Introduction to IEEE 802.15.4

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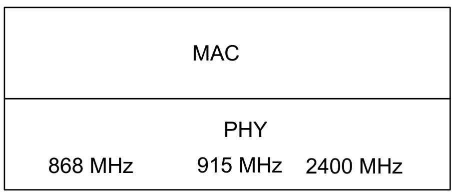
IEEE 802.15.4

- *Short range, low bit rate, low power consumption*
  - *Home*
  - *Automotive*
  - *Industrial applications*
  - *Games*
  - *Metering*

802.15.4

- PHY speeds
  - 250 kbps
  - 40 kbps
  - 20 kbps.
- Basic topologies
  - Star
  - Peer-to-Peer
- Modulation: BPSK for 20 and 40 kbps, O-QPSK with DSSS for 250 kbps

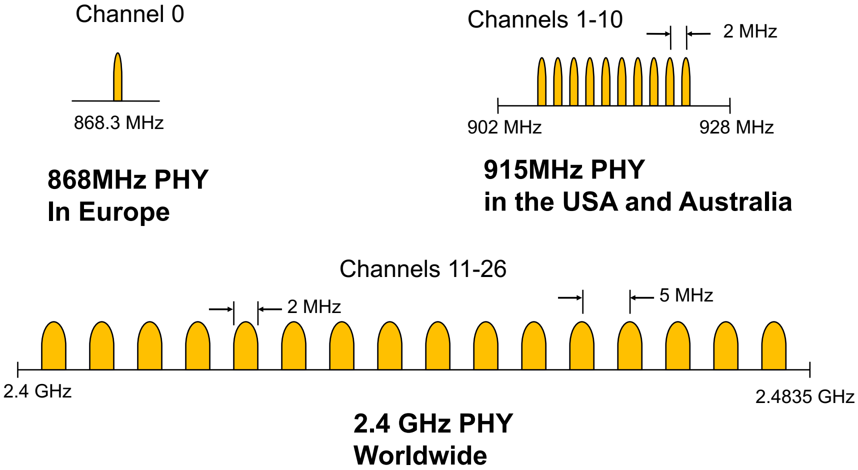
802.15.4



802.15.4 Physical layer

- Channels
  - 16 channels in the 2.4 GHz ISM band
  - 10 channels in the 915 MHz ISM band in the USA and Australia
  - 1 channel in the European 868 MHz band
  - 1 channel in China's 784 MHz band

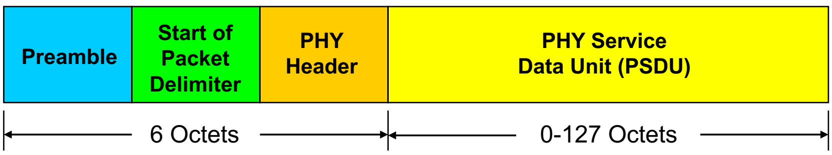
IEEE 802.15.4 PHY Overview Operating Frequency Bands



IEEE 802.15.4 PHY Overview Packet Structure

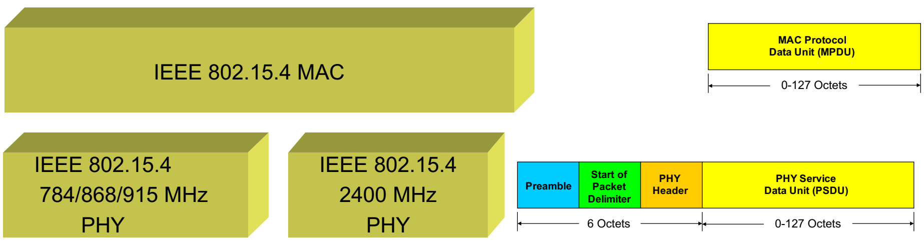
PHY Packet Fields

- Preamble (32 bits) – synchronization
- Start of Packet Delimiter (8 bits)
- PHY Header (8 bits) – PSDU length
- PSDU (0 to 1016 bits) – Data field



Some more details later.

802.15.4 Architecture



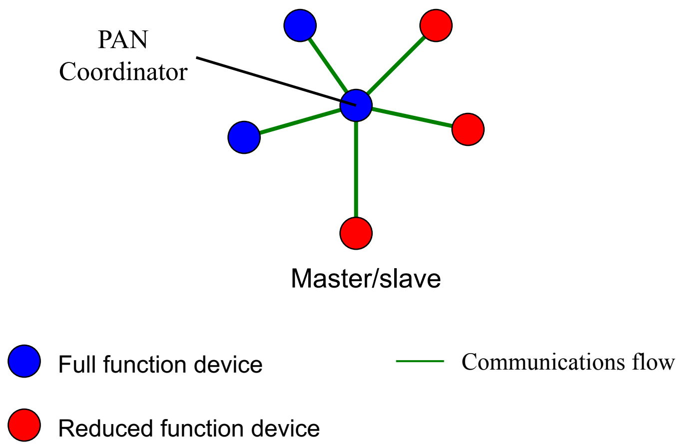
IEEE 802.15.4 MAC Overview Design Drivers

- Extremely low cost
- Ease of implementation
- Reliable data transfer
- Short range operation
- Very low power consumption

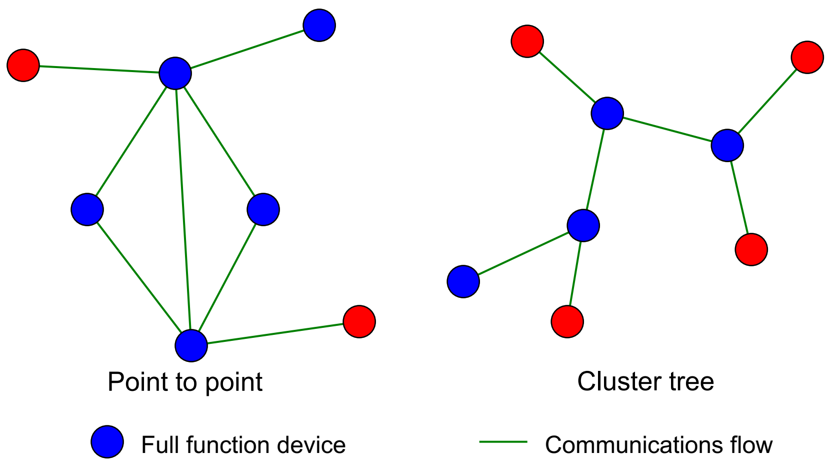
IEEE 802.15.4 MAC Overview Device Classes

- Full function device (FFD)
  - Any topology
  - Network coordinator capable
  - Talks to any other device
- Reduced function device (RFD)
  - Limited to star topology
  - Cannot become a network coordinator
  - Talks only to a network coordinator
  - Very simple implementation

IEEE 802.15.4 MAC Overview
Star Topology



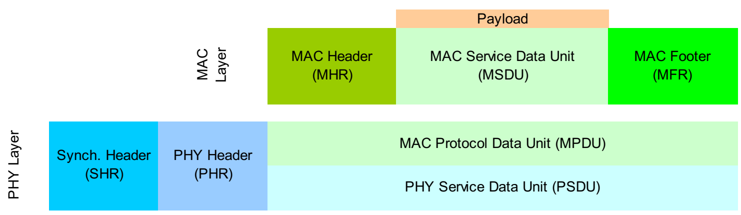
IEEE 802.15.4 MAC
Peer-Peer Topology



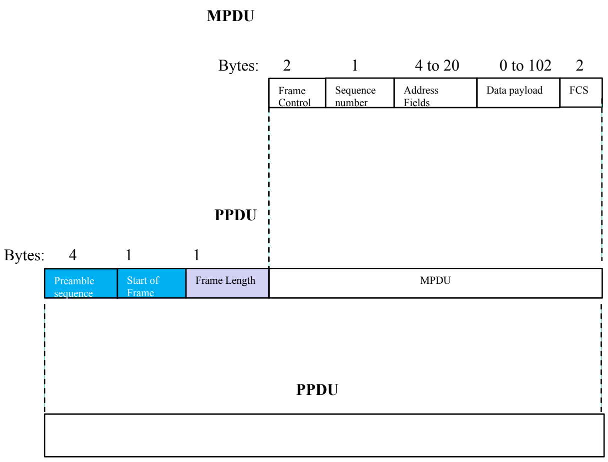
Types of Frames

- Data Frame
- Beacon Frame
- Acknowledgment Frame
- MAC Command Frame

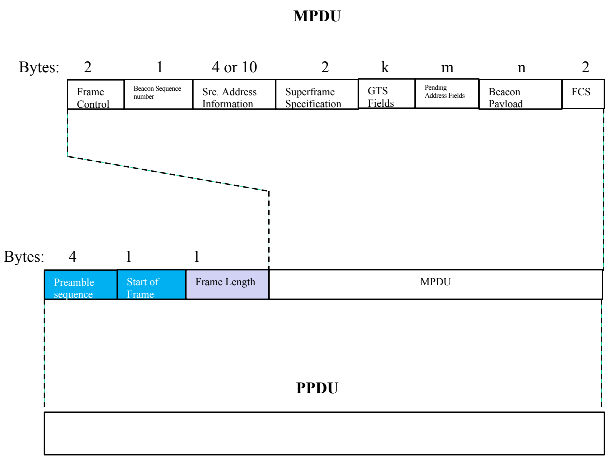
IEEE 802.15.4 MAC Overview General Frame Structure



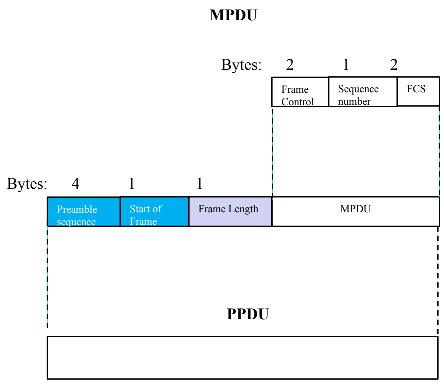
Data Frame Structure



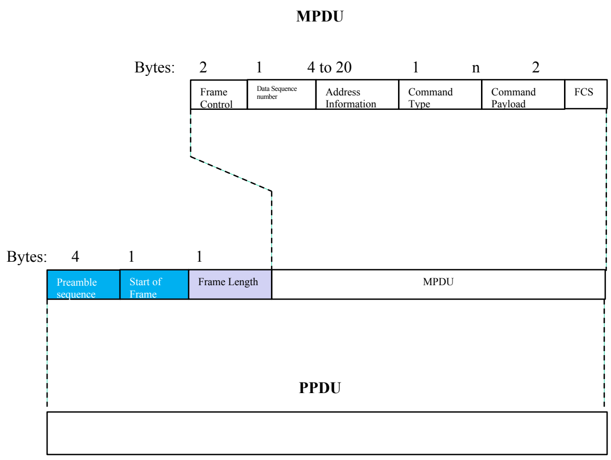
Beacon Frame Structure



ACK Frame Structure



Command Frame Structure



Frame Structure

Frame control

Bits:	3	1	1	1	1	3	3	3	3
	Frame Type	Security Enabl.	Frm. Pend.	ACK Req.	PAN ID compr.	reservd	Dest. Addr. Mode	Frame version	Src. Addr. Mode
	000 Beacon 001 Data 010 ACK 011 Command	0: No Frame Protec. 1: Prot. By MAC Aux. Sec. Header Field Presnt.	0: No Frms. Pendg. 1: Frms Pendg. In Sendr.	0: No ACK Reqtd. 1: ACK Reqtd.	0: No ACK Reqtd. 1: ACK Reqtd.				

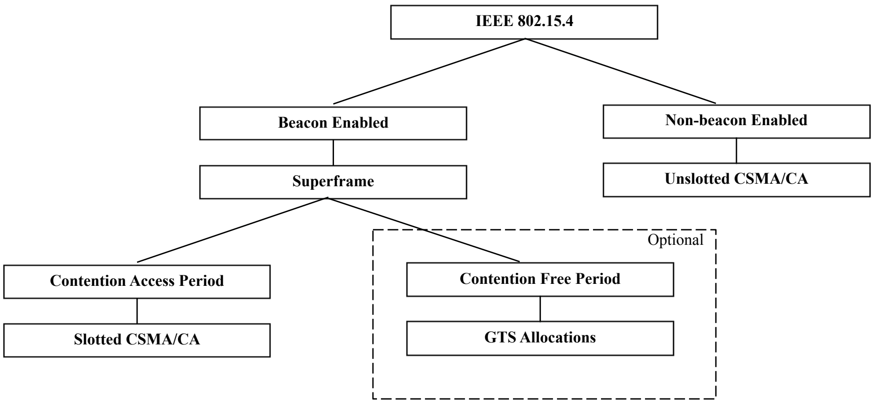
Exercise

1. The payload in data frames for data applications is typically 30 to 60 bytes long. Calculate the transmission time for the Data frame with a 45-byte payload if the transmission rate is 250 kbps
2. Calculate the maximum transmission time for the Data frame if the transmission rate is 250 kbps
3. Calculate the transmission time for an ACK frame

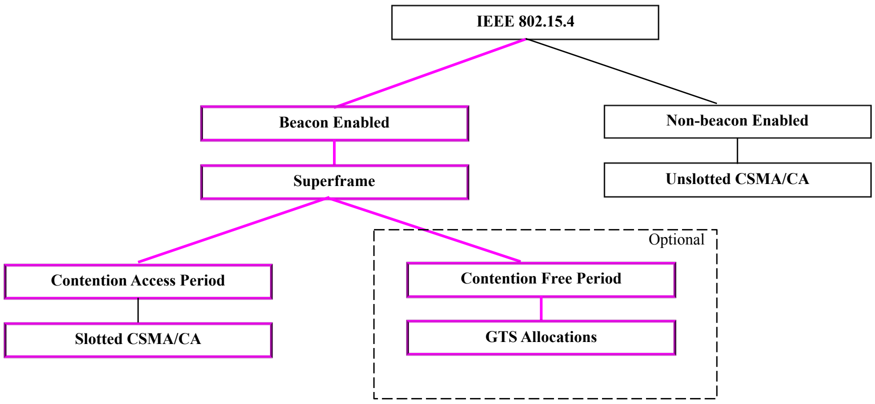
Three Channel Access Mechanisms

1. Slotted CSMA/CA
2. CSMA/CA
3. Contention Free (Guaranteed Time Slots)

IEEE 802.15.4 MAC



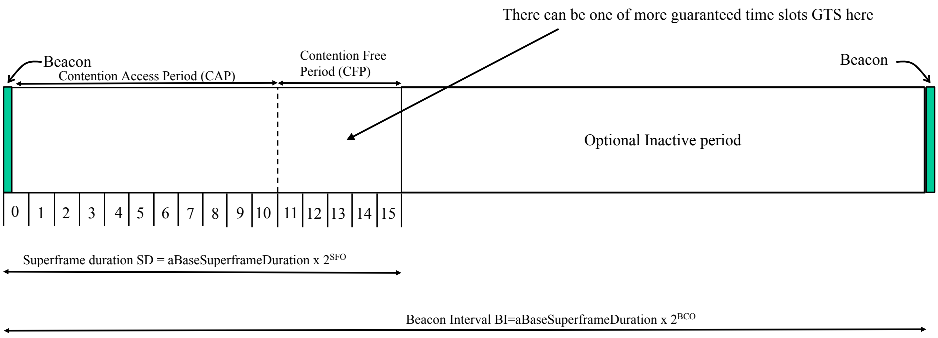
IEEE 802.15.4 MAC



Beacon Enabled 802.15.4 Mode

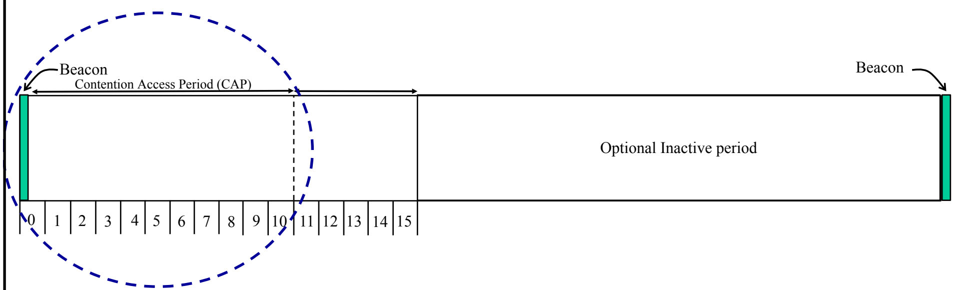
- Beacons are transmitted periodically by the coordinator
- Used to
  - Synchronize associated nodes
  - Identify the PAN
  - Delimit the beginning of a superframe
  - Channel access mostly by Slotted CSMA/CA
  - Also possible to allocate contention free Guaranteed Time Slots (GTSs).

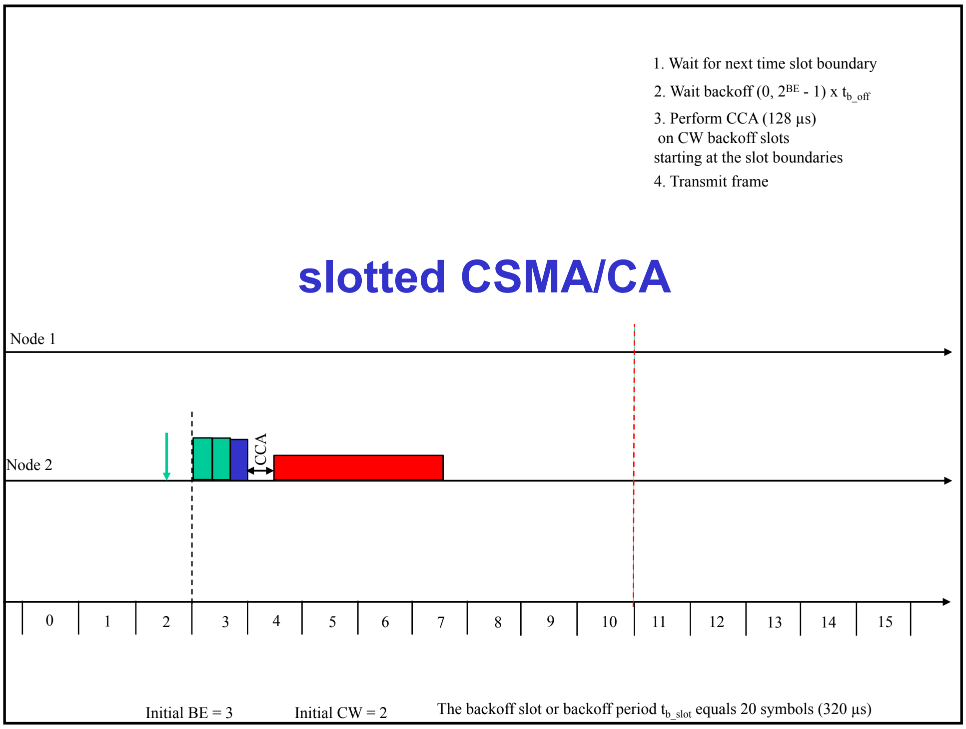
Superframe Structure

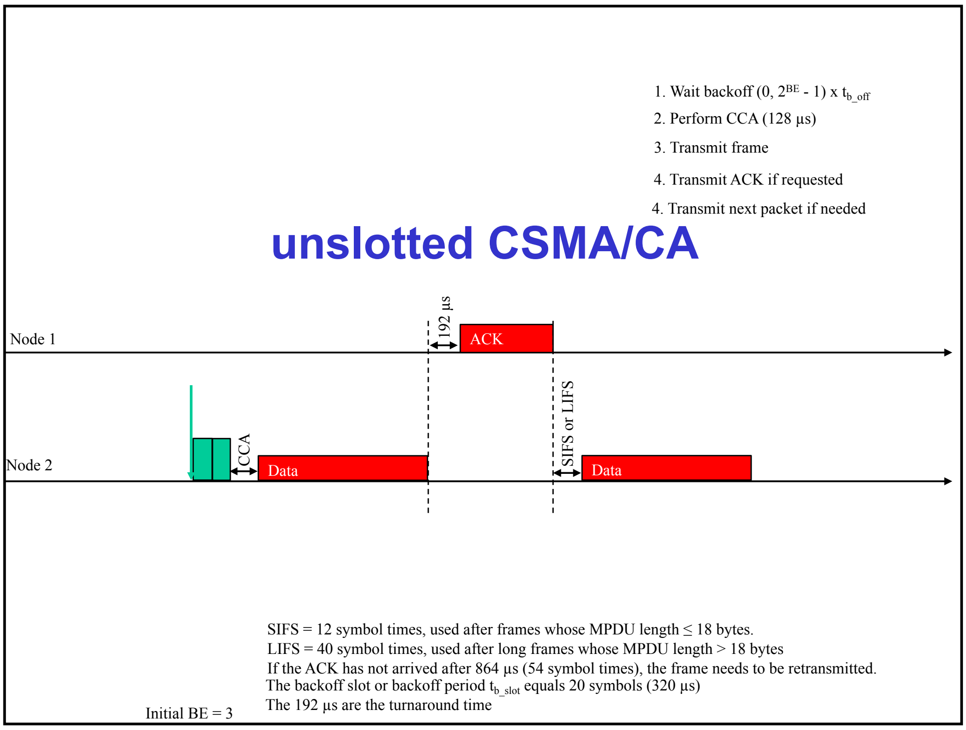


aBaseSuperframeDuration = 960 symbols or 15.36 ms (for 250 kbps)
The backoff slot or backoff period t_{b_slot} (to be used in CSMA/CA) equals 20 symbols (320 µs)
SD is always composed of 16 slots numbered 0 to 15 (not the same as t_{b_slot})
$0 \leq SFO \leq BCO \leq 14$

slotted CSMA/CA




1. Wait for next time slot boundary
2. Wait backoff (0, 2^{BE} - 1) x t_{b_off}
3. Perform CCA (128 µs)
on CW backoff slots
starting at the slot boundaries
4. Transmit frame
slotted CSMA/CA
Node 1
Node 2
CCA
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Initial BE = 3
Initial CW = 2
The backoff slot or backoff period t_{b_slot} equals 20 symbols (320 µs)


1. Wait backoff (0, 2^{BE} - 1) x t_{b_off}
2. Perform CCA (128 µs)
3. Transmit frame
4. Transmit ACK if requested
4. Transmit next packet if needed
unslotted CSMA/CA
Node 1
192 µs
ACK
Node 2
CCA
Data
SIFS or LIFS
Data
SIFS = 12 symbol times, used after frames whose MPDU length ≤ 18 bytes.
LIFS = 40 symbol times, used after long frames whose MPDU length > 18 bytes
If the ACK has not arrived after 864 µs (54 symbol times), the frame needs to be retransmitted.
The backoff slot or backoff period t_{b_slot} equals 20 symbols (320 µs)
The 192 µs are the turnaround time
Initial BE = 3

Exercise

- Calculate the maximum data rate for a transmission using unslotted CSMA/CA with the maximum length assuming that ACKs are used and that no retransmissions are required.

Establishing a WPAN

1. WPAN Coordinator selects an available channel
2. Association procedure for devices to associate with it

Channel selection

- Find a channel which is free from interference
- Use energy detection scan over all the channels in the appropriate frequency band

Association procedure

1. Search for available WPANs
2. Select the WPAN to join
3. Start the association procedure with the WPAN coordinator or with another FFD device, which has already joined the WPAN.

Search for available WPANs

- Passive scan:
  - In beacon-enabled networks: eavesdrop on beacons transmitted periodically by associated devices
- Active scan:
  - In non beacon-enabled networks: beacons are explicitly requested by the device through beacon request command frames.

Select the WPAN to join

- No logic is given in the standard 80215.4
- This is, therefore, implementation-dependent

Association procedure

- Device sends an association request frame
- An association response command frame is sent to the requesting device
- The MAC association is referred to as a parent-child relationship

Routing

- Implemented at the Zigbee NWK layer (802.15.4)
- Based on Ad-hoc On-Demand Distance Vector (AODV)

Characteristics

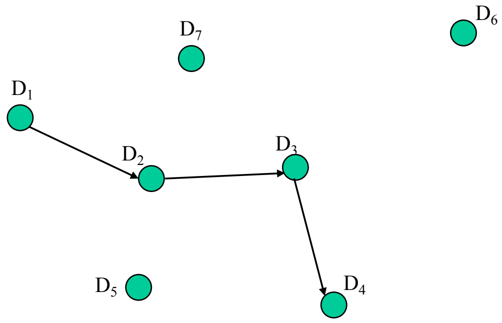
- No loops are formed
- Converge also when a node moves
- On-demand algorithm (finds routes only if source asks for them)

Used Commands

- Route request Command
  - Search for a route to a specified device
- Route reply Command
  - Response of a route request
- Route Error notification
- Leave notification
- Route Record
  - Notification of list of nodes used in relaying a frame.
- Rejoin request notification
- Rejoin response

Route Choice

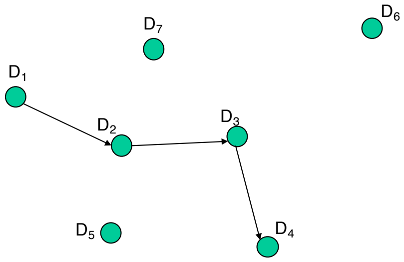
- Based on total link cost*



*The devices along the route were numbered sequentially and the equations in subsequent slides will use this assumption too. This is only done so that the equations can be written in a more compact form.

Route Choice in many practical applications

- The total link cost is often just the number of hops
- In the case of the route in the figure hereunder, the cost would be 3.



Route Choice according to Zigbee specification

- The total link cost of path P is calculated using the following equations:

$$P = \{[D_1, D_2], [D_2, D_3], \dots, [D_{L-1}, D_L]\}$$

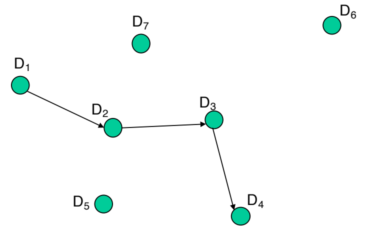
$$C\{P\} = \sum_{i=1}^{L-1} C\{[D_i, D_{i+1}]\}$$

$$C\{[D_i, D_{i+1}]\} = \min(7, round\left(\frac{1}{p_{i,i+1}}\right))$$

Where $p_{i,i+1}$ is the probability that a packet will be delivered correctly between nodes i and i+1.

Example

We are given the number of packets transmitted and received between the nodes in the three hops shown in the figure (see next slide)



Number of received packets per 100 packets transmitted by neighbor

Number of received packets for each 100 transmitted packets				
	D_1	D_2	D_3	D_4
D_1		30		
D_2			10	
D_3				80

Probabilities

$P_{1,2}$	0.30
$P_{2,3}$	0.10
$P_{3,4}$	0.80

Cost per hop

$C\{[D_1,D_2]\}$	7
$C\{[D_2,D_3]\}$	7
$C\{[D_2,D_3]\}$	2

Total cost

$C\{[D_1,D_2]\}$	7
$C\{[D_2,D_3]\}$	7
$C\{[D_2,D_3]\}$	2
Total	16

Path discovery

- When a device has data to transmit, it launches a path discovery procedure explained in the next few slides

Path discovery

- If a node has a packet it wants to transmit
  - It broadcasts a Route Request (RREQ) to neighbors

Src. Address	Req ID	Dest Address	Src Seq. #	Dest Seq. #	Hop Count

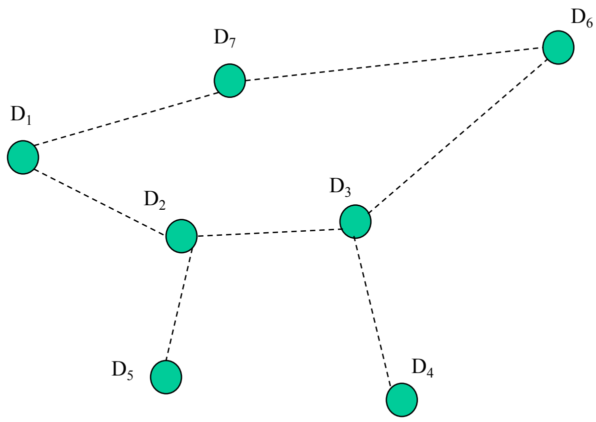
  - The neighbors rebroadcast the packet to their neighbors
  - Intermediate nodes reply with RREP if they have a route to destination with higher dsn

Path discovery

– The Route Reply (RREP) is a unicast packet

Src. Address	Dest Address	Dest Seq. #	Hop Count	Life Time

Example D1->D4



Sequence of packets

Recherche de route de D1 à D4									Nouvelle entrée dans la tabelle de routage			
NWK Adresse	De	à	Type de message	Req ID	Src Seq #	Dest Seq #	Hops		Dest	Seq	Hops	Next
Broadcast	D1	D7	RREQ	1	1	0	0		D1	1	1	D1
Broadcast	D1	D2	RREQ	1	1	0	0		D1	1	1	D1
Broadcast	D7	D6	RREQ	1	1	0	1		D1	1	2	D7
Broadcast	D7	D1	RREQ	1	1	0	1		Ecarter (même disp.)			
Broadcast	D2	D5	RREQ	1	1	0	1		D1	1	2	D2
Broadcast	D2	D3	RREQ	1	1	0	1		D1	1	2	D2
Broadcast	D2	D1	RREQ	1	1	0	1		Ecarter (même disp.)			
Broadcast	D6	D7	RREQ	1	1	0	2		Ecarter puisque déjà reçu			
Broadcast	D6	D3	RREQ	1	1	0	2		Ecarter puisque déjà reçu			
Broadcast	D5	D2	RREQ	1	1	0	2		Ecarter puisque déjà reçu			
Broadcast	D3	D2	RREQ	1	1	0	2		Ecarter puisque déjà reçu			
Broadcast	D3	D6	RREQ	1	1	0	2		Ecarter puisque déjà reçu			
Broadcast	D3	D4	RREQ	1	1	0	2		D1	1	3	D3
Unicast->D1	D4	D3	RREP	1	15	1	0		D4	15	1	D4
Unicast->D1	D3	D2	RREP	1	15	1	1		D4	15	2	D3
Unicast->D1	D2	D1	RREP	1	15	1	2		D4	15	3	D2