Advanced Internet of Things Technologies

Designed by: Thuat NGUYEN-KHANH

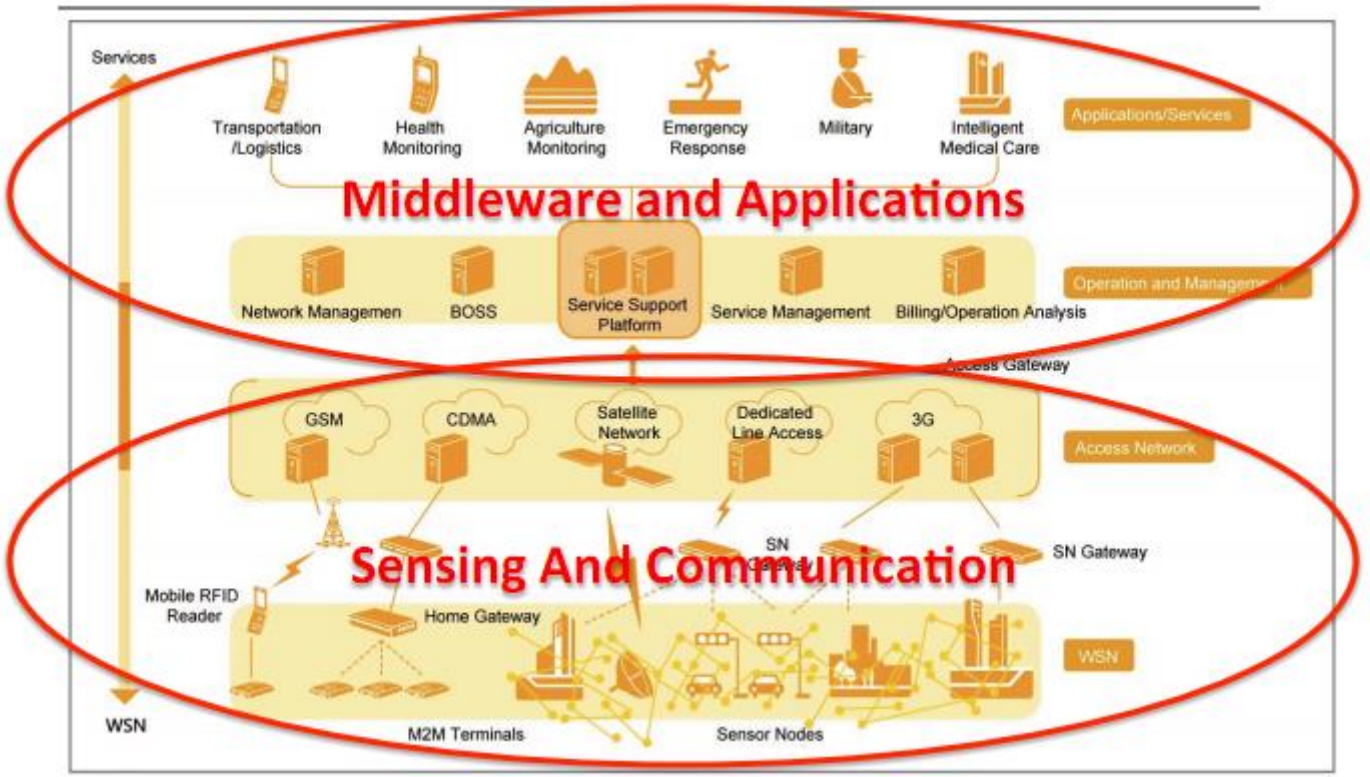
Lecturer at The Faculty of Computer Networks & Communications - UIT - VNU-HCM

Email: thuatnk@uit.edu.vn

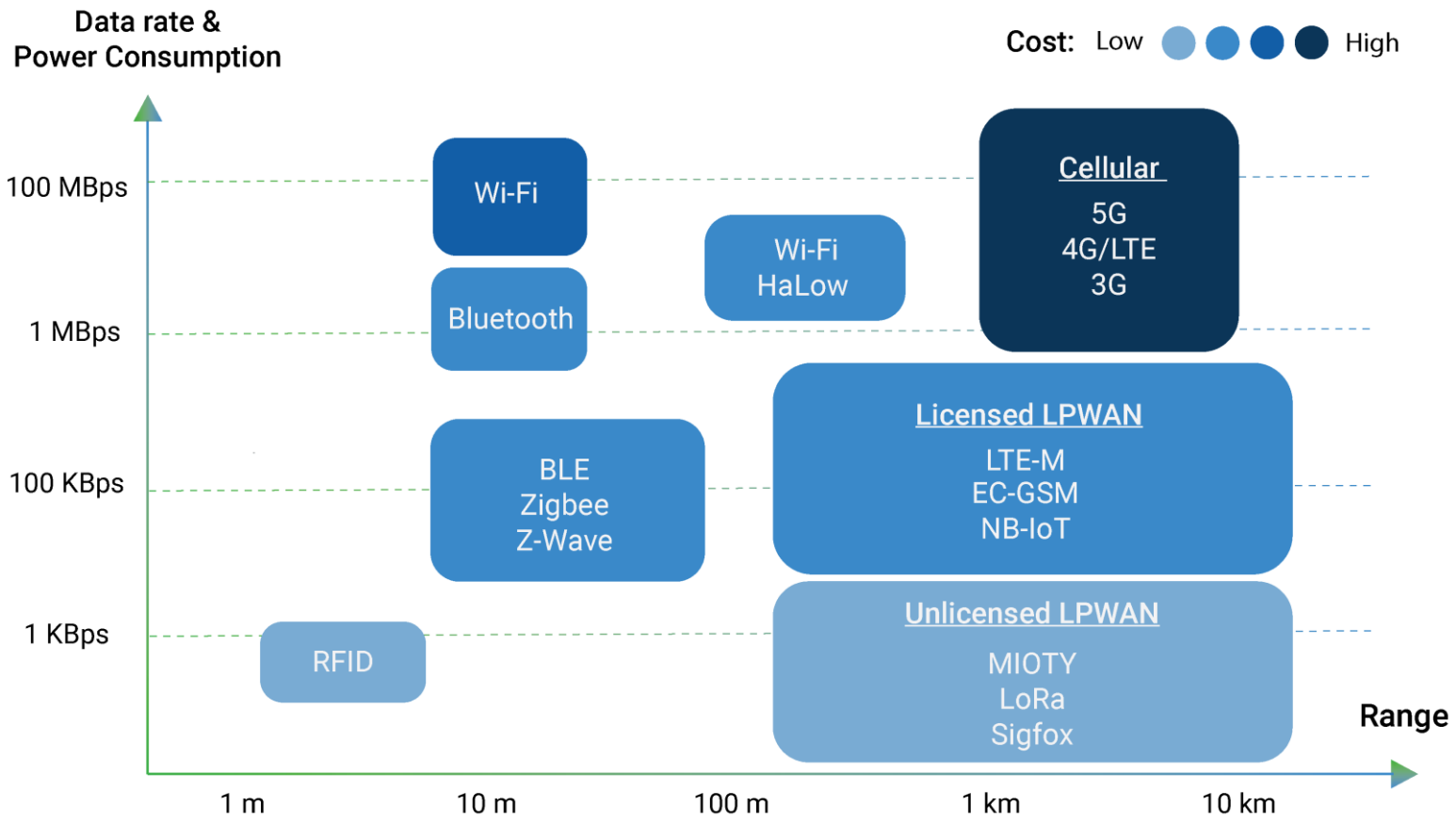
Chapter 4: IoT Wireless Technologies

- Zigbee Overview
- Physical Layer
- MAC Layer
- Network Layer
- Application Layer
- Security Service Provider
- ZigBee Address Assignment

IoT Layered Architecture

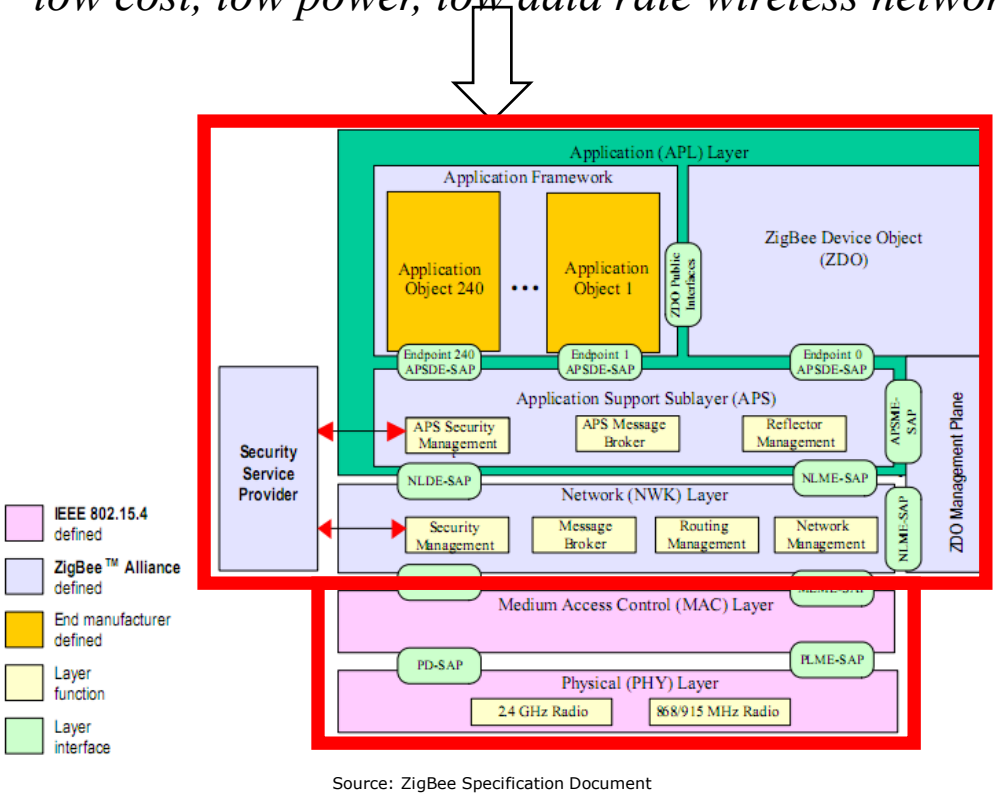


- Source: ZTE


Data rate &
Power Consumption
Cost: Low High
100 MBps
1 MBps
100 KBps
1 KBps
Wi-Fi
Bluetooth
BLE
Zigbee
Z-Wave
RFID
Wi-Fi
HaLow
Cellular
5G
4G/LTE
3G
Licensed LPWAN
LTE-M
EC-GSM
NB-IoT
Unlicensed LPWAN
MIOTY
LoRa
Sigfox
Range
1 m
10 m
100 m
1 km
10 km

ZigBee Overview

"low cost, low power, low data rate wireless networking"



Source: ZigBee Specification Document

ZigBee Alliance

- "The Software"
- Network, Security & Application Layers

IEEE 802.15.4

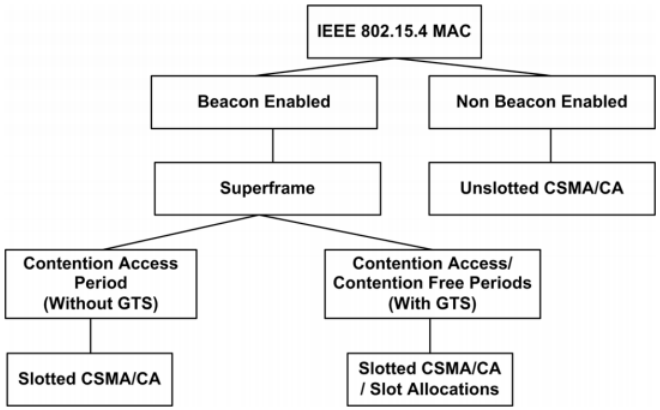
- "The Hardware"
- Physical & Medium Access Control Layers

ZigBee Physical Layer

- Physical Layer:
  - Frequency band:
    - 868 – 868.8 MHz (Europe) channel 0: 20kb/s
    - 902 – 928 MHz (USA, Canada, Australia) channel 1-11: 40kb/s
    - 2.4 – 2.4835 GHz (Other Country) channel 12-27: 250kb/s

ZigBee MAC (1/3)

- Medium Access Control (MAC) Layer:
  - Beacon Mode
    - Contention Access Period (CAP)
    - Contention Access Period (CAP)/ Contention Free Period (CFP)
  - Non Beacon Mode



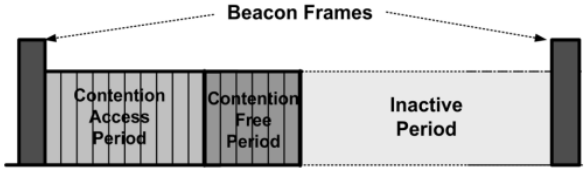
Source: IEEE 802.15.4 for Wireless Sensor Networks: A Technical Overview

ZigBee MAC (2/3)

- Medium Access Control (MAC) Layer:
  - Beacon Mode
    - Contention Access Period (CAP)

Source: IEEE 802.15.4 for Wireless Sensor Networks: A Technical Overview

    - Contention Access Period/Contention Free Period: (CAP/CFP)



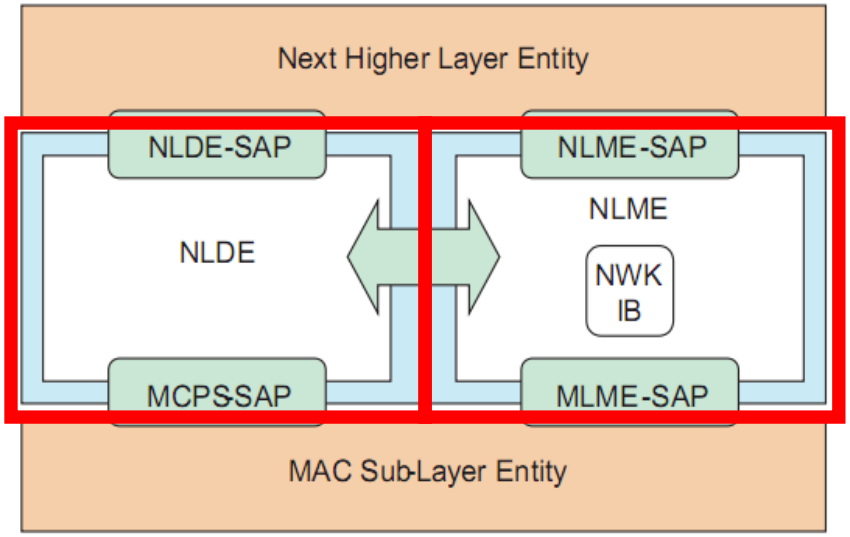
Source: IEEE 802.15.4 for Wireless Sensor Networks: A Technical Overview

ZigBee MAC (3/3)

- Medium Access Control (MAC) Layer:
  - Non Beacon Mode
    - Unslotted CSMA/CA
    - ACK frame

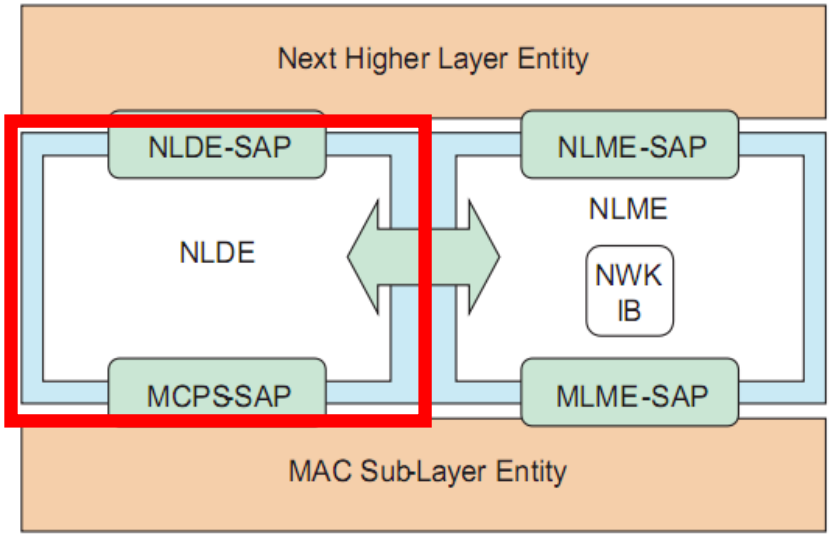
ZigBee Network Layer (1/3)

- Network Layer:
  - Network Layer Data Entity (NLDE)
  - Network Layer Management Entity (NLME)



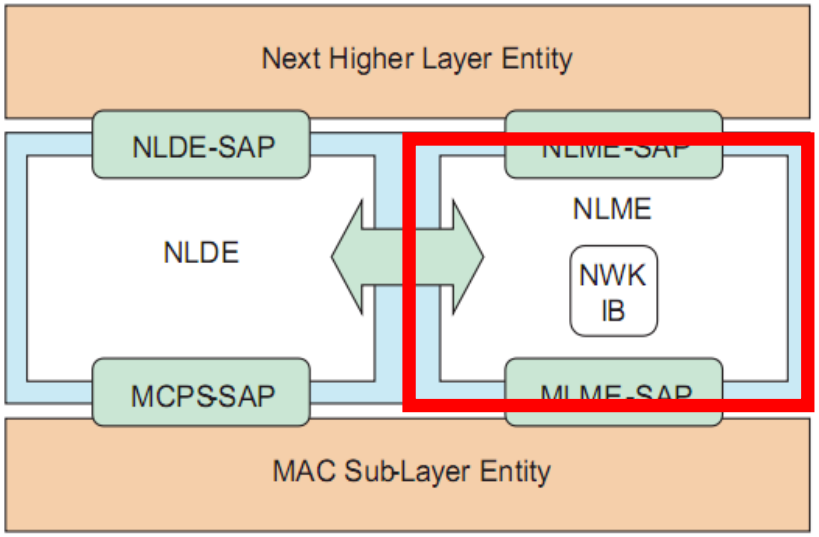
ZigBee Network Layer (2/3)

- Network Layer:
  - Network Layer Data Entity (NLDE):
    - Generation of the Network level PDU
    - Topology-specific routing
    - Security



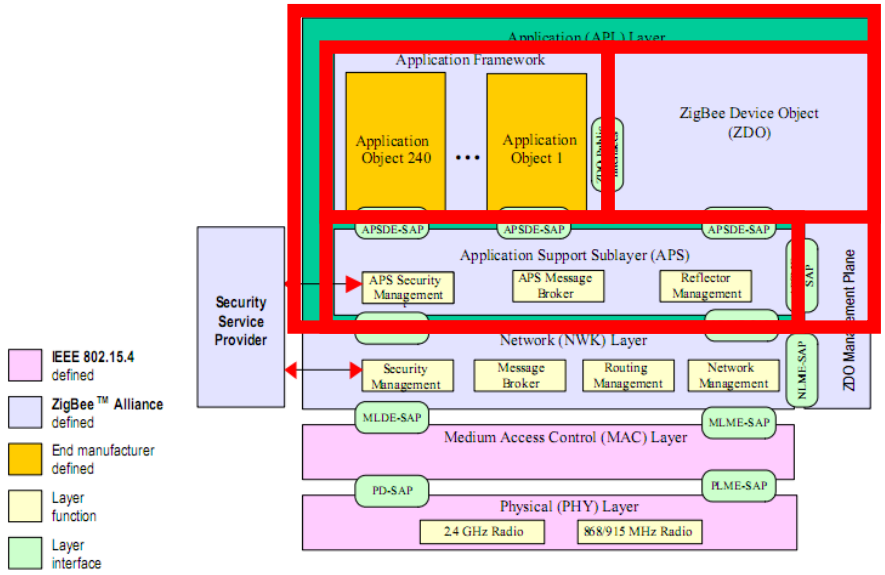
ZigBee Network Layer (3/3)

- Network Layer:
  - Network Layer Management Entity (NLME):
    - Configuring a new device
    - Starting a network
    - Joining, rejoining and leaving a network
    - Addressing
    - Neighbor discovery
    - Route discovery
    - Reception control
    - Routing



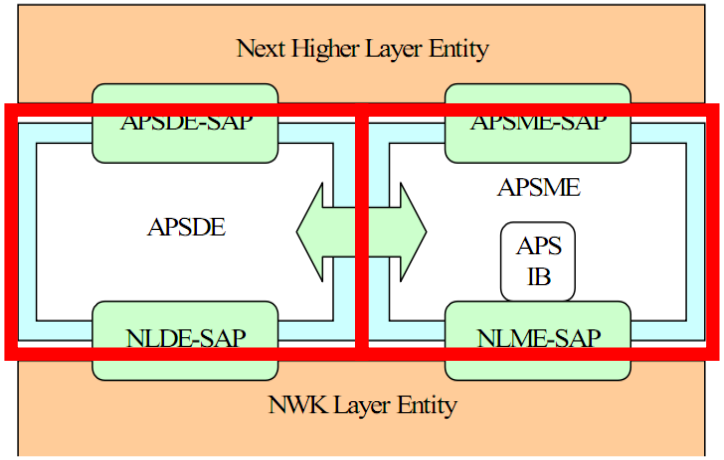
ZigBee Application Layer (1/8)

- Application Layer:
  - Application Support Sub-Layer (APS)
  - Application Framework
  - Zigbee Device Object (ZDO)



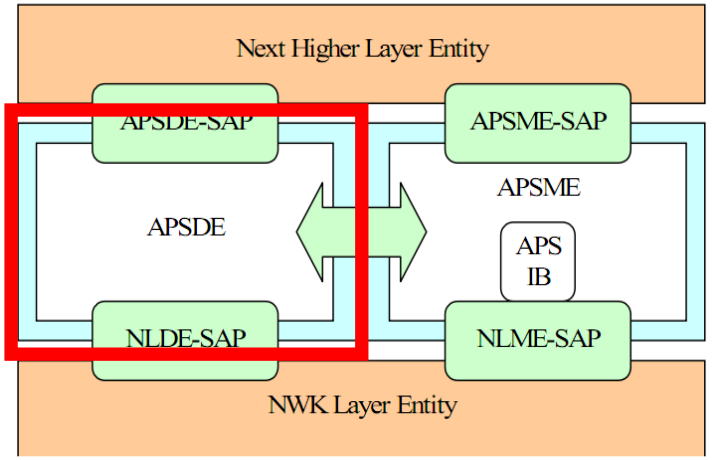
ZigBee Application Layer (2/8)

- Application Layer:
  - Application Support Sub-Layer (APS)
    - APS Data Entity (APSDE)
    - APS Management Entity (ASPME)



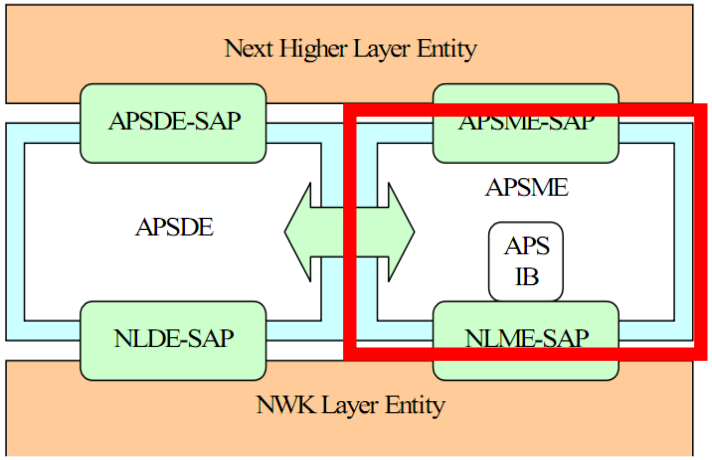
ZigBee Application Layer (3/8)

- Application Layer:
  - Application Support Sub-Layer (APS)
    - APS Data Entity (ASPDE)
      - Generation of the Application level PDU
      - Binding
      - Group address filtering
      - Reliable transport
      - Duplicate transport
      - Fragmentation



ZigBee Application Layer (4/8)

- Application Layer:
  - Application Support Sub-Layer (APS)
    - APS Management Entity (APSME)
      - Binding management
      - AIB management
      - Security
      - Group management

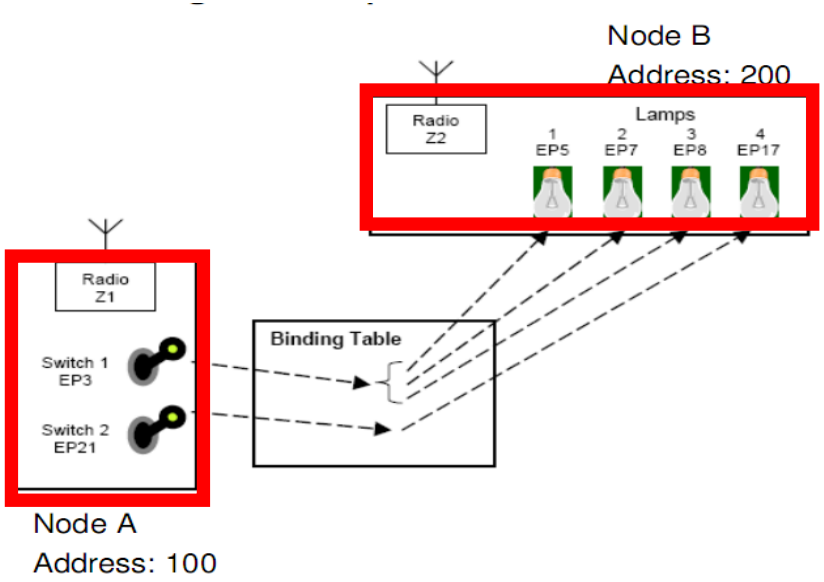


ZigBee Application Layer (5/8)

- Application Layer:
  - Application Framework:
    - Environment for hosting manufacturer defined application objects on Zigbee devices
    - Up to 240 Application Object can be defined (End Point 1-240)
      - EP 0: data interface to ZDO
      - EP 251-254: reserved
      - EP 255: broadcast data to all Application Object
    - Application Profile: agreements for messages, message formats and processing actions between any Application Object on the same Device

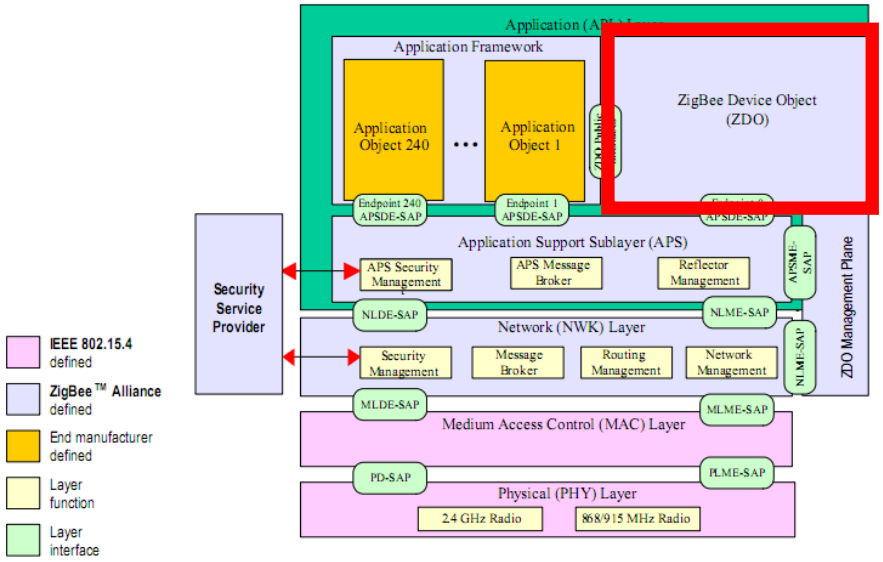
ZigBee Application Layer (6/8)

- Application Layer:
  - Application Framework:
    - Example:



ZigBee Application Layer (7/8)

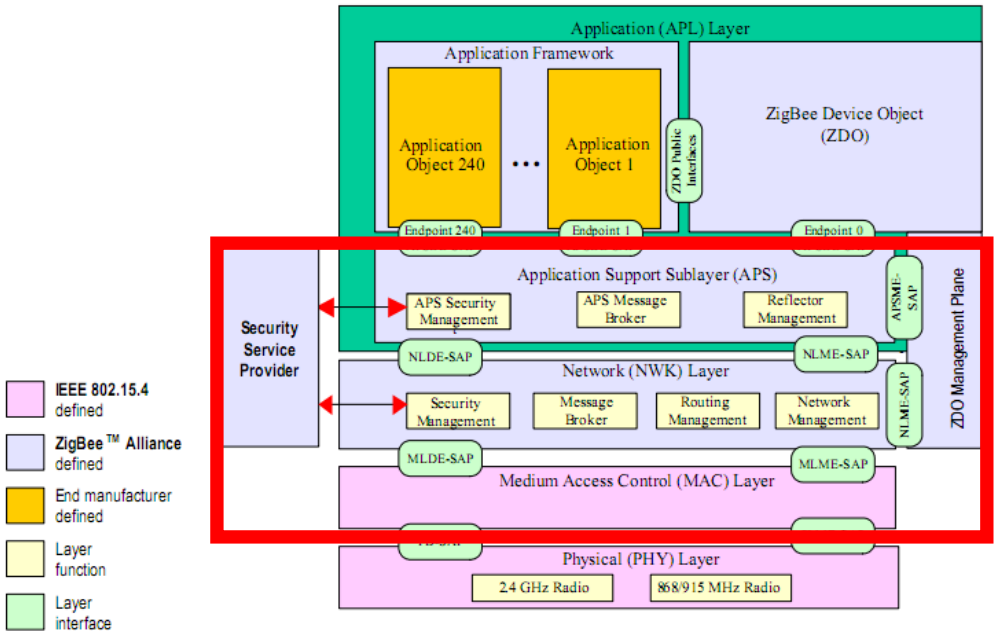
- Application Layer:
  - Zigbee Device Object (ZDO)



ZigBee Application Layer (8/8)

- Application Layer:
  - Zigbee Device Object (ZDO)
    - Be Implemented by all Node in network
    - Provides an interface between the Application Objects, the Device Profile and the APS
    - Four key inter-device communication functions:
      - Device and Service Discovery
      - End Device Bind and Unbind
      - Binding Table Management
      - Network Management

ZigBee Security Service Provider



- Security Service Provider:
  - Three Layers:
    - MAC security
    - NWK security
    - APL security
  - Three Key Types:
    - Master Key
    - Link Key
    - Network Key
  - Two Security Modes
    - Standard
    - High

ZigBee Address Assignment

- Each node gets a unique 16-bit address
- Two Schemes: Distributed and Stochastic
  - Distributed Scheme: Good for tree structure
    - Each child is allocated a sub-range of addresses.
    - Need to limit maximum depth L, Maximum number of children per parent C, and Maximum number of routers R
    - Address of the n^{th} child is parent + 1 + (n-1)*S(d)

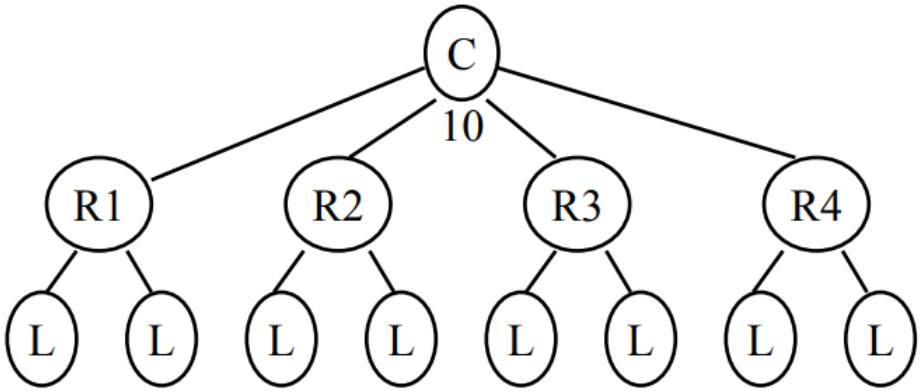
$$S(d) = \begin{cases} 1 + C(L-d) & \text{if } R = 1 \\ \frac{CR^{L-d-1} - 1 - C + R}{R-1} & \text{if } R > 1 \end{cases}$$

ZigBee Address Assignment

- Each node gets a unique 16-bit address
- Two Schemes: Distributed and Stochastic
  - Stochastic Scheme:
    - Parent draws as 16 bit random number between 1 and 2^{16}-1 and assigns it to a new child
    - Parent then advertises the number child to the network
    - If another node has that address an address conflict message is returned and the parent draws another number and repeats

ZigBee Address Assignment

- Distributed Scheme Example



d = 0

S(0) = ?

d = 1

S(1) = ?

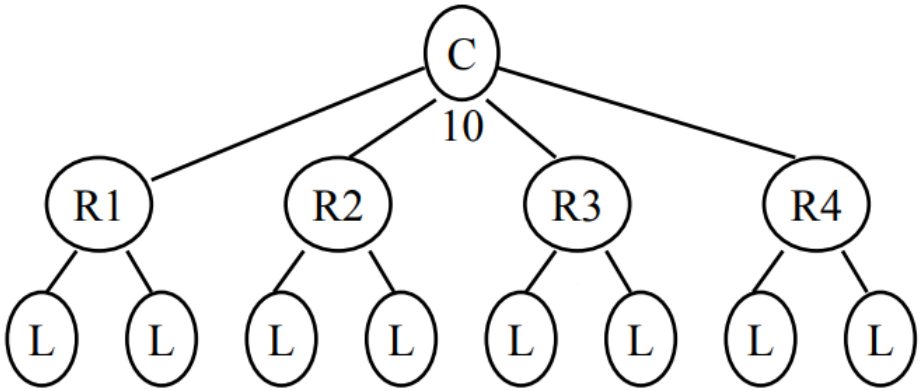
d = 2

Max depth L=2, Routers R=4, Children C=3

$$S(d) = \begin{cases} 1 + C(L-d) & \text{if } R = 1 \\ \frac{CR^{L-d-1} - 1 - C + R}{R-1} & \text{if } R > 1 \end{cases}$$

ZigBee Address Assignment

- Distributed Scheme Example



d = 0

S(0) = 4

d = 1

S(1) = ?

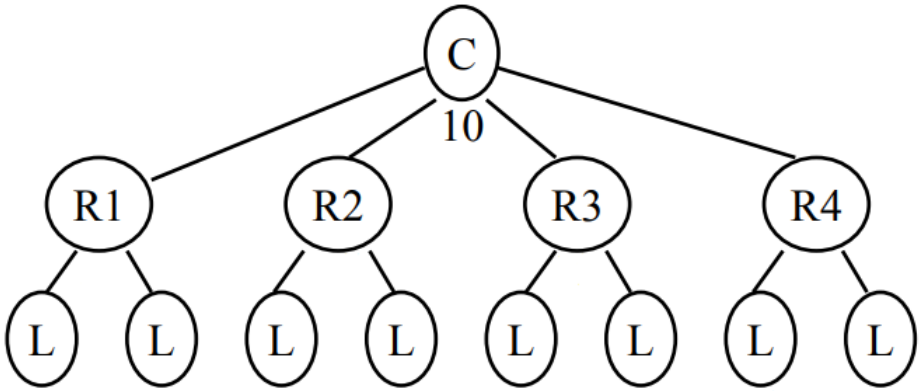
d = 2

Max depth L=2, Routers R=4, Children C=3

$$S(0) = \frac{CR^{L-d-1} - 1 - C + R}{R - 1} = \frac{3 \times 4^{2-0-1} - 1 - 3 + 4}{4 - 1} = 4$$

ZigBee Address Assignment

- Distributed Scheme Example



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d = 1

S(1) = 1

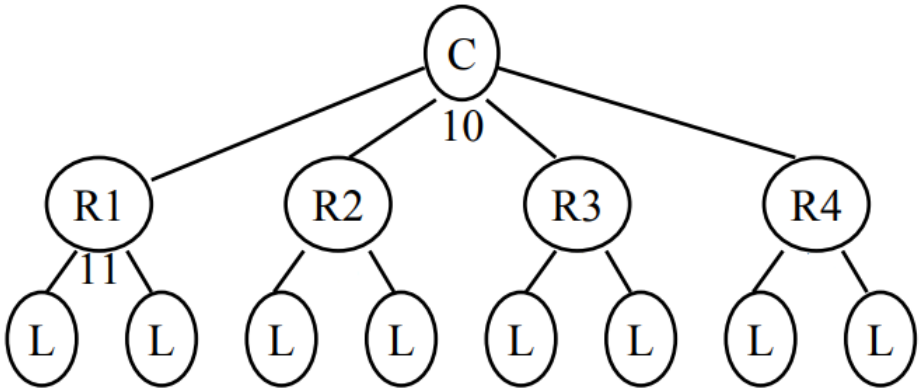
d = 2

Max depth L=2, Routers R=4, Children C=3

$$S(1) = \frac{CR^{L-d-1} - 1 - C + R}{R - 1} = \frac{3 \times 4^{2-1-1} - 1 - 3 + 4}{4 - 1} = 1$$

ZigBee Address Assignment

- Distributed Scheme Example



d = 0

S(0) = 4

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S(1) = 1

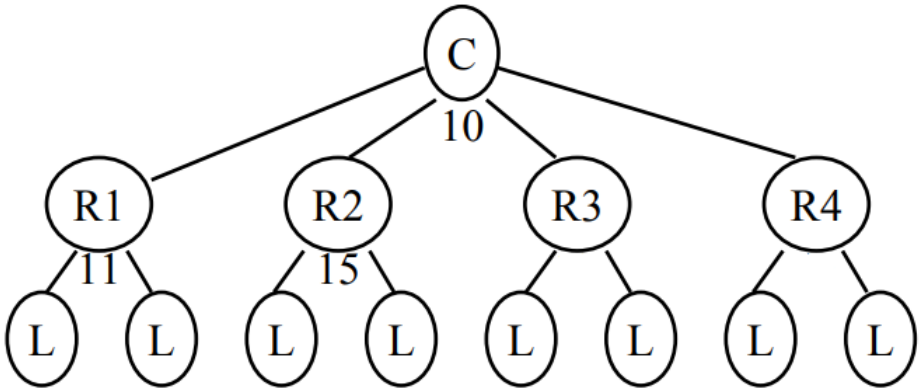
d = 2

Address of the n^{th} child is parent + 1 + (n-1)*S(d)

Address of R1: 10 + 1 + (1-1)*4 = 11

ZigBee Address Assignment

- Distributed Scheme Example



d = 0

S(0) = 4

d = 1

S(1) = 1

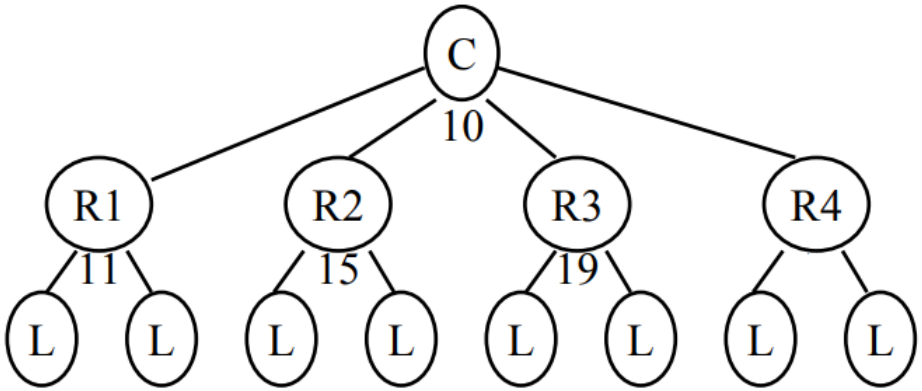
d = 2

Address of the n^{th} child is parent + 1 + (n-1)*S(d)

Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15

ZigBee Address Assignment

- Distributed Scheme Example



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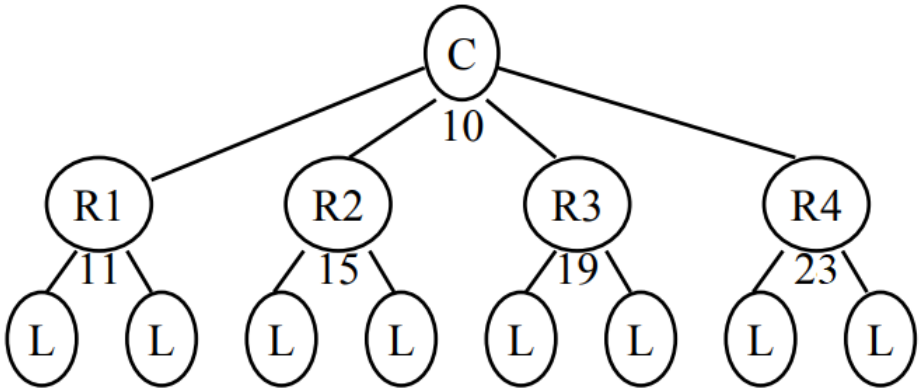
Address of the n^{th} child is parent + 1 + (n-1)*S(d)

Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15
Address of R3: 10 + 1 + (3-1)*4 = 19

ZigBee Address Assignment

- Distributed Scheme Example



d = 0

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S(1) = 1

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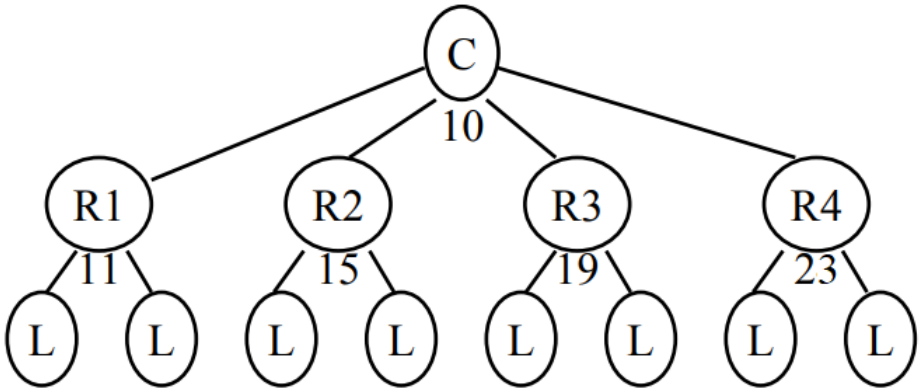
Address of the n^{th} child is parent + 1 + (n-1)*S(d)

Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15
Address of R3: 10 + 1 + (3-1)*4 = 19
Address of R4: 10 + 1 + (4-1)*4 = 23

ZigBee Address Assignment

- Distributed Scheme Example



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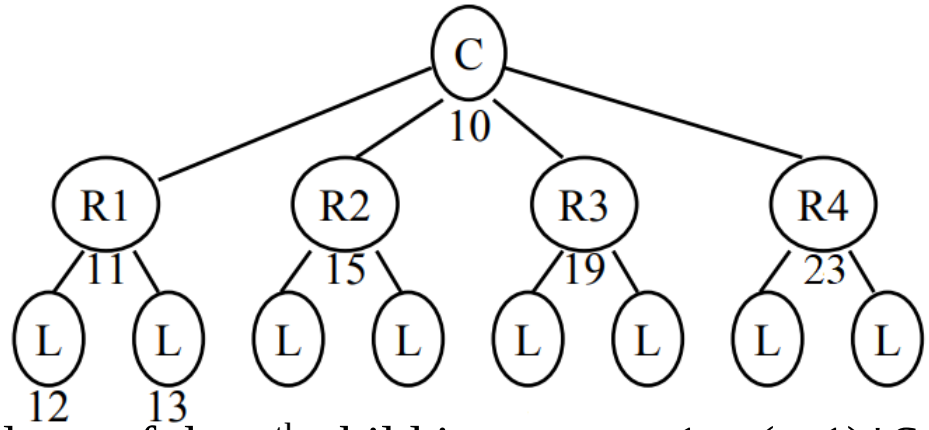
Address of the n^{th} child is parent + 1 + (n-1)*S(d)

Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15
Address of R3: 10 + 1 + (3-1)*4 = 19
Address of R4: 10 + 1 + (4-1)*4 = 23

Address of R1's child: ??

ZigBee Address Assignment

- Distributed Scheme Example



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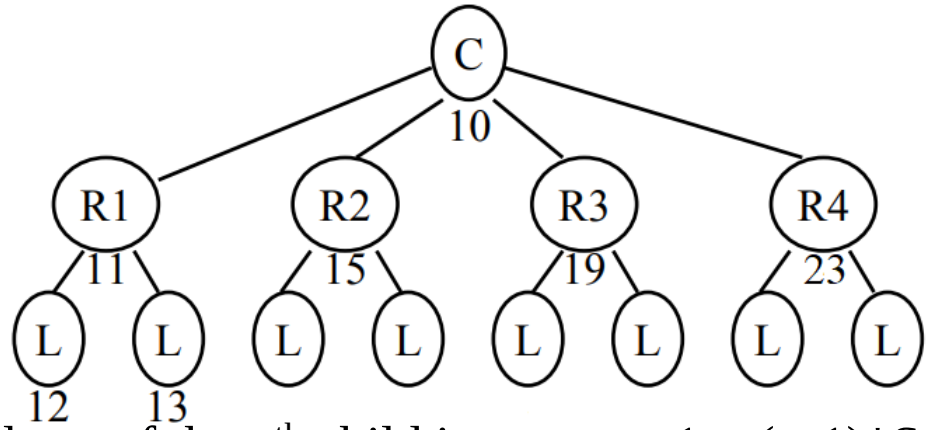
Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15
Address of R3: 10 + 1 + (3-1)*4 = 19
Address of R4: 10 + 1 + (4-1)*4 = 23

Address of R1's child: 12 and 13

ZigBee Address Assignment

- Distributed Scheme Example



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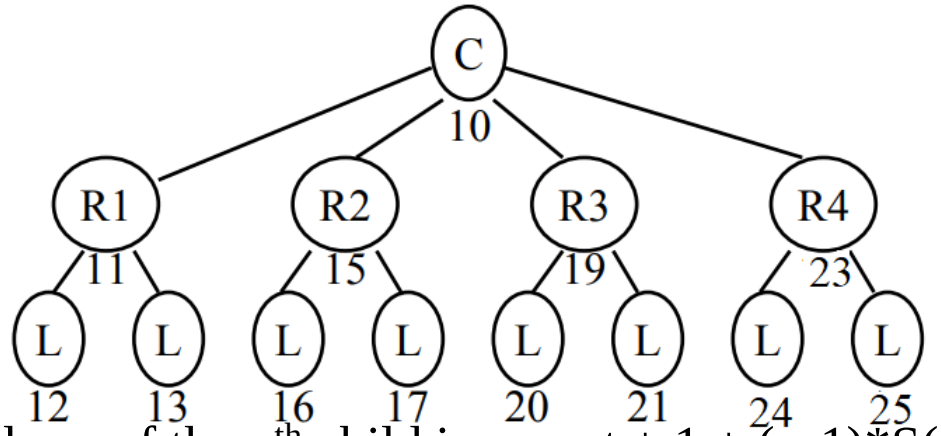
Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15
Address of R3: 10 + 1 + (3-1)*4 = 19
Address of R4: 10 + 1 + (4-1)*4 = 23

Address of R1's child: 12 and 13
Address of R2's child: ??
Address of R3's child: ??
Address of R4's child: ??

ZigBee Address Assignment

- Distributed Scheme Example



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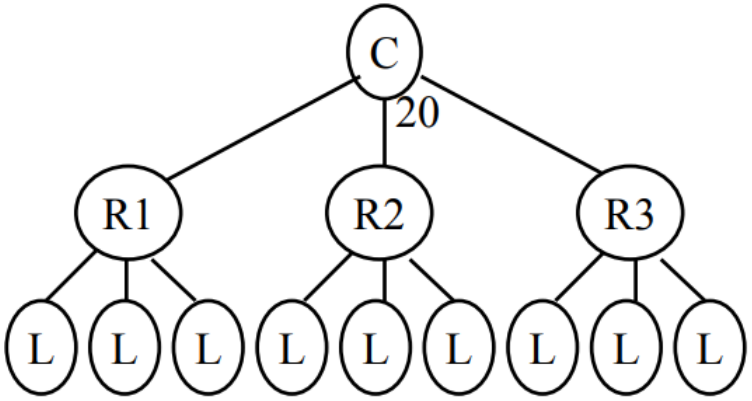
Address of R1: 10 + 1 + (1-1)*4 = 11
Address of R2: 10 + 1 + (2-1)*4 = 15
Address of R3: 10 + 1 + (3-1)*4 = 19
Address of R4: 10 + 1 + (4-1)*4 = 23

Address of R1's child: 12 and 13
Address of R2's child: 16 and 17
Address of R3's child: 20 and 21
Address of R4's child: 24 and 25

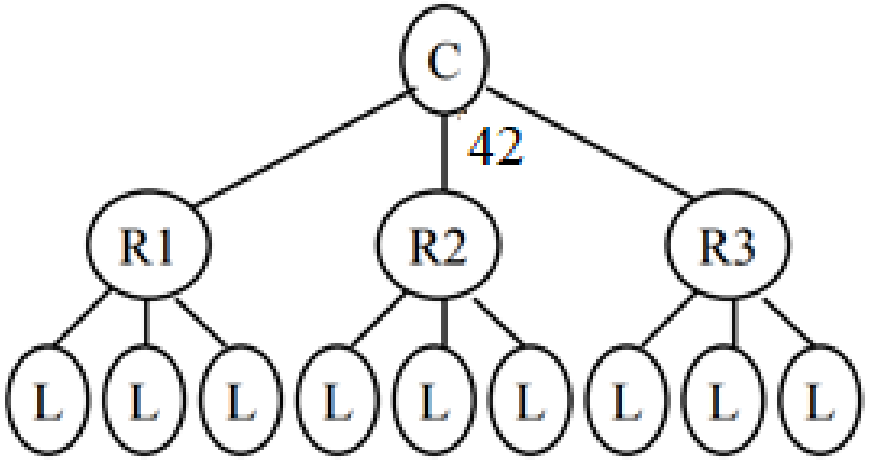
Exercise 1

Assuming that IEEE 802.15.4 network is being planned with a maximum of 5 children per node to a depth of 2 levels and maximum 4 routers. Compute sub-ranges to be assigned to each router and the addresses assigned to each node in the network assuming the coordinator has an address of 20.



Exercise 2

The same to Exercise 1, but Max depth L=2, Routers R=3, Children C=3, Coodinator Address is 42



Summary

- Introduce to Zigbee
- The 2 lower layers is IEEE 802.15.4
- The 2 upper layers are defined by Zigbee Alliance
- ZigBee Security Service Provider
- Two Type of Zigbee Address Assignment
- Zigbee Address Assignment example


Q & A