overlays carrier signal
  - Used in 1st generation wireless signals



Fundamentals II

- **Digital signals**
  - Use of analog signals to transmit numbers
  - Conversion into bits
  - Transmission: streams of 1s and 0s
  - Used in all 2nd generation networks



"9" in 4 bit representation

Benefits of Digital Networks I

- **Efficiency**
  - Higher data transfer than analog networks
  - Enables compression for higher efficiency
  - Smaller power consumption
- **Security**
  - Simple eavesdropping for analog signals with radio tuner
  - Even true for encrypted packets on analog networks
  - Digital networks: encryption of different strengths

Benefits of Digital Networks II

- **Degradation and restoration**
  - Degraded signals can be restored because each bit is either 0 or 1
  - Leads to better sound quality with less interference
- **Error detection**
  - Parity bit signals if transmission was successful
  - Otherwise: retransmission or even error correction
- **Features**
  - Caller ID and call answer
  - Data traffic

Switching Mechanisms

- **Circuit switching**
  - Establish a physical connection between sender and receiver
  - Used for landline telephone networks
  - Good voice but inefficient for data transmission
  - Lost connection results in long connection times
- **Packet switching**
  - Share a connection between users
  - Divide data into small units with a destination address
  - Receiver restores original data format
  - No dedicated connection is established (quick)
  - Basis for 3G networks

Signal Propagation

Transmission range

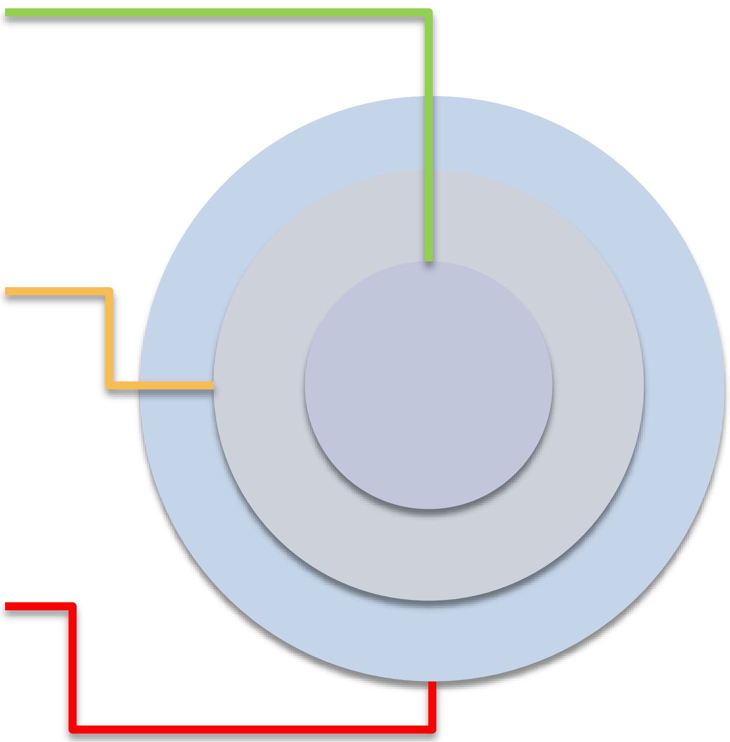
- Communication with low errors

Detection range

- Detection but no communication
  (or with too many errors)

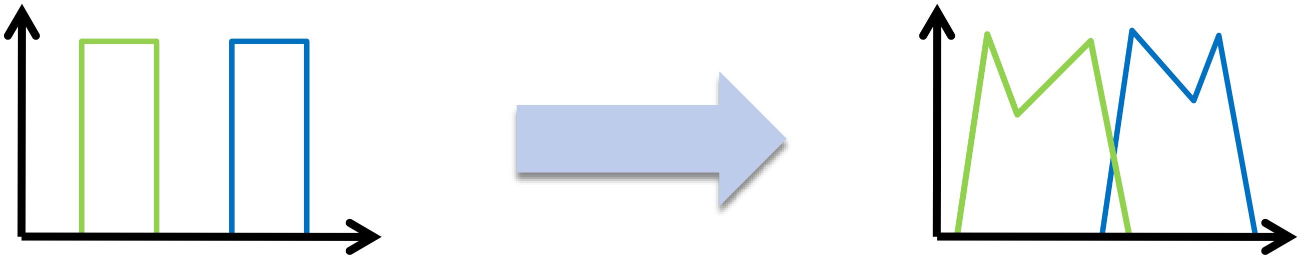
Interference range

- Signal cannot be detected
- Signal is part of the background noise



Issues in Wireless Transmission

- **Problems for wave propagation**
  - Large objects: shadowing & reflection (important indoors)
  - Small objects -> signal diffusion (scattering)
  - Large edges and corners -> signal deviation (diffraction)
  - Variation in medium density -> signal change and reflection (refraction)
- **Multipath propagation**
  - Signal takes different paths between sender and mobile device

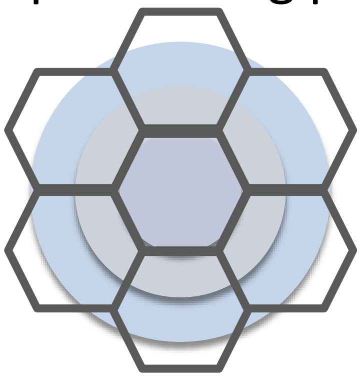


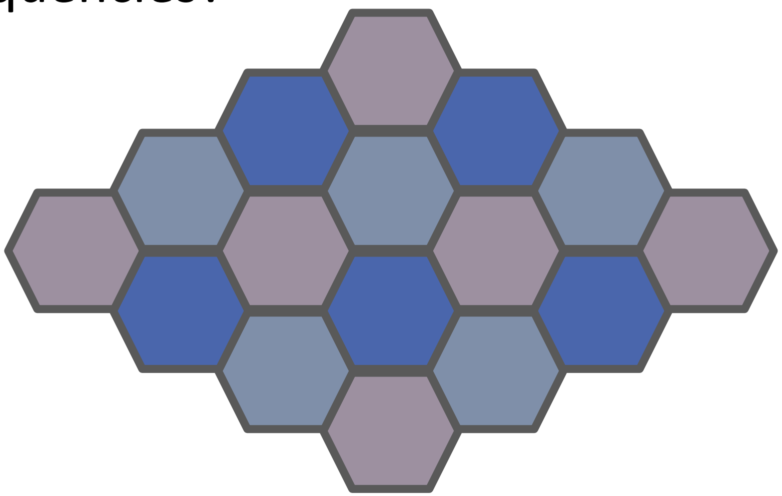
Multiplexing

- **Idea**
  - Multiple channels share one medium with minimal interference
- **Multiplexing in 4 dimensions**
  - Space
  - Frequency
  - Time
  - Code
- **Guard spaces**
  - Reduce risk of interference between channels

Space Division Multiplexing

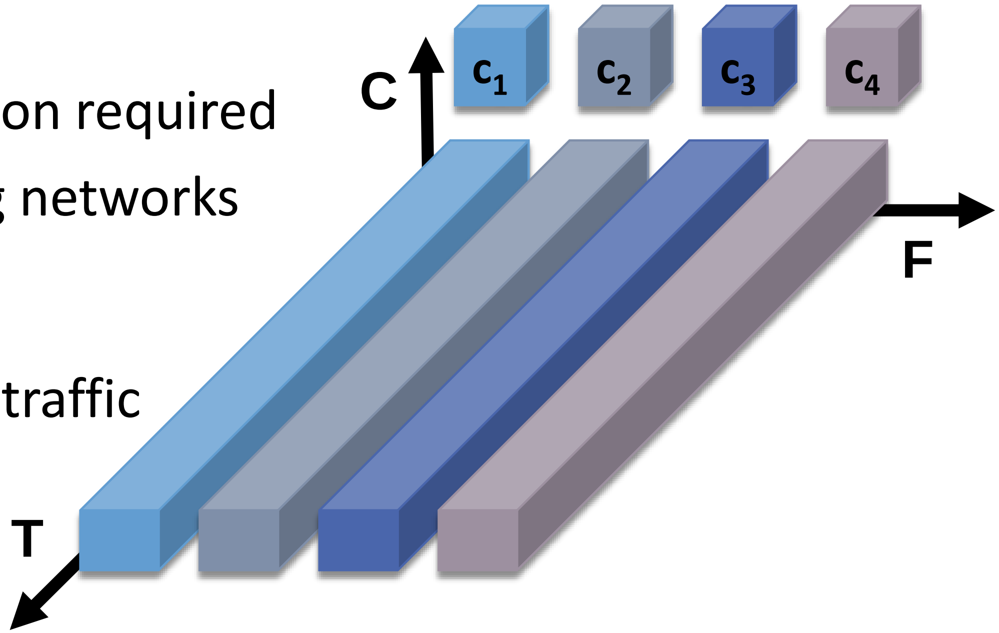
- **SDM**
  - Communication using a single channel
  - Space channels physically apart to avoid interference
- **Cellular network**
  - Reuse frequencies if certain distance between the base stations
  - How often can we reuse frequencies?
  - Graph coloring problem





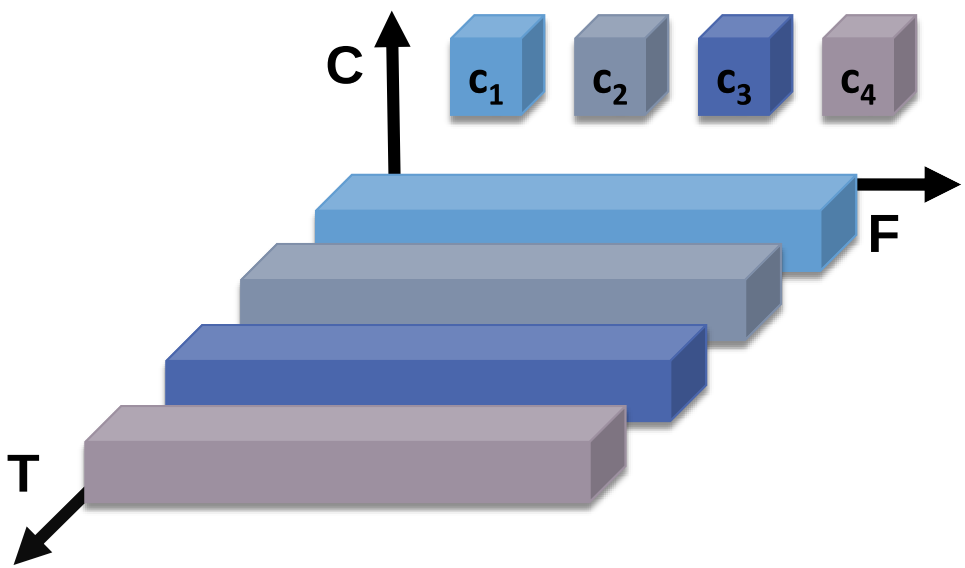
Frequency Division Multiplexing

- **FDM**
  - Division of spectrum into smaller non-overlapping frequency bands with guard spaces in between to avoid overlapping
  - Channel gets band of the spectrum for the whole time
- **Advantages**
  - No dynamic coordination required
  - Can be used for analog networks
- **Disadvantages**
  - Waste of bandwidth if traffic distributed unevenly
  - Guard spaces



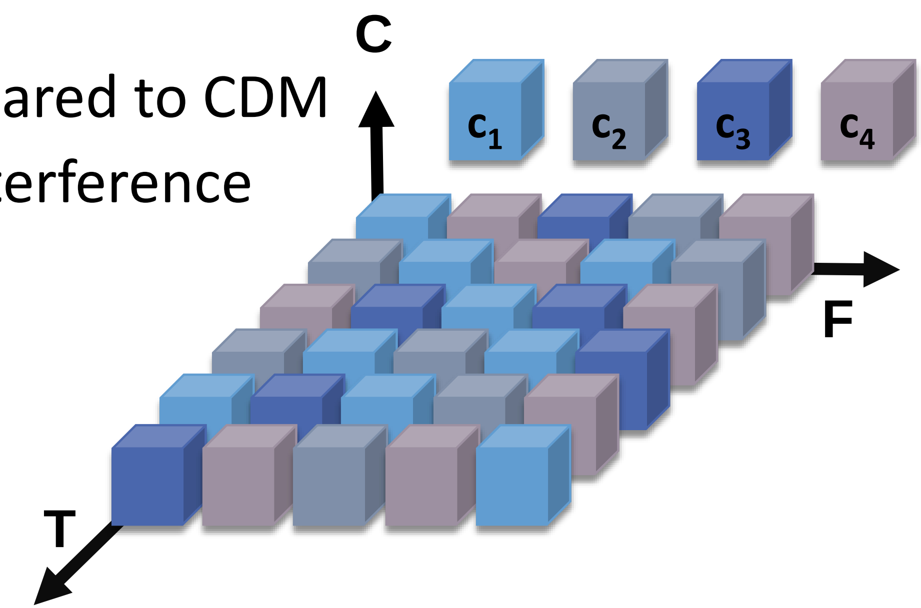
Time Division Multiplex

- TDM
  - A channel gets the whole spectrum for a short time
  - All channels use same frequency at different times
  - Co-channel interference: overlap of transmissions
- Advantage
  - High throughput for many channels
- Disadvantage
  - Precise clock synchronisation



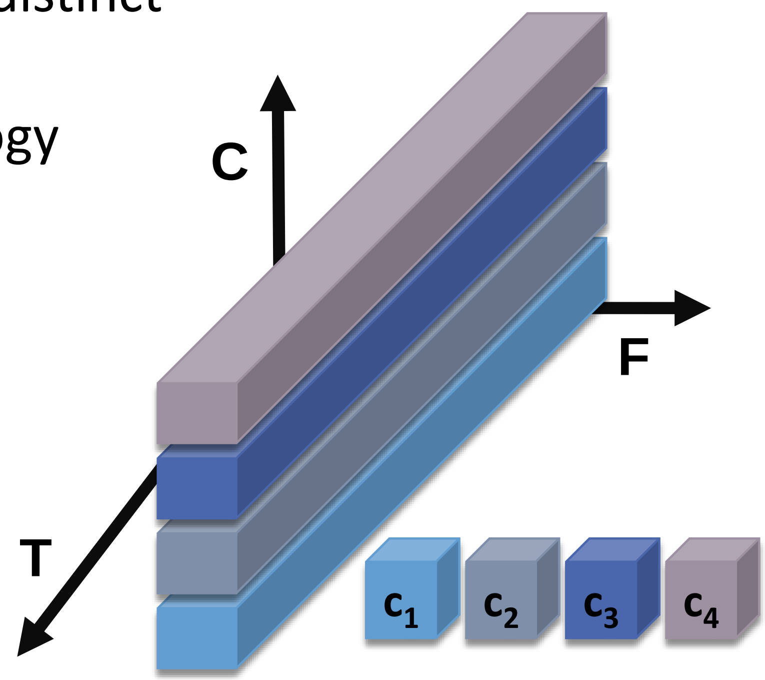
Combining FDM & TDM

- **FDM/TDM**
  - Each channel gets a certain frequency band for a certain amount of time
  - More efficient use of resources
- **Advantage**
  - Higher data rates compared to CDM
  - More robust against interference and tapping
- **Disadvantage**
  - Precise clock synchronisation



Code Division Multiplex

- **CDM**
  - Each channel has a unique code (chipping sequence)
  - All channels use the same frequency
  - Each code must be sufficiently distinct for appropriate guard spaces
  - Uses spread spectrum technology
- **Advantage**
  - No coordination and synchronization required
  - Bandwidth efficient
- **Disadvantage**
  - Lower user data rates



Wireless Personal Area Networks

Overview of Wireless Networks

- 4 types of networks

Type	Coverage	Function	Cost	Through put	Standards
WPAN	Personal space, 10 m	Cable replacement	Very low	0.1 Mbps – 4 Mbps	IrDA, 802.15, Bluetooth
WLAN	Building, 100 m	Extension/ alternative to wired LAN	Low – medium	1 Mbps – 540 Mbps	802.11 a, b, g, n, ac
WWAN	City or country	Extension of LAN	Medium – high	8 Kbps – 2 Mbps	GSM, TDMA, CDMA, GPRS, EDGE, WCDMA
Satellite	Global coverage	Extension of LAN	Very high	2 Kbps – 19.2 Kbps	TDMA, CDMA

WPANs

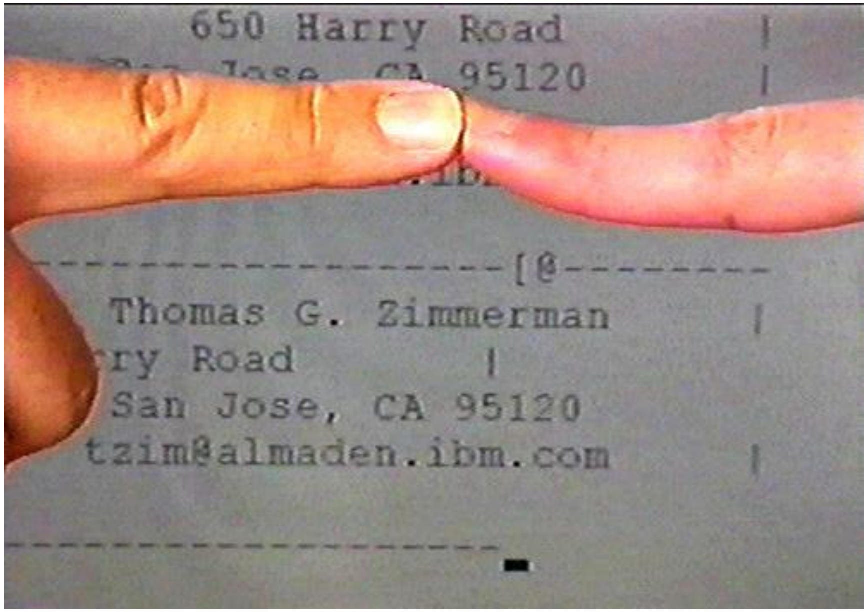
- **WPANs: wireless personal area networks**
  - Short range communication (personal space)
  - Low power consumption
  - Low cost
  - Small networks
  - No pre-existing infrastructure or direct connectivity other networks

WPAN Standards

- **Sorted by data rate**
  - UWB (Ultra-wideband)
    - Wireless monitors, data transfer from digital camcorders, wireless printing of digital pictures
    - File transfer among cell phones and mobile devices
  - Bluetooth
  - ZigBee

Body Area Networks

- **Idea**
  - Use natural electrical conductivity of the human body to transmit electronic data (2.4 KB/s up to 400 KB/s)
- **Possible applications**
  - Car or phone recognizes a user
  - Pay by touching a device in a bus
  - Device configures itself through touch



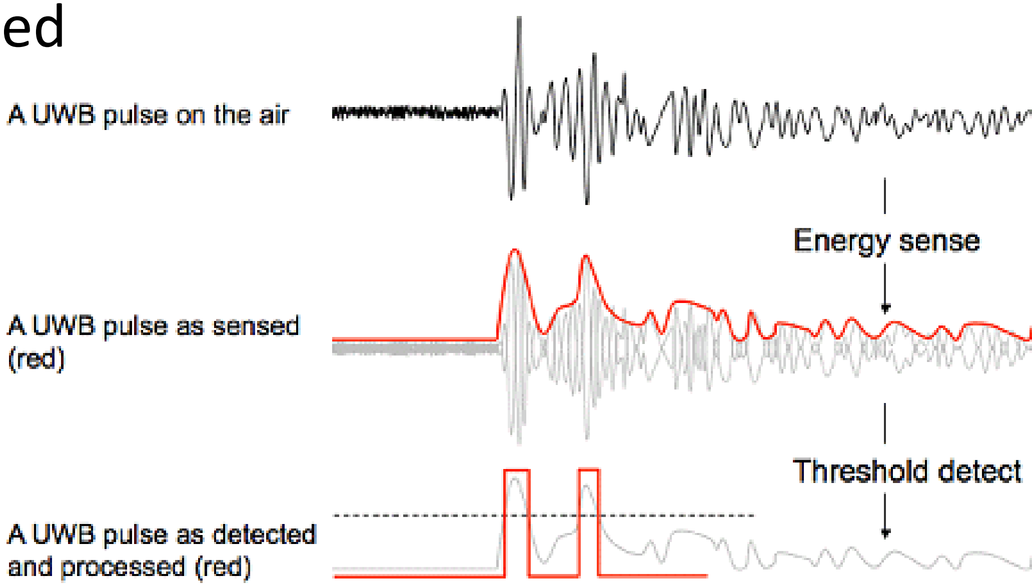
http://www.almaden.ibm.com/cs/user/pan/pan.html

Ultra Wide Band I

- **UWB**
  - Possible successor of Bluetooth for transmitting high data rates at short ranges
  - Operates in the 3.1–10.6 GHz frequency band
  - Radio always transmits at 640 Mbps but maximum actual data rate is 480 Mbps due to error correction
- **Applications**
  - Stream compressed video short distances, e.g., from a set-top box to a TV or from a camcorder to a PC
  - Wireless printing and wireless monitors

Ultra Wide Band II

- What makes UWB special?
  - P_t is transmit power and P_r is receive power or receiver sensitivity, and *d* is distance: d ~ $(P_t/P_r)^{½}$ or $P_r{*}d^2 \sim P_t$
  - Send a short pulse of an electrical charge into an antenna instead of varying the frequency or power level of a wave
  - Signal cannot be detected by conventional radios
- High power efficiency
  - Data is transmitted in short periods of time, i.e., the radio is mostly in low power state



http://www.sensorsmag.com/networking-communications/asset-tracking/asset-tracking-industrial-settings%E2%80%94a-review-wireless-technol-1500

Ultra Wide Band III

- **Security**
  - Stronger security than Bluetooth and WLAN
  - All devices have unique IDs
  - Generate cryptographic checksums to ensure that a message originated from a specific device ID
  - Cryptographic sequence number: guards against replay attacks
- **Future applications**
  - Precise location systems and real time location systems
  - Precision radar imaging technology, even through walls

Bluetooth (IEEE 802.15.1)

- **Goal**
  - Ad-hoc wireless connectivity for electronic devices
  - Low-cost replacement for wires
- **Name**
  - Suggested by Ericsson
  - Harald Bluetooth
    - Viking king in Denmark, 10^{th} century
    - United the country and introduced Christianity

Bluetooth Technology

- **Radio Technology**
  - Short-range: 10 m – 100 m
  - Unlicensed ISM (Industrial, Scientific and Medical) frequency band (2.45 GHz)
  - 1 mW transmission power
- **Networking**
  - Point to point: serial wire replacement between 2 devices
  - Point to multipoint: ad-hoc networking of up to 8 devices

Bluetooth as a Cable Replacement

- **Communication medium**
  - IrDA: infrared light
  - Bluetooth: radio waves

	Bluetooth	**IrDA**
Obstacles	Radio waves penetrate obstacles	Light is blocked by obstacles
Alignment	Omni-directional	Narrow focused beam
Data rate	2 Mbps	1 – 4 Mbps
Range	10 – 100m	2m
Energy	More power	Less power
Price	Moderate ($10)	Cheap ($1)

Bluetooth Applications

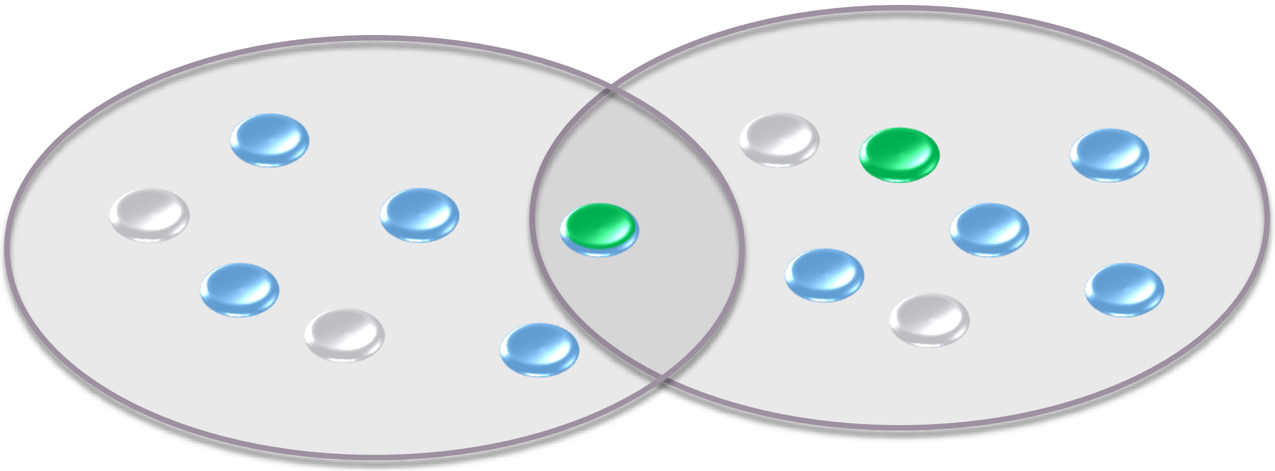
- Headsets for mobile phones
- Peripherals: mouse, keyboard, printer
- Game controllers
- File transfers for mobile devices
- Remote control
- …

Piconets

- **Ad-hoc network of up to 8 active devices**
  - One device acts as a master, the other devices as slaves
  - Each active slave has a 3-bit active member address; up to 7 active slaves
  - Additional slaves synchronized to the master but not active are called parked
  - A parked device has an 8-bit parked member address; up to 255 parked slaves

Scatternets

- **Idea**
  - Connecting 2 up to 10 piconets
  - A device acts a master in one piconet and as a slave in another piconet
  - Devices were expected 2008 …



Bluetooth Specification

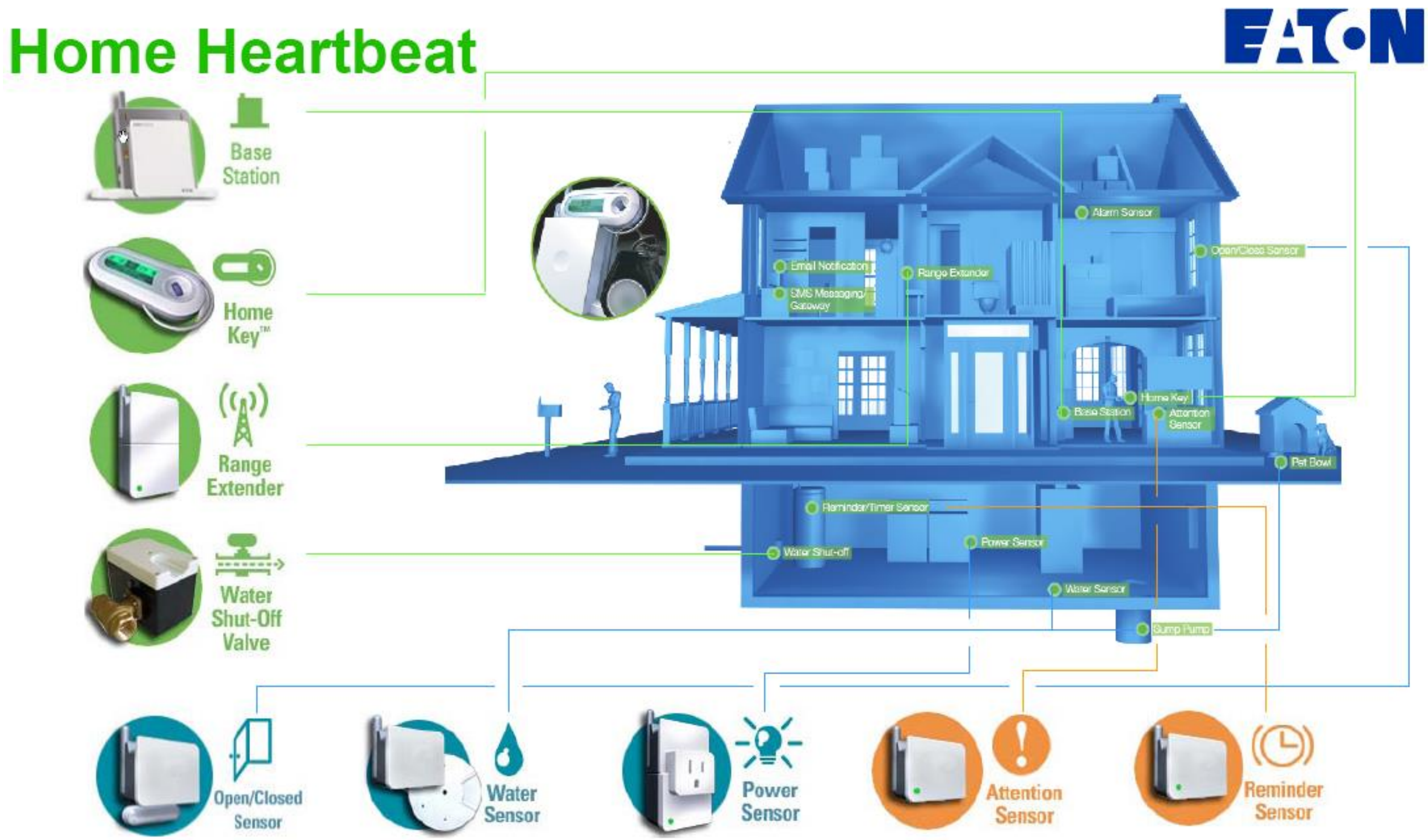
- **Specification**
  - Radio technology
  - Software stack
  - Profiles
- **Spread spectrum frequency hopping**
  - Packets are transmitted to a receiver over 79 hop frequencies in a pseudo random pattern
  - Transmitter switches hop frequencies 1,600 times per second
- **Bluetooth security**
  - Authentication and data encryption

Pairing

- **Trusted relationship between two devices**
  - Share a secret passkey
  - Passkeys are stored on the device's file system (and not the Bluetooth chip)
  - Trusted devices can encrypt data for exchange (128 bit)
  - Trusted devices can cryptographically authenticate the identity
  - Device either requires pairing or asks whether a remote device can use its services

ZigBee

ZigBee in Action



Source: http://www.homeheartbeat.com/

ZigBee Introduction

- **Goal**
  - Wireless standard for sensing and control applications
  - Highly reliable and secure, interoperable
  - Started in 1999 and completed (1.0) end of 2004
- **ZigBee (IEEE 802.15.4: low rate WPAN)**
  - Extremely low power
  - 200 Kbps maximum
  - Sensors, interactive toys, smart badges, remote controls, home automation
  - Routing protocol: AODV

What is ZigBee?

- **Standard for control and sensor networks**
  - Developed by the ZigBee alliance
  - Based on the IEEE 802.15.4 Standard
- **802.15.4**
  - Coded into the chip CC2420
  - SunSPOTs have this chip
  - Requires a license (not free)
- **Compliancy**
  - Requires no changes to the code
  - Not ideal for research purposes

IEEE 802.15.4

- **Huge address space**
  - 18,450,000,000,000,000,000 devices (64 bit IEEE address)
- **Dual PHY**
  - 2.4GHz (16 channels), 250kbps
  - 868/915MHz (1/10 channels), 20/40kbps
- **Power**
  - Designed for months to years on batteries
  - Optimized for low-duty cycle (less than 0.1%)
  - 50m range (5-500m environment dependent)

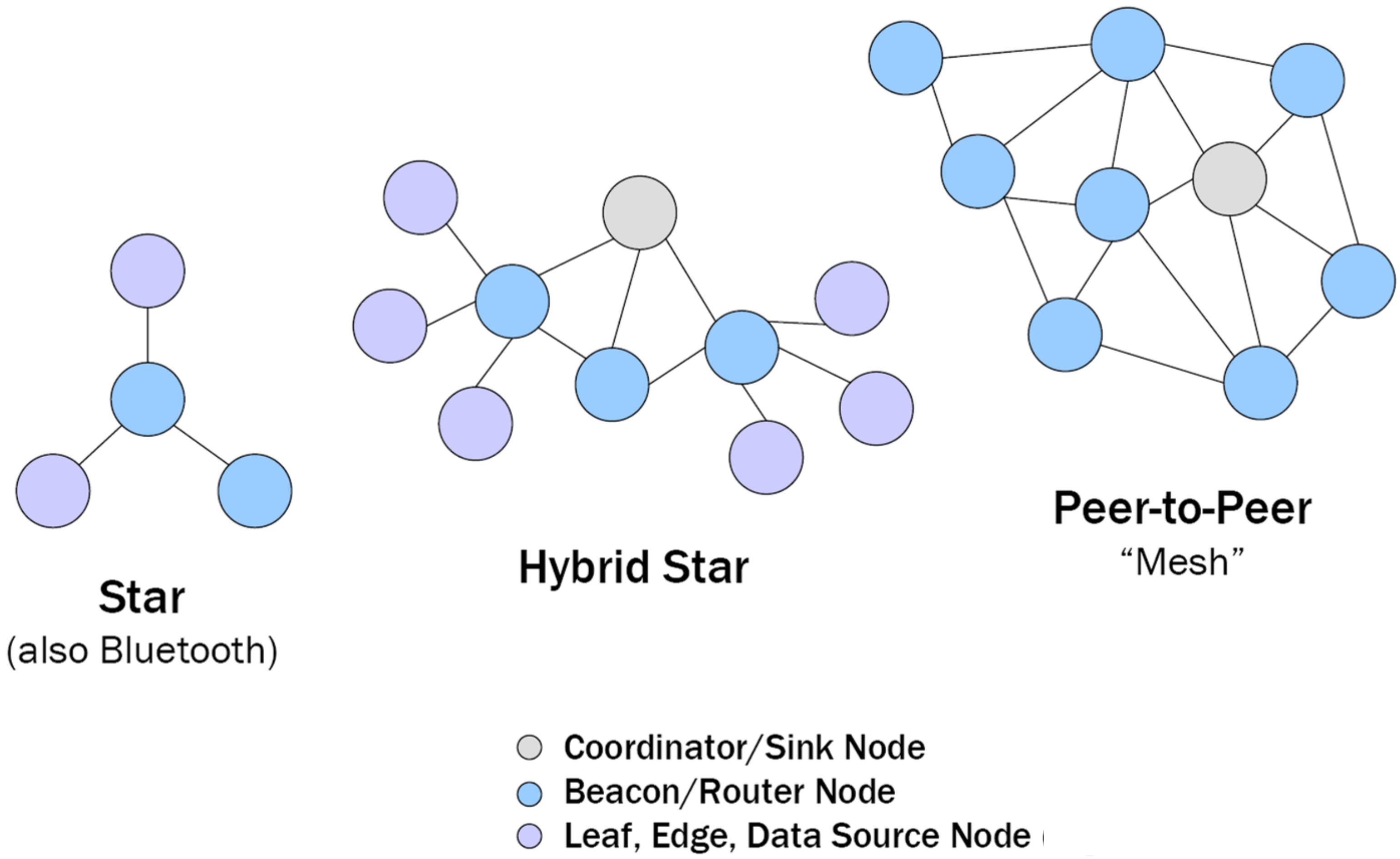
Comparison: ZigBee vs Bluetooth

ZigBee	Bluetooth
Smaller packets over a large network: 2^{64}	Larger packets over a small network: 8
Low memory requirement: 4 – 32KB	Require more system resources: 250KB
Rapid network joins in milliseconds	Long network joins in seconds
Very Low cost: less than a dollar	Complex design: ~dollars
Small bandwidth: 20 – 250kbps	Medium bandwidth: 1Mbps
Medium range: 10 – 100m	Medium range: 10m (up to 100m)
Battery lifetime: years	Battery lifetime: days

Components of a ZigBee Network

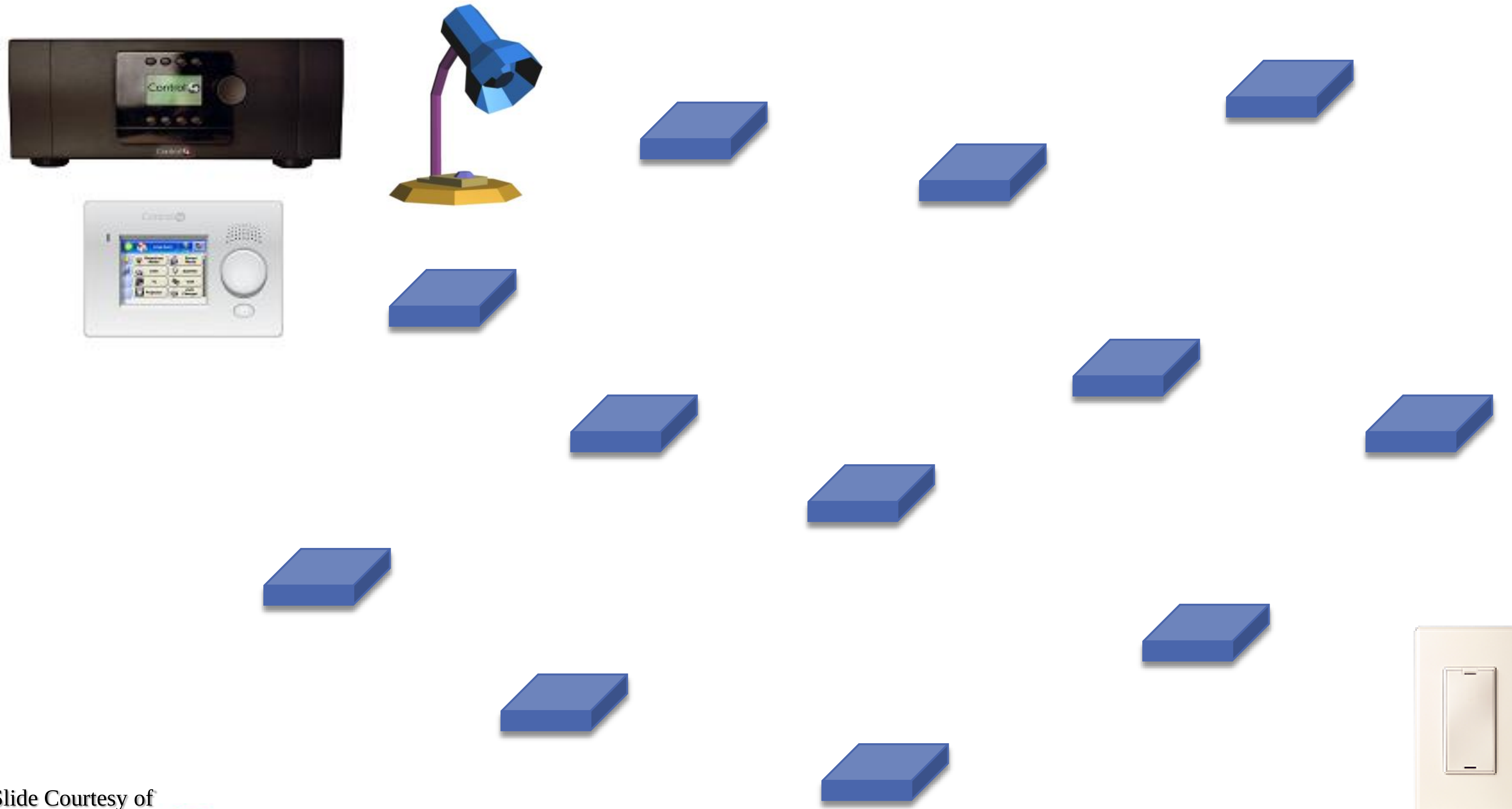
- **PAN Coordinator**
  - Acts as a master
  - Governs the network
- **Routers**
  - Relay information to the end devices
  - Can communicate among each other and the coordinator
- **End device (actual sensor motes)**
  - Can sleep (but not the coordinator or routers)
  - Can be battery-powered (but not the coordinator or routers)
  - Can only (!) communicate with routers or the coordinator

Topologies



Star
(also Bluetooth)
Hybrid Star
Peer-to-Peer
"Mesh"
Coordinator/Sink Node
Beacon/Router Node
Leaf, Edge, Data Source Node

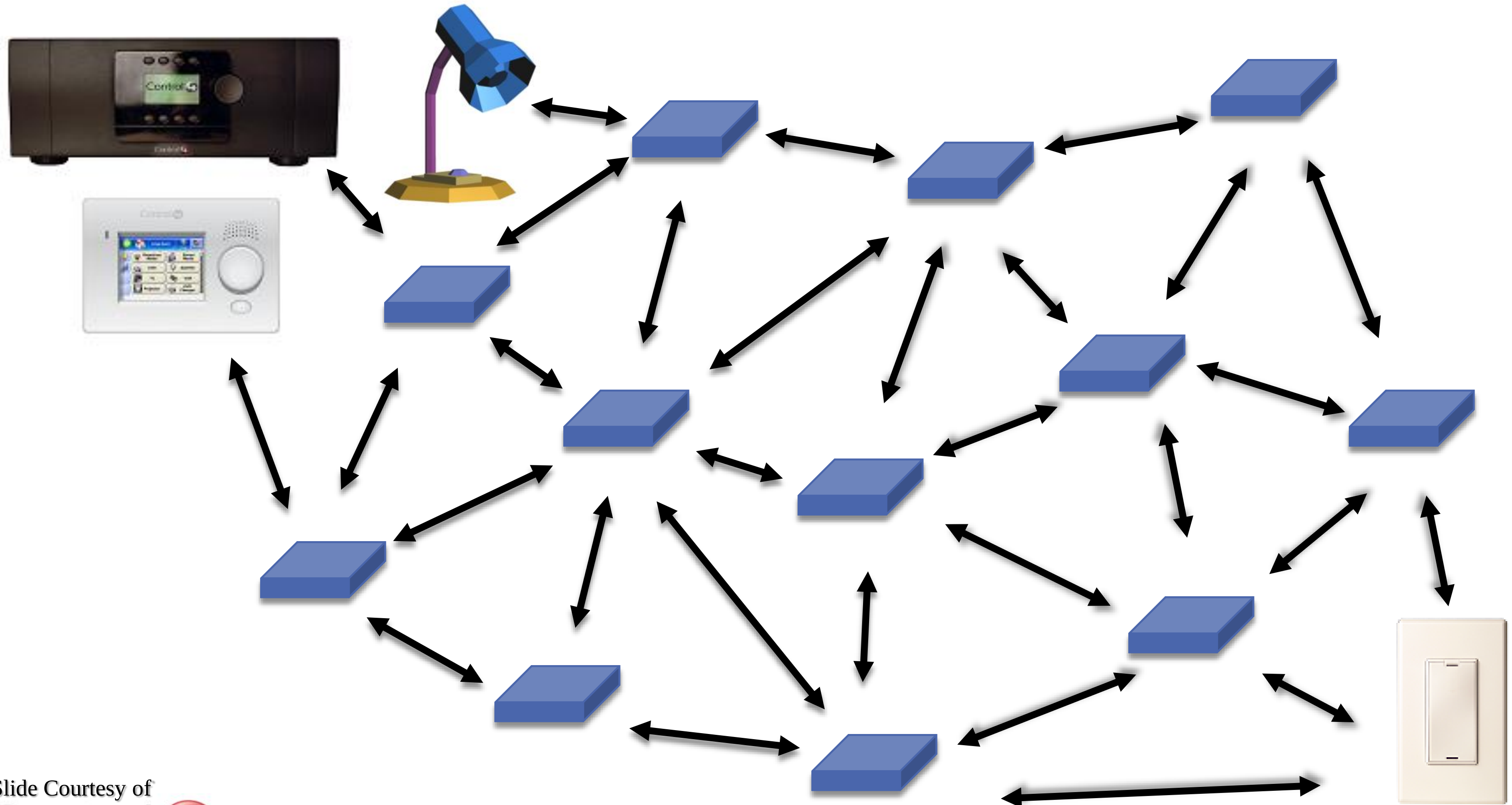
ZigBee Mesh Networking



Slide Courtesy of Control4

Source: http://www.zigbee.org/en/resources/#SlidePresentations

ZigBee Mesh Networking



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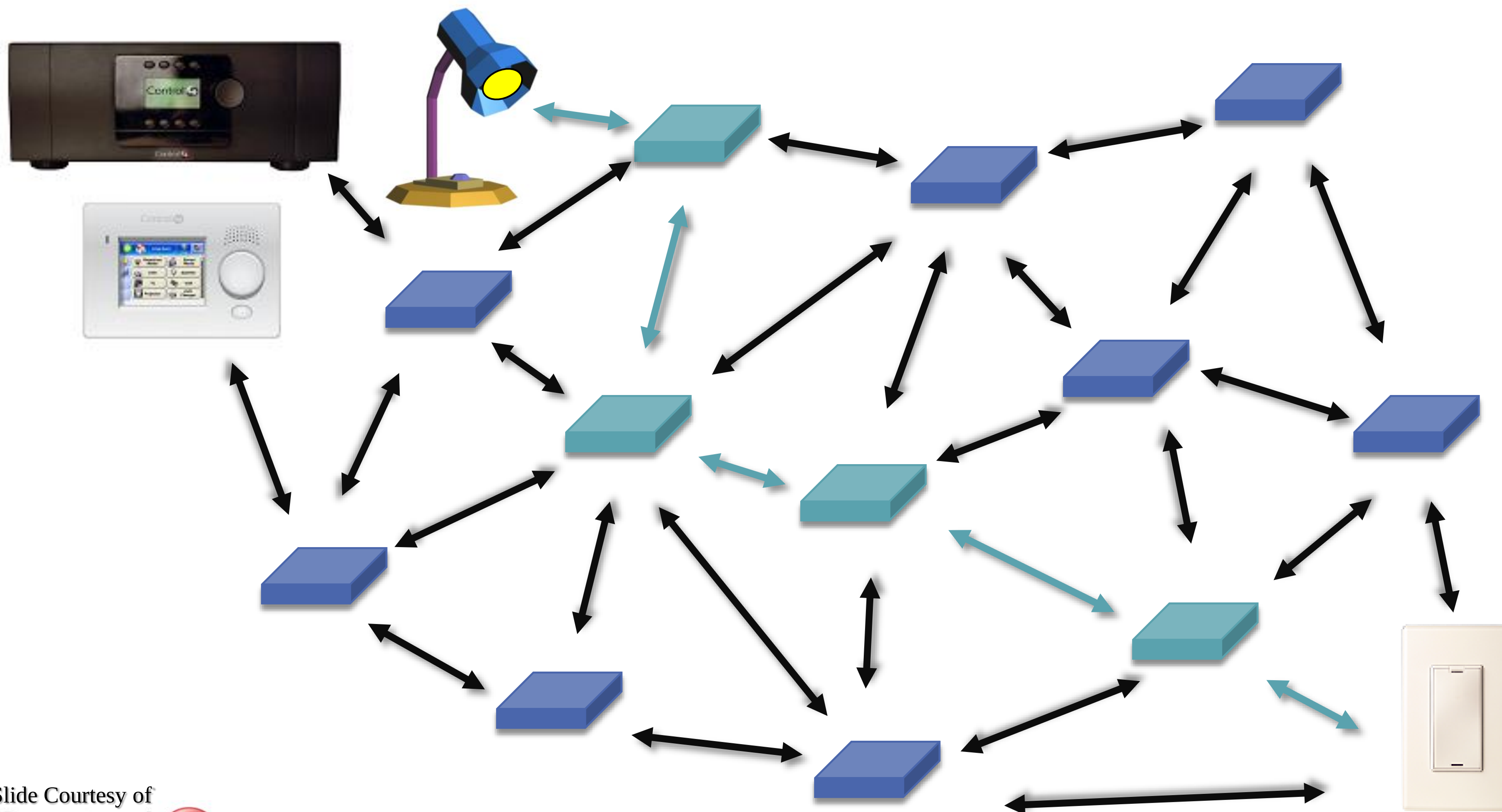

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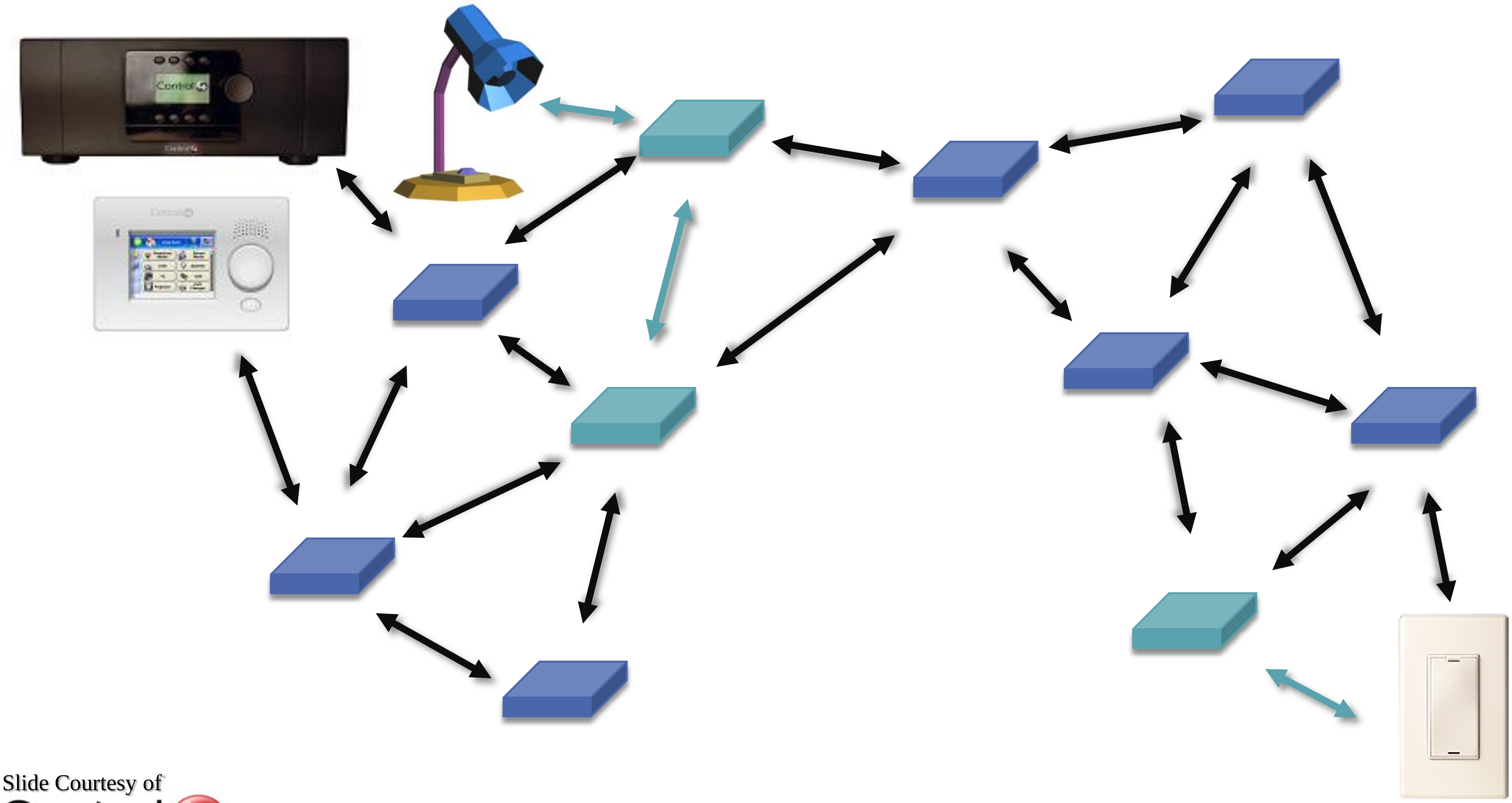

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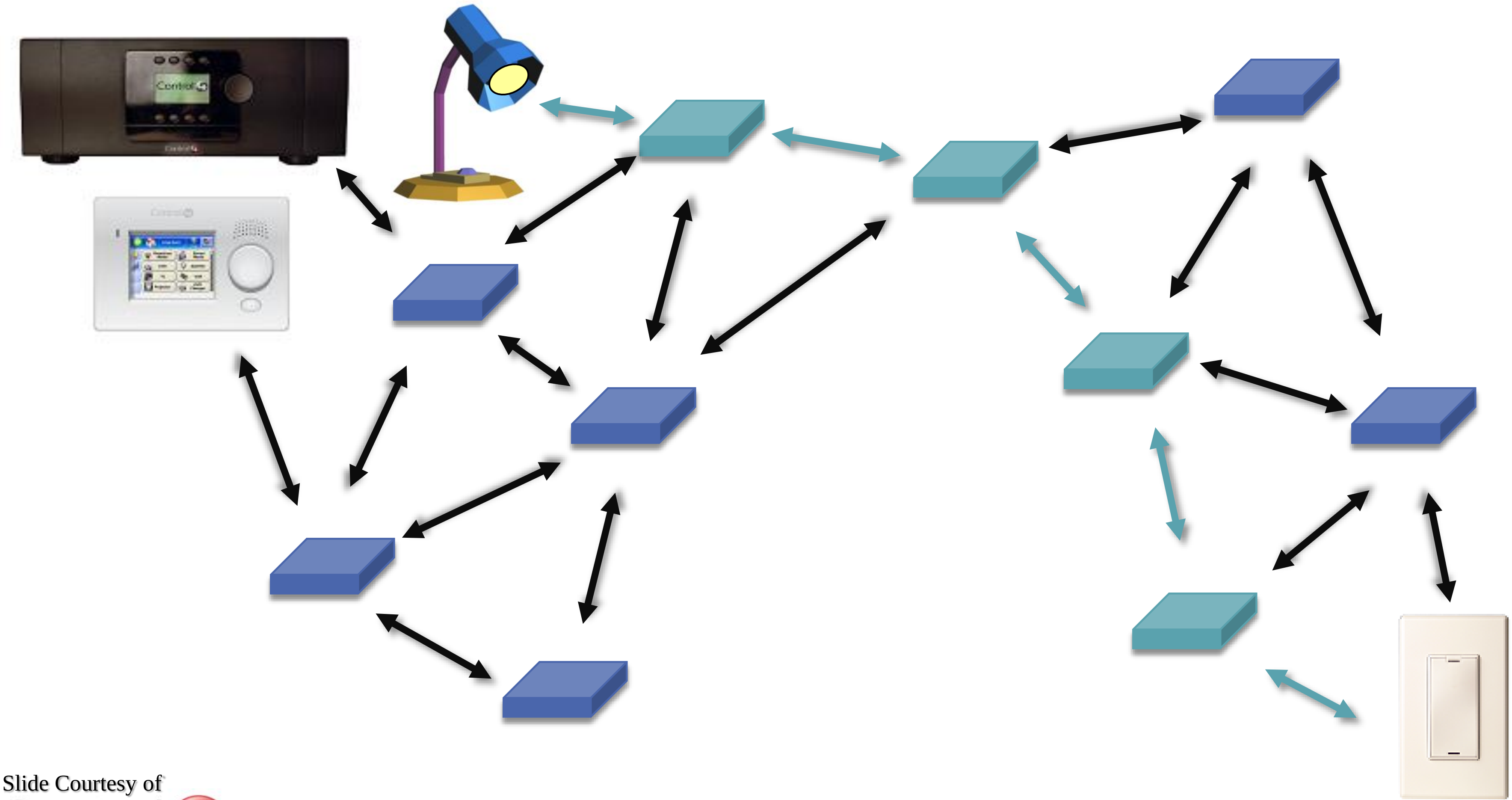

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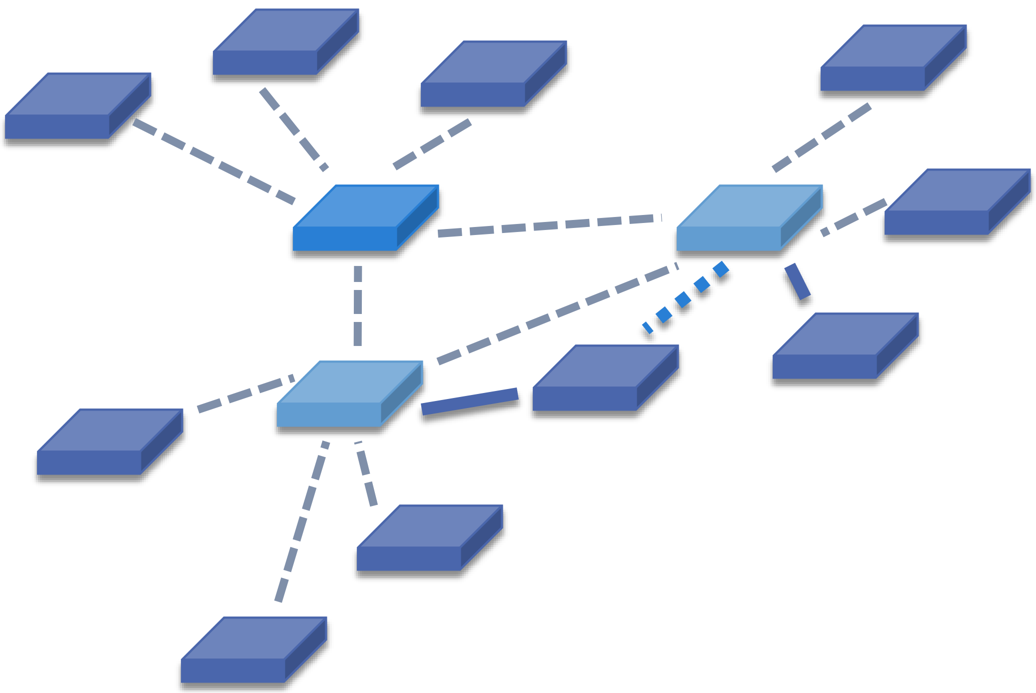
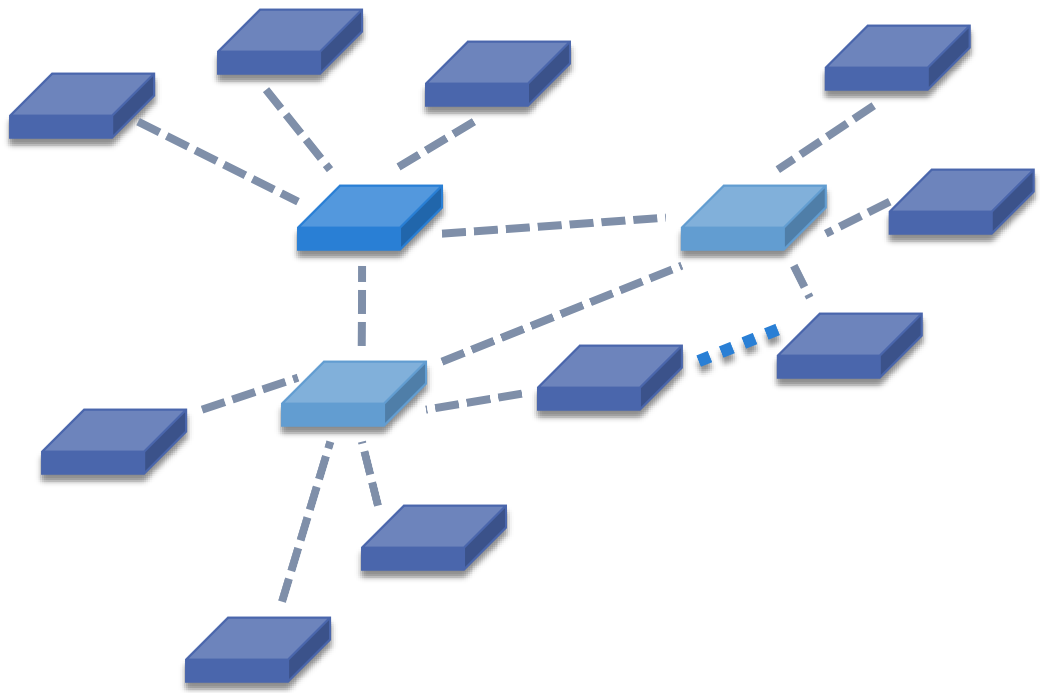
Packet Collisions in ZigBee I

- ZigBee does not specify coordination between routers if they communicate with their end devices



Packet Collisions in ZigBee II

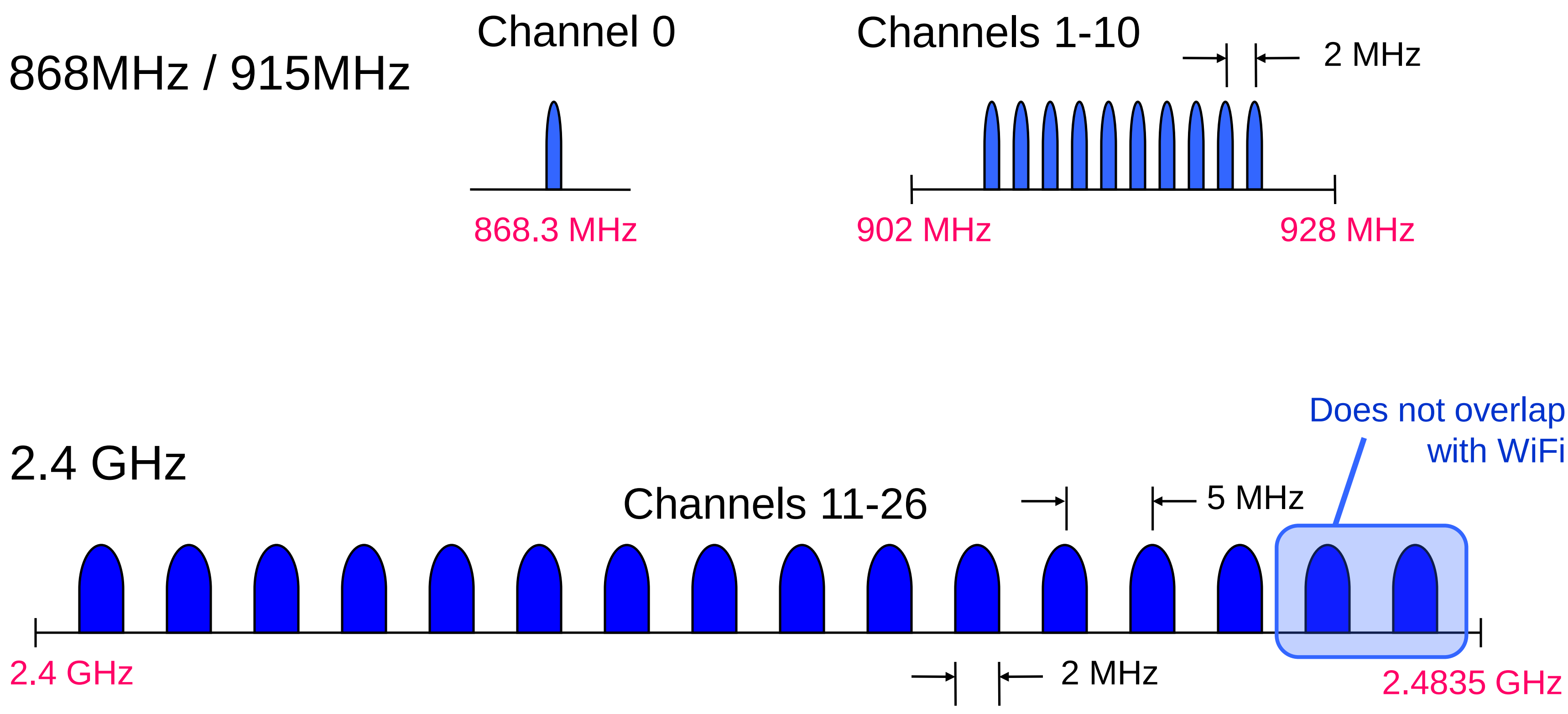
- ZigBee does not specify coordination between routers if they communicate with their end devices



802.15.4 and Interference

- **CSMA-CA**
  - Carrier Sense Multiple Access-Collision Avoidance
  - A node listen to the medium before transmission
  - If energy found is higher than a threshold a the node waits during a random time and tries again
- **Guarantee Time Slots (GTS)**
  - A centralized node (PAN coordinator) assigns one of 16 time slots to each node when they have to transmit
  - A node sends a GTS request message to the PAN coordinator
  - The coordinator sends the allocated slots

802.15.4: Channels



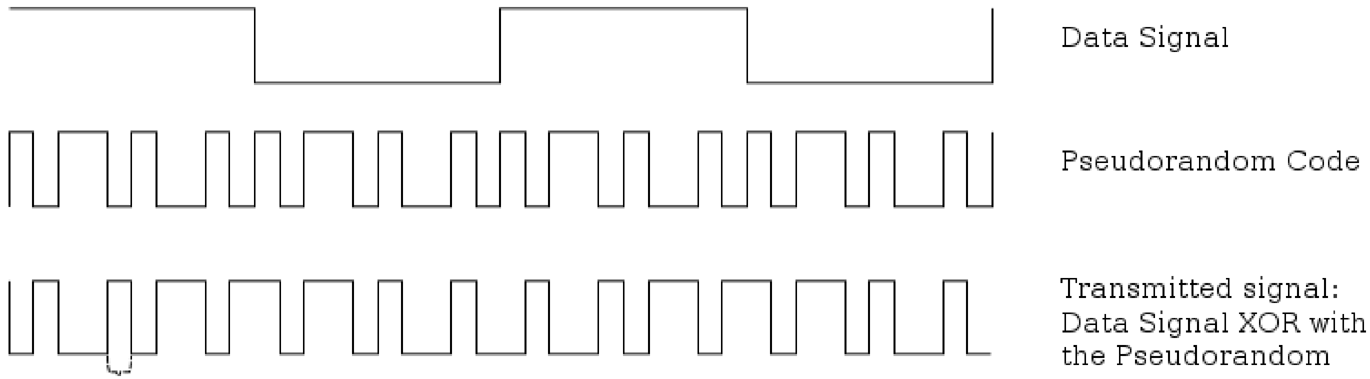
Adapted from: Joe Dvorak, "IEEE 802.15.4 and ZigBee Overview", Motorola, 2005

Noise: Spread Spectrum Technology I

- **Idea**
  - Trade bandwidth efficiency for reliability and integrity
- **FHSS (frequency hopping spread spectrum)**
  - Rapid cycling through frequencies
  - Pseudo random number sequence is known by sender & receiver
  - Fast Hopping: several frequencies per user bit
  - Slow Hopping: several user bits per frequency
- **DSSS (direct sequence spread spectrum)**
  - Spread the signal across a band of frequencies simultaneously
  - Chip: redundant bit pattern for recovery

Spread Spectrum Technology II

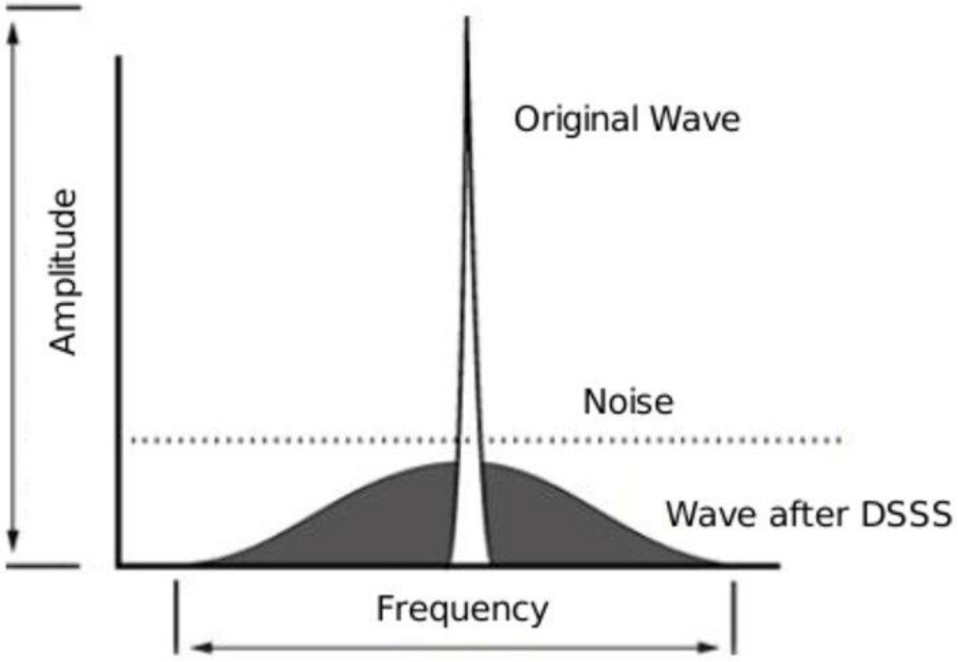
- **DSSS (direct sequence spread spectrum)**
  - Spread the signal across a band of frequencies simultaneously
  - Chip: pseudorandom bit pattern consisting of +1s and -1s
  - Data signal is XORed with the chipping sequence
  - Chip rate is much higher than data rate: every data symbol is represented by multiple chips



http://en.wikipedia.org/wiki/Code_division_multiple_access

Spread Spectrum Technology III

- **DSSS (direct sequence spread spectrum)**
  - Trade bandwidth efficiency for reliability and integrity
  - Spread the signal across a band of frequencies simultaneously
  - Each bit of information to be transmitted is modulated into 4 different signals



Source: http://www.libelium.com/802-15-4-vs-zigbee/

Routing in ZigBee

Topology-based Routing

- **Approach**
  - Use information about *links* in the network
- **Proactive protocols**
  - Maintain (large) routing tables about routes even if they are currently not used
  - High maintenance for frequent topology changes; in particular, if a broadcast to all nodes is required
- **Reactive protocols**
  - Maintain only the routes that are currently used
  - Requires route discovery ➡ delay for 1st packet

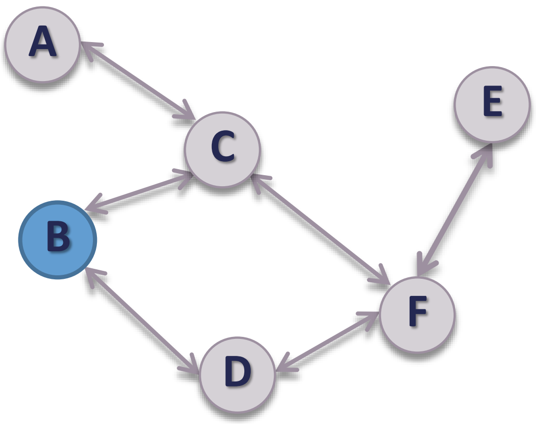
Distance Vector Routing I

- **Proactive protocols**
  - Important method for wired networks
- **Approach**
  - Each node stores a routing table
  - Each entry stores: destination, neighbor, distance
- **Updates**
  - Occur if a router notices a change in its neighborhood or receives an update message from a neighbor
  - Are sent to neighbor nodes

Distance Vector Routing II

- **Discussion**
  - Messages are routed along shortest path
  - Updates only occur for topology changes
  - But: often topology changes are irrelevant for source–destination route
  - Each node has to store a large table (example for node B)

Destination	Neighbor	Distance
A	C	2
C	C	1
D	D	1
E	D	3
F	D	2



AODV (Ad-Hoc On-Demand DV) I

- **AODV**
  - Reactive protocol
  - Assumes symmetric links!
- **RREQ (route request)**
  - Node S broadcasts request for communication with destination D
  - A RREQ is rebroadcasted: nodes forward request and record sending node
- **Routing table**
  - Each node maintains destination, neighbor address of the 1st broadcasted packet, destination sequence number, hop count

RREQ

- Destination IP address
- Source IP address
- Current sequence numbers for source and destination
- Message ID (= Broadcast ID and source IP address)
- Hop count

Source: http://w3.antd.nist.gov/wctg/aodv_kernel/aodv_guide.pdf

AODV II

- **Sequence numbers**
  - Determine if a path known to an intermediate node is more recent
  - Prevent loops if RERRs are lost
  - Every time a node sends a message it increases its own sequence number
- **Features**
  - Slow flooding: if route request fails, another route request can be sent after twice the time of the previous timeout
  - Link failure detection: send periodic hello messages

AODV: Routing Table & RREP

- Routing table of node S

Destination	Neighbor	Distance	Sequence Nr
A	A	1	112
D	E	4	213
E	E	1	178

RREP

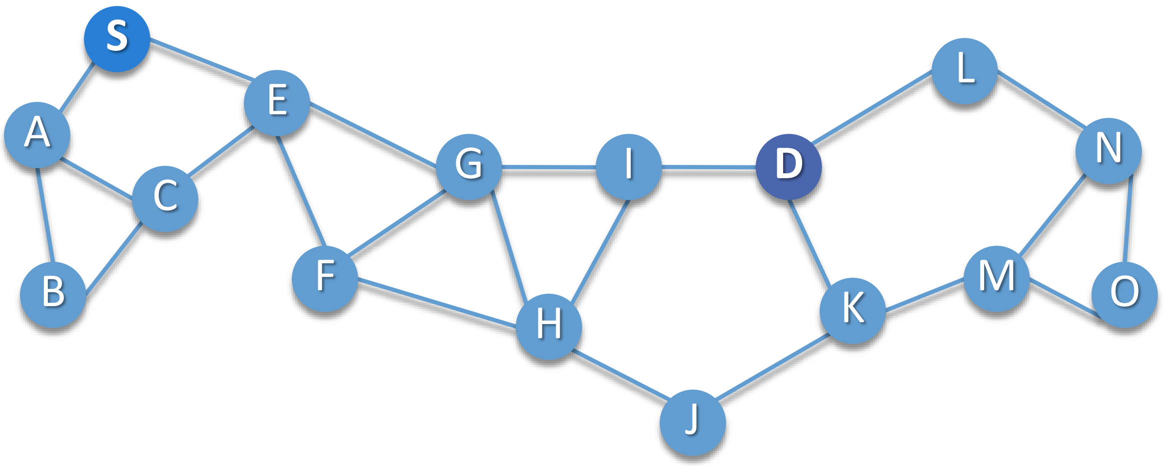
- Destination
- Source
- Hop Count
- Destination sequence Number

AODV III

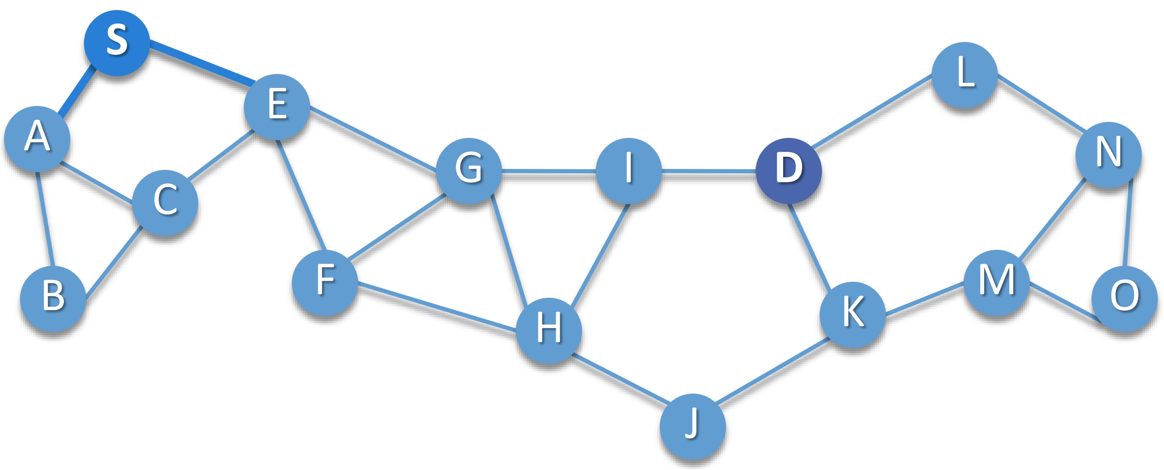
- **RREP (route reply)**
  - If a node receives the message and has a fresh route to D, it responds and sends a message backwards to S
  - Test: destination sequence number in packet ≤ sequence number in table
  - Nodes set up forward pointers to D
  - S uses the route with the least number of hops to D and the most recent sequence number
  - Probability of a RREP is smaller for AODV than for DSR (why?)
- **RERR (route error)**
  - If a node dies, moves or is outside communication range, AODV has to adjust routes
  - Nodes received a route error remove all occurrences in the route table of that node

Source: http://w3.antd.nist.gov/wctg/aodv_kernel/aodv_guide.pdf

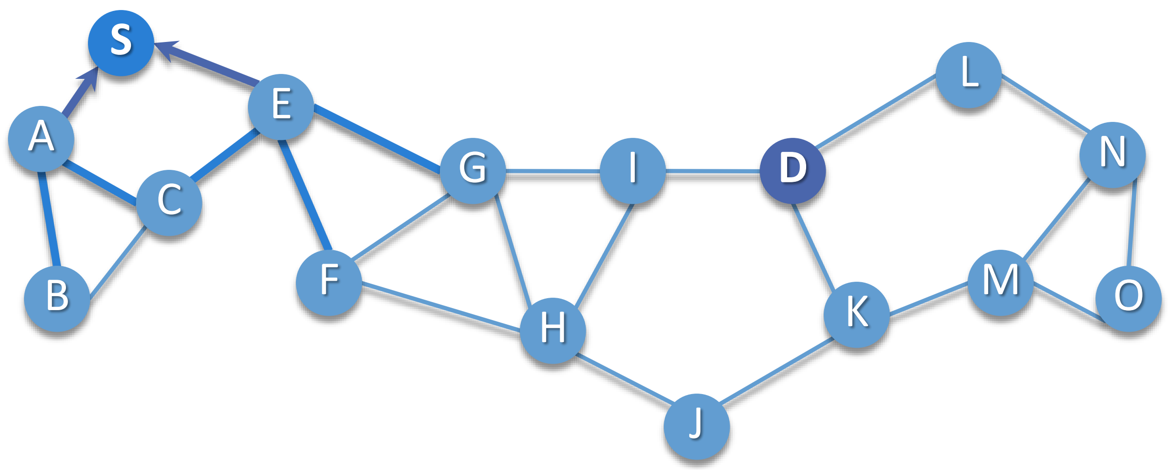
AODV: Example



AODV: Example

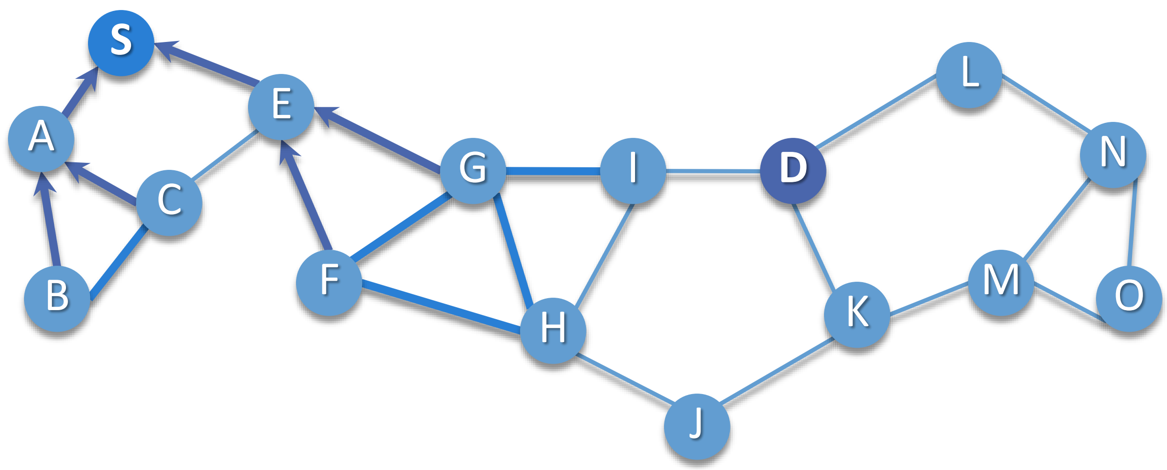


AODV: Example



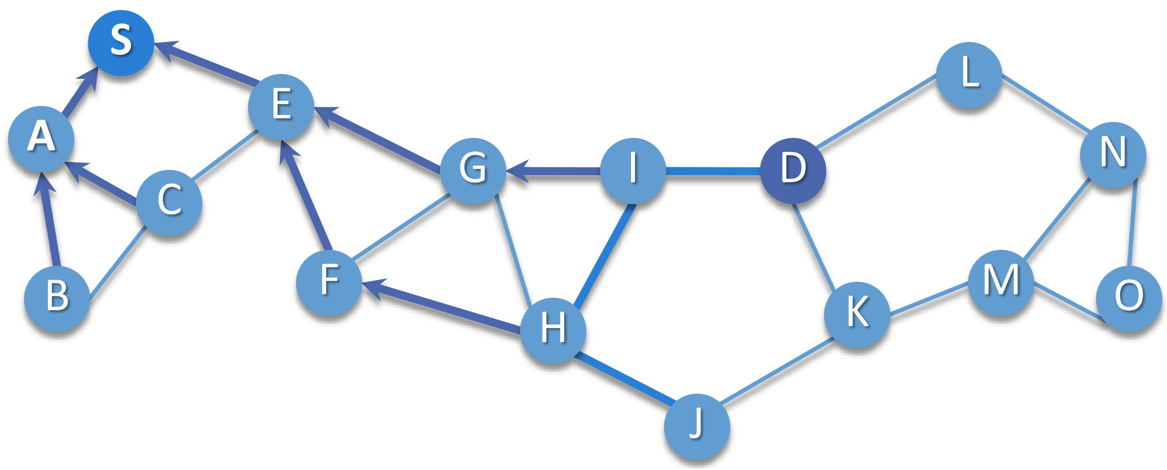
AODV: Example

- Although node C receives a RREQ from node E, it does not forward it again, as it received already a RREQ from S earlier



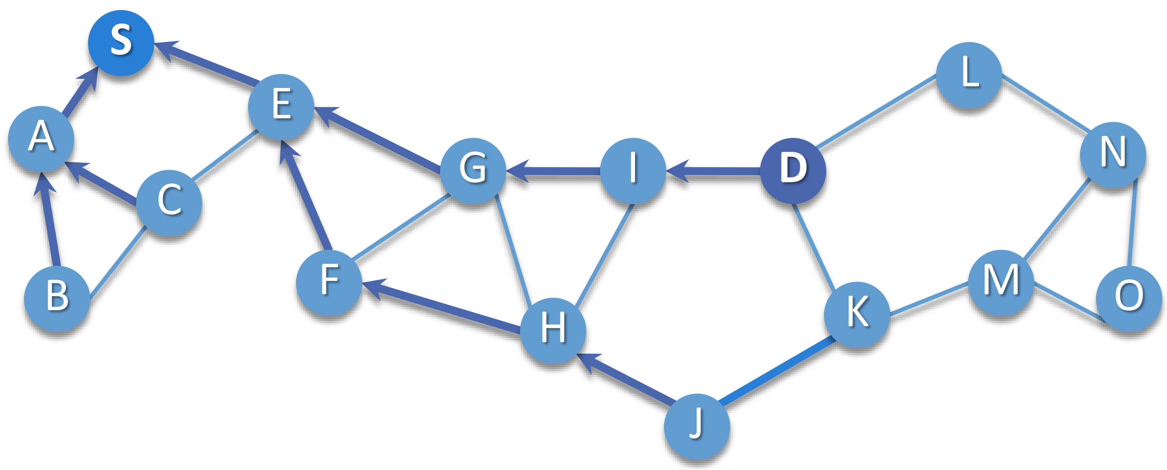
AODV: Example

- Although node F receives a RREQ from node G, it does not forward it again, as it received already a RREQ from S earlier; similarly H (for G)



AODV: Example

- Node D does not forward the route request because it is the destination



AODV: Example

- After a few more iterations …