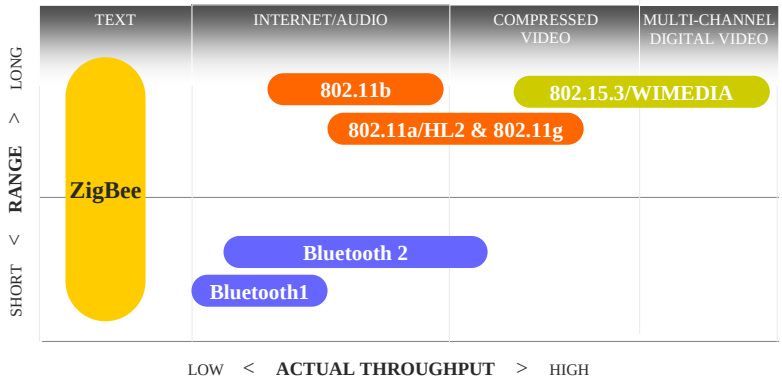
IEEE 802.15.4 MAC

Outline

- ZigBee Overview
- IEEE 802.15.4 MAC overview
- General MAC frame format
- Superframe structure

The Wireless Market



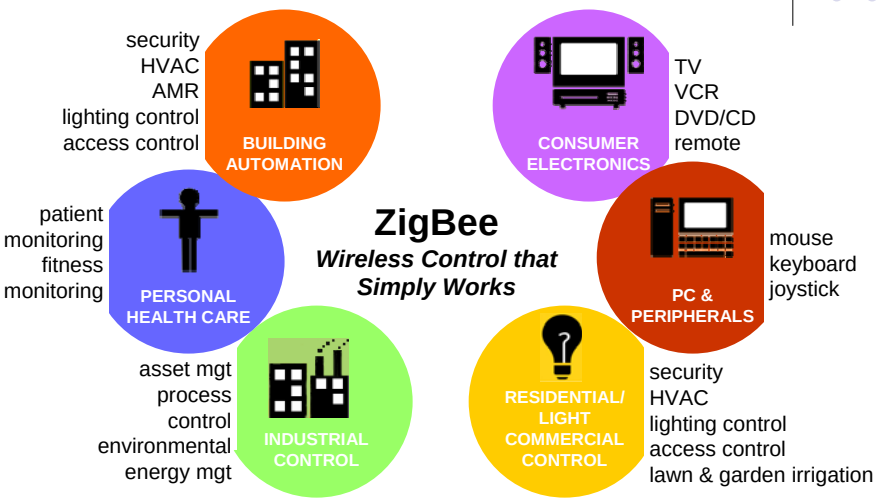
What is the ZigBee Alliance?

- An Organization
  - Define reliable, cost-effective, low-power, wirelessly networked, **monitoring and control** products based
- Alliance provides
  - upper layer stack and application profiles
  - compliance and certification testing
  - branding
- Result is a set of interoperable solutions recognizable in the market

Why do we need ZigBee technology?

- No standard approach today
  - Enables the **broad-based** deployment of reliable wireless networks with *low complexity, low cost solutions*
  - Provides the ability to run for years on inexpensive primary batteries for a typical monitoring application
  - Capable of inexpensively supporting robust mesh networking technologies

Applications



Wireless Technology Comparison Chart

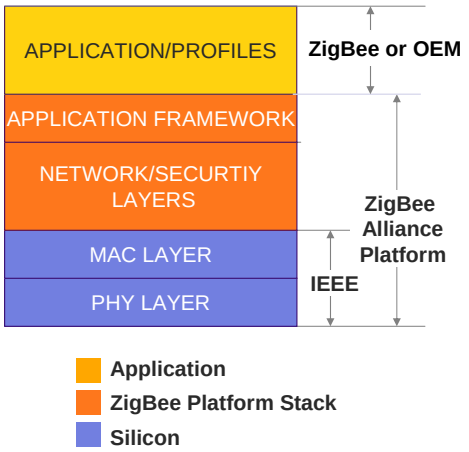
Standard	Bandwidth	Power Consumption	Protocol Stack Size	Stronghold	Applications
Wi-Fi	Up to 54Mbps	400+mA TX, standby 20mA	100+KB	High data rate	Internet browsing, PC networking, file transfers
Bluetooth	1Mbps	40mA TX, standby 0.2mA	~100+KB	Interoperability, cable replacement	Wireless USB, handset, headset
ZigBee	250kbps	30mA TX, standby 356 µA	34KB /14KB	Long battery life, low cost	Remote control, battery-operated products, sensors

How is ZigBee related to IEEE 802.15.4?

- ZigBee takes full advantage of a powerful physical radio specified by IEEE 802.15.4
- ZigBee adds logical network, security and application software
- ZigBee continues to work closely with the IEEE to ensure an integrated and complete solution for the market

Protocol Stack Features

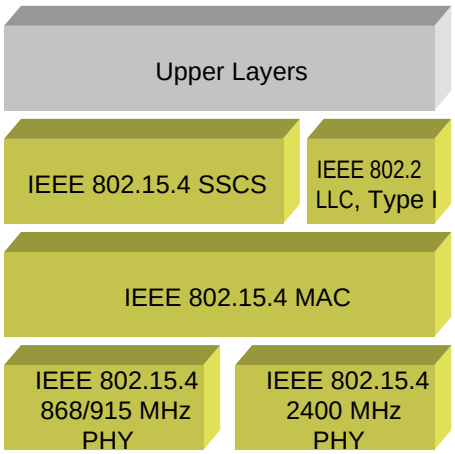
- 8-bit microcontroller (e.g. 80c51)
- Compact protocol stack
- Supports even simpler slave-only stack



Frequencies and Data Rates

BAND	COVERAGE	DATA RATE	# OF CHANNEL(S)
2.4 GHz ISM	Worldwide	250 kbps	16
868 MHz	Europe	20 kbps	1
915 MHz ISM	Americas	40 kbps	10

IEE 802.15.4 System Architecture



IEEE 802.15.4 MAC Overview

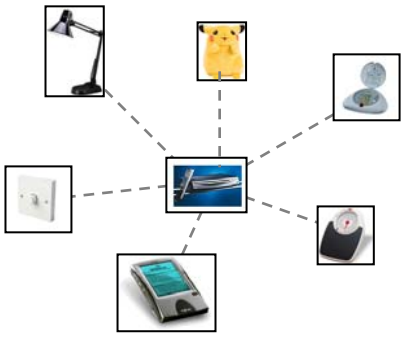
Design Drivers

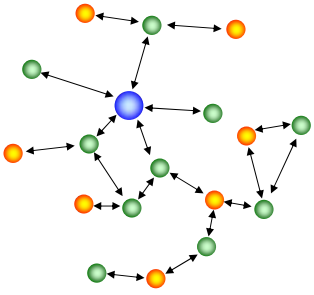
- Extremely low cost
- Ease of implementation
- Reliable data transfer
- Short range operation
- Very low power consumption

Simple but flexible protocol

IEEE 802.15.4 MAC Overview

Typical Network Topologies





IEEE 802.15.4 MAC Overview

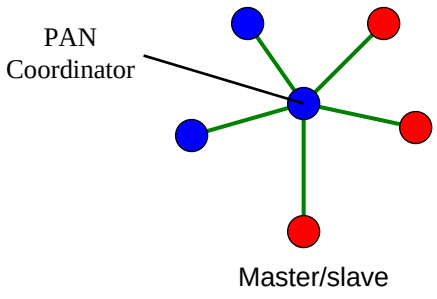
Device Classes

- 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
Device Classes

- Network Device: An RFD or FFD implementation containing an IEEE 802.15.4 medium access control and physical interface to the wireless medium.
- Coordinator: An FFD with network device functionality that provides coordination and other services to the network.
- PAN Coordinator: A coordinator that is the principal controller of the PAN. A network has exactly one PAN coordinator.

IEEE 802.15.4 MAC Overview
Star Topology



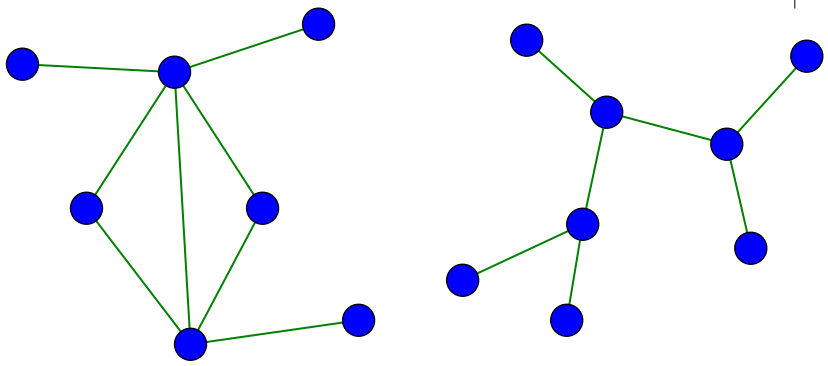
Full function device

Reduced function device

Communications flow

IEEE 802.15.4 MAC Overview

Peer-Peer Topology



Point to point

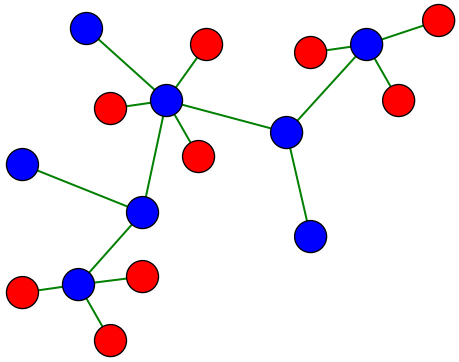
Cluster tree

Full function device

Communications flow

IEEE 802.15.4 MAC Overview

Combined Topology



Clustered stars - for example, cluster nodes exist between rooms of a hotel and each room has a star network for control.

Full function device

Reduced function device

Communications flow

IEEE 802.15.4 MAC Overview

Traffic Types

- Periodic data
  - Application defined rate (e.g. sensors)
- Intermittent data
  - Application/external stimulus defined rate (e.g. light switch)
- Repetitive low latency data
  - Allocation of time slots (e.g. mouse)

IEEE 802.15.4 MAC Overview

Design Drivers

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- Ease of implementation
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- Short range operation
- Very low power consumption

Simple but flexible protocol

IEEE 802.15.4 MAC Overview
Low-Power Operation

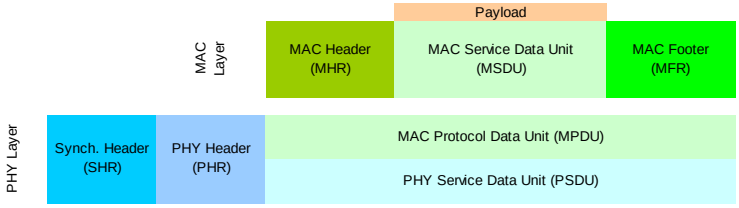
- Duty-cycle control using superframe structure
  - Beacon order and superframe order
  - Coordinator battery life extension
- Indirect data transmission
- Devices may sleep for extended period over multiple beacons
- Allows control of receiver state by higher layers

IEEE 802.15.4 MAC overview

- The MAC sublayer is responsible for the following tasks:
  - Generating network ***beacons*** if the device is a coordinator.
  - ***Synchronizing*** to the beacons.
  - Supporting PAN ***association*** and ***disassociation***.
  - Supporting device ***security***.
  - Employing the ***CSMA-CA mechanism*** for channel access.
  - Handling and maintaining the ***GTS*** mechanism.
  - Providing a ***reliable link*** between two peer MAC entities.

IEEE 802.15.4 MAC Overview

General Frame Structure

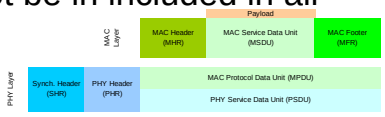


4 Types of MAC Frames:

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

General MAC frame format

- The MAC frame format is composed of a MHR, a MAC payload, and a MFR.
- The addressing fields may not be in included in all frames.



Octets:2	1	0/2	0/2/8	0/2	0/2/8	variable	2
Frame control	Sequence number	Destination PAN identifier	Destination address	Source PAN identifier	Source address	Frame payload	Frame check sequence
		Addressing fields					
MAC header						MAC payload	MAC footer

General MAC Frame Format

Octets:2	1	0/2	0/2/8	0/2	0/2/8	variable	2
Frame control	Sequence number	Destination PAN identifier	Destination address	Source PAN identifier	Source address	Frame payload	Frame check sequence
		Addressing fields					
MAC header						MAC payload	MAC footer

Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame type	Security enabled	Frame pending	Ack. Req.	Intra PAN	Reserved	Dest. addressing mode	Reserved	Source addressing mode

Frame control field

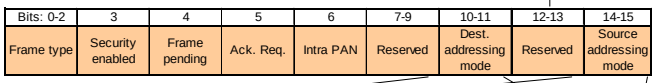
Frame type subfield

Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame type	Security enabled	Frame pending	Ack. Req.	Intra PAN	Reserved	Dest. addressing mode	Reserved	Source addressing mode

Frame type value $b_2\ b_1\ b_0$	Description
000	Beacon
001	Data
010	Acknowledgment
011	MAC command
100–111	Reserved

- 3 bits in length and shall be set to one of the nonreserved value.

Destination and source addressing mode subfield



Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame type	Security enabled	Frame pending	Ack. Req.	Intra PAN	Reserved	Dest. addressing mode	Reserved	Source addressing mode

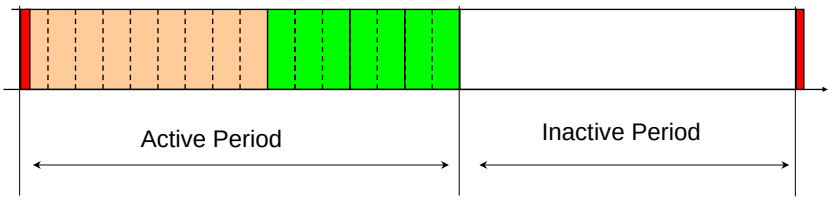
Addressing mode value $b_1\ b_0$	Description
00	PAN identifier and address field are not present.
01	Reserved.
10	Address field contains a 16 bit short address.
11	Address field contains a 64 bit extended address.

- All devices operating on a network shall have unique 64 bit extended addresses.
  - For direct communication within the PAN
  - Exchanged for a short address allocated by the PAN coordinator when the device associates

Superframe structure

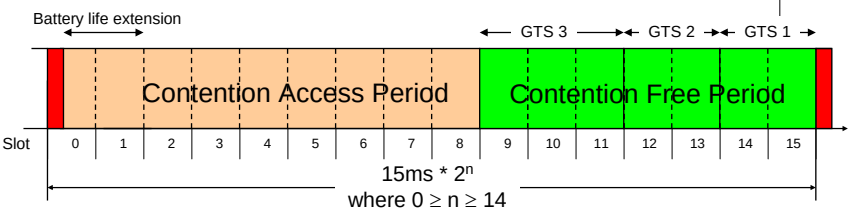
- Coordinator on a PAN can optionally bound its channel time using a superframe structure.
- A superframe is bounded by the transmission of a beacon frame and can have an active portion and an inactive portion.
- The coordinator shall interact with its PAN only during the active portion of the superframe
  - Enter a low power (sleep) mode during the inactive portion.

Optional Frame Structure



- Superframe may have inactive period

Optional Frame Structure



Network beacon		Transmitted by PAN coordinator. Contains network information, frame structure and notification of pending node messages.
Contention period		Access by any node using CSMA-CA
Guaranteed Time Slot		Reserved for nodes requiring guaranteed bandwidth [n = 0].

Superframe structure

- Beacons
  - Synchronize the attached devices
  - Identify the PAN
  - Describe the structure of the superframe.
- Any device wishing to communicate during CAP between two beacons shall compete with other devices
  - Slotted CSMA/CA mechanism.
- All transactions shall be completed by the time of the next network beacon

Superframe structure

- For low-latency applications or applications requiring specific data bandwidth, the PAN coordinator may dedicate portions of the active superframe to that application.
  - Guaranteed time slots (GTSs)
  - Appears at the end of the active superframe starting at a slot boundary immediately following the CAP.
  - GTSs form the contention-free period (CFP)

Superframe structure

- The PAN coordinator may allocate up to seven of these GTSs and a GTS may occupy more than one slot period.

- All contention based transactions shall be complete before the CFP begins.
- Each device transmitting in a GTS shall ensure that its transaction is complete before the time of the next GTS or the end of the CFP.