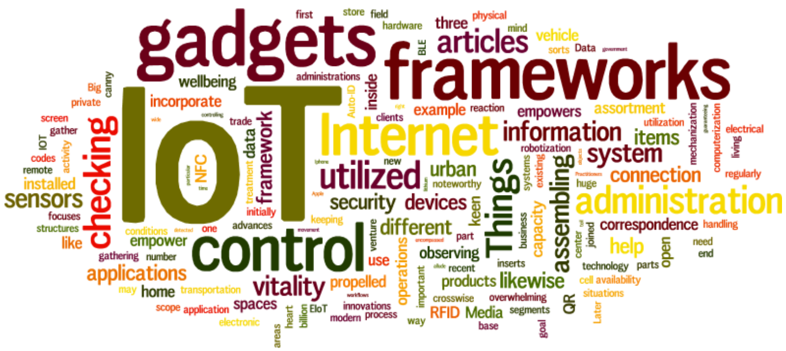
CS578: Internet of Things

Long Range
IoT Access Technologies

LoRa, HaLow, NB-IoT



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"All Birds find shelter during a rain. But Eagle avoids rain by flying above the Clouds" – **APJ Abdul Kalam**

IoT Access Technologies

- there are many IoT technologies in the market today

Sub-1GHz
LoRaWAN™
ZigBee®
4G
5G
WirelessHART
6LoWPAN
NB-IoT™
NFC
HaLow 802.11ah
Bluetooth®
sigfox
6TiSCH
WiFi
nwave
THREAD
Z-WAVE®

LoRaWAN

LoRaWAN is a wireless networking protocol **published in 2015**.

For more details: https://lora-alliance.org/

LPWA Technology

- A new set of wireless technologies has received a lot of attention from the industry, know as
  - **Low-Power Wide-Area** (LPWA) networking technology

- unlicensed-band LPWA technology
  - LoRaWAN

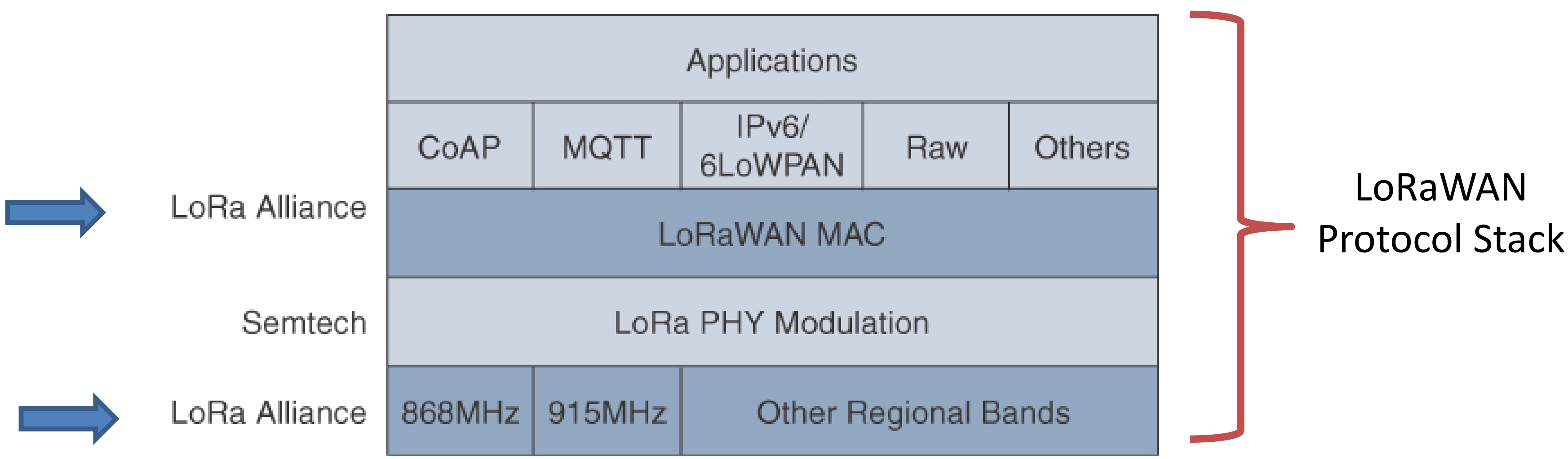
- licensed-band LPWA technology
  - NB-IoT and Other LTE Variations

LoRa Alliance

- Initially, **LoRa** was a **PHY layer modulation scheme**
  - developed by a French company “Cycleo”;   Later, Cycleo was acquired by Semtech.
  - **Semtech LoRa**: PHY modulation technology available by multiple chipset vendors

- The **LoRa Alliance** is a technology alliance committed to
  - enabling large scale deployment of Low-Power Wide Area Networks (LPWAN) IoT
  - publishing LoRaWAN specifications for LPWAN

- **LoRaWAN** is a premier solution for global LPWAN deployments at present
  - Its MAC-layer protocol built on top of LoRa PHY



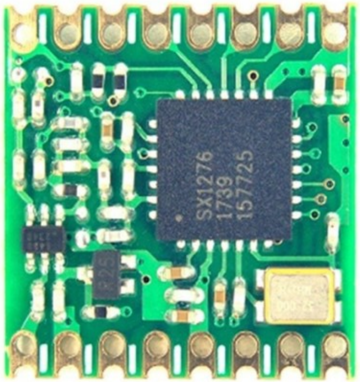
LoRa PHY layer

- Semtech LoRa PHY

- Uses a variation of **chirp spread spectrum** (CSS) modulation
  - ➢ it allows demodulation below the noise floor.
    So, offers robustness to noise and interference

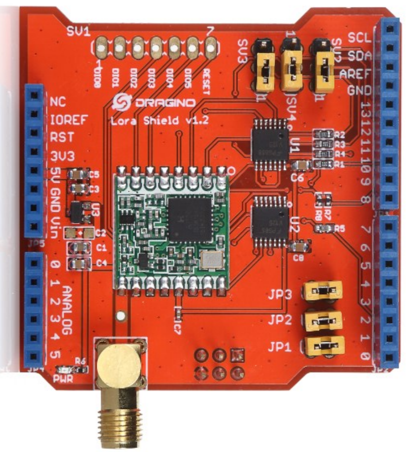
  - ➢ manages a single channel occupation by different spreading factors (SFs)

- Main unlicensed sub-GHz frequency bands
  - 433 MHz
  - 779–787 MHz
  - 863–870 MHz (In India: 868 MHz)
  - 902–928 MHz



LoRa Module: **SX1276**
868MHz band

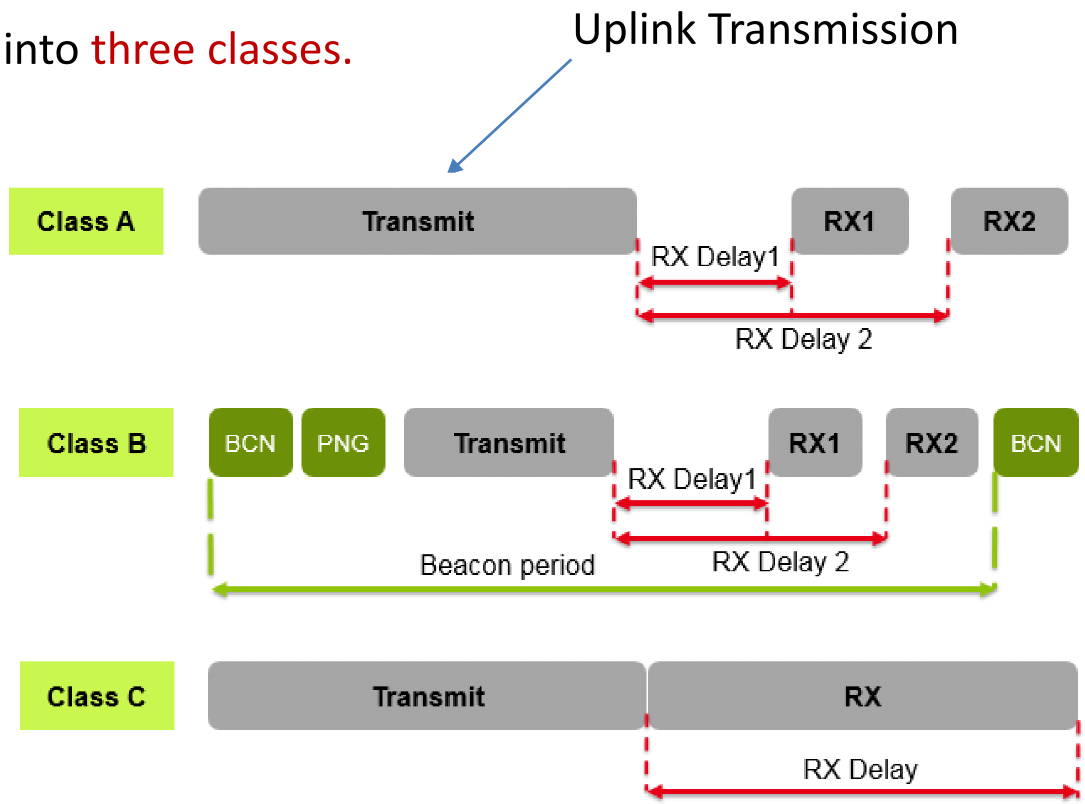
LoRa GPS Shield
with Arduino



LoRa Shield for Arduino

LoRaWAN MAC layer

- LoRaWAN endpoints are classified into three classes.



Class A:

- this is default implementation
- optimized for battery-powered nodes

- allows bidirectional communications
- two receive windows are available after each transmission

Class B:

- Class B node should get additional receive windows compared to Class A controlled by BCN

- gateways are synchronized through a beaconing process

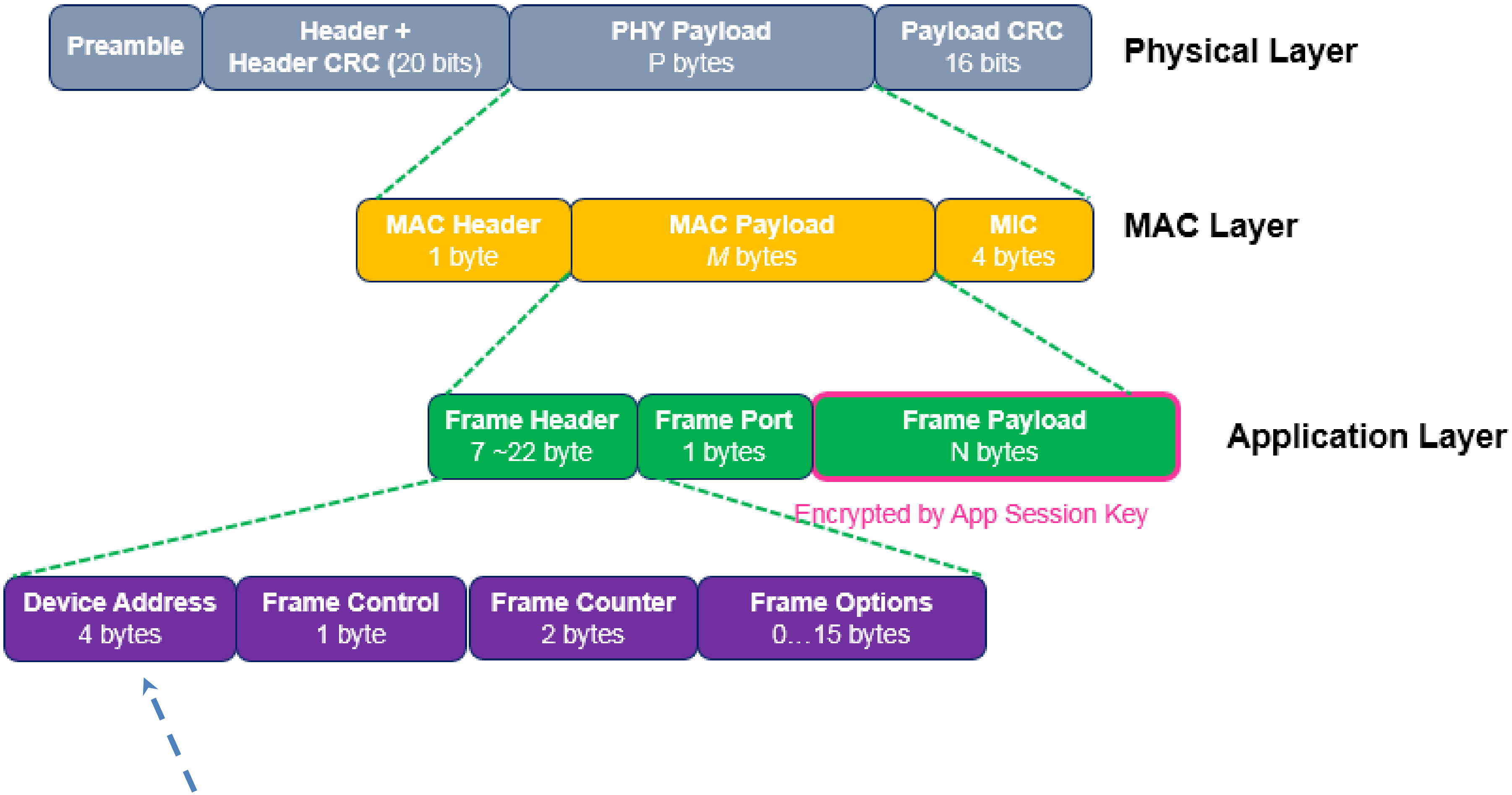
- "ping slots", can be used by the network infrastructure to initiate a downlink communication

Class C:

- This class is particularly adapted for powered nodes

- enables a node to be continuously listening by keeping its receive window open when not transmitting

LoRaWAN MAC Frame Format



Node Addressing: endpoints are also known by their **32-bit end device address**

- 7 bit for network + 25 bit for devices

LoRaWAN Address Space

- LoRaWAN uses a number of identifiers for devices, applications and gateways.
  - DevAddr - 32 bit device address (non-unique)
  - **DevEUI** - 64 bit end-device identifier, EUI-64 (unique)
  - **AppEUI** - 64 bit application identifier, EUI-64 (unique)
  - **GatewayEUI** - 64 bit gateway identifier, EUI-64 (unique)
- In LoRaWAN , DevEUI is assigned to the device by the chip manufacturer or the authorized owner.
- However, all local communication is done with a dynamic DevAddr
  - of which 7 bits are fixed for the Network, leaving 25 bits can be assigned to individual devices.

* EUI-64 (Extended Unique Identifier) has a method we can use to automatically configure IPv6 host addresses.

LoRaWAN Gateway

- LoRa **gateway** is deployed as the **centre hub** of a star network architecture.

- It uses multiple transceivers and channels
  - It can demodulate multiple channels at once
  - It can also demodulate multiple signals on the same channel simultaneously

- LoRa **gateways** serve as a transparent Bridge relaying data between endpoints

- The **endpoints** use a single-hop wireless connection to communicate with one or many gateways

- **Data rate** varies depending on the frequency bands and adaptive data rate (ADR)
  - ADR is an algorithm that manages data rate and radio signal for each endpoint.

Dragino
LoRa Gateway Device

Cont…

- LoRa has the ability to handle various data rates via spreading factor (SF)
- Best practices:
  - Use **adaptive data rate** (ADR) for fixed endpoints
  - Use **fixed data rate** or **spreading factor (SF)** for mobile endpoints

LoRaWAN Data Rate Example

- Low SF → high data rate, less distance
- High SF → low data rate, longer distance

Configuration	863–870 MHz bps	902–928 MHz bps
LoRa: SF12/125 kHz	250	N/A
LoRa: SF11/125 kHz	440	N/A
LoRa: SF10/125 kHz	980	980
LoRa: SF9/125 kHz	1760	1760
LoRa: SF8/125 kHz	3125	3125
LoRa: SF7/125 kHz	5470	5470
LoRa: SF7/250 kHz	11,000	N/A
FSK: 50 kbps	50,000	N/A
LoRa: SF12/500 kHz	N/A	980
LoRa: SF11/500 kHz	N/A	1760
LoRa: SF10/500 kHz	N/A	3900
LoRa: SF9/500 kHz	N/A	7000
LoRa: SF8/500 kHz	N/A	12,500
LoRa: SF7/500 kHz	N/A	21,900

LoRaWAN Security

- LoRaWAN supports to protect communication and data privacy across the network
- LoRaWAN **endpoints** must implement **two layers of security**
  - Network security applied in MAC layer
    - **Authentication**: do authentication of the endpoints
    - **Confidentiality**: encrypt LoRaWAN packets using AES
    - Each endpoint implements a network session key (NwkSKey)
    - **Integrity**: The NwkSKey ensures data integrity using message integrity code (MIC) of every data packet
  - Data security applied at the end points (end device / application server)
    - second layer of security by an application session key (AppSKey)
    - performs encryption / decryption between the Endpoint and its Application server.
    - it computes and checks the application-level MIC
- LoRaWAN **service provider** does not have access to the application payload if it is not allowed

LoRaWAN Node Registration

- LoRaWAN endpoints attached to a LoRaWAN network must get registered and authenticated.
  - **Activation by personalization** (ABP)
    - Endpoints don't need to run a join procedure
    - Individual details (e.g. NwkSKey and AppSKey keys, and DevAddr) are **preconfigured** and **stored in the end device**.
    - This same information is registered in the LoRaWAN network server.
  - **Over-the-air activation** (OTAA)
    - Endpoints are allowed to **dynamically join** a particular LoRaWAN network after successfully going through a join procedure.
    - During the join process, the node establishes its credentials with a LoRaWAN network server, exchanging its <u>globally unique DevEUI, AppEUI, and AppKey.</u>
    - AppKey is then used to derive the session keys: NwkSKey and AppSKey.

IEEE 802.11ah

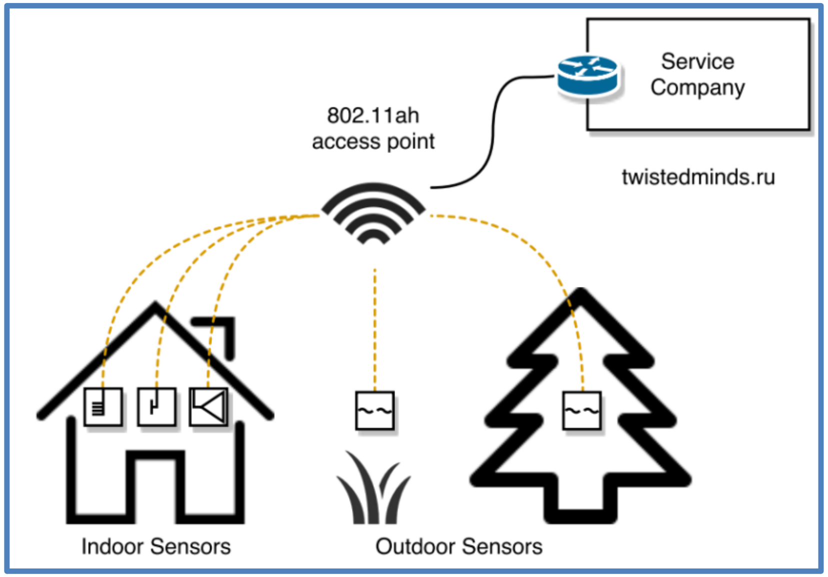
IEEE 802.11ah is a wireless networking protocol **published in 2016**.

For more details: https://ieeexplore.ieee.org/document/7920364

IEEE 802.11ah

- **Advantages** of WiFi
  - Most successful endpoint wireless technology
  - Useful for high data rate devices, for audio-video analytics devices, for deploying WiFi backhaul infrastructure
- **Disadvantages** of WiFi
  - Less signal penetration
  - Unsuitable for battery powered nodes
  - Unable to support large number of devices

- Wi-Fi Alliance defined a new technology called Wi-Fi HaLow
  - ❖ ah → **Ha**
  - ❖ Low power network → **Low**
- Main use cases for IEEE 802.11ah
  - ➢ Sensors and meters covering a smart grid
  - ➢ Backhaul aggregation of industrial sensors and meter data
  - ➢ Extended range Wi-Fi



802.11ah PHY layer

- Operating in unlicensed sub-GHz bands
  - 868–868.6 MHz for EMEAR (Europe, Middle East, Africa, and Russia)
  - 902–928 MHz for North America and Asia Pacific (India, Japan, Korea, …)
  - 314–316 MHz, 430–434 MHz, 470–510 MHz, 779–787 MHz for China
- OFDM Modulation
- Channels of 2, 4, 8, or 16 MHz (and also 1 MHz for low-bandwidth transmission)
- Provides one-tenth of the data rates of IEEE 802.11ac
- Provide an extended range for its lower speed data
  - For data rate of 100 kbps, the outdoor transmission range approx 1 Km

802.11ah MAC layer

Enhancements and features

- Number of devices: Has been scaled up from 250 to 8192 per access point (AP).
- MAC header: Has been shortened

- Null data packet (NDP) support: to cover control and management frames.
  - It is only transmitted by a STA; It carry's no data payload.

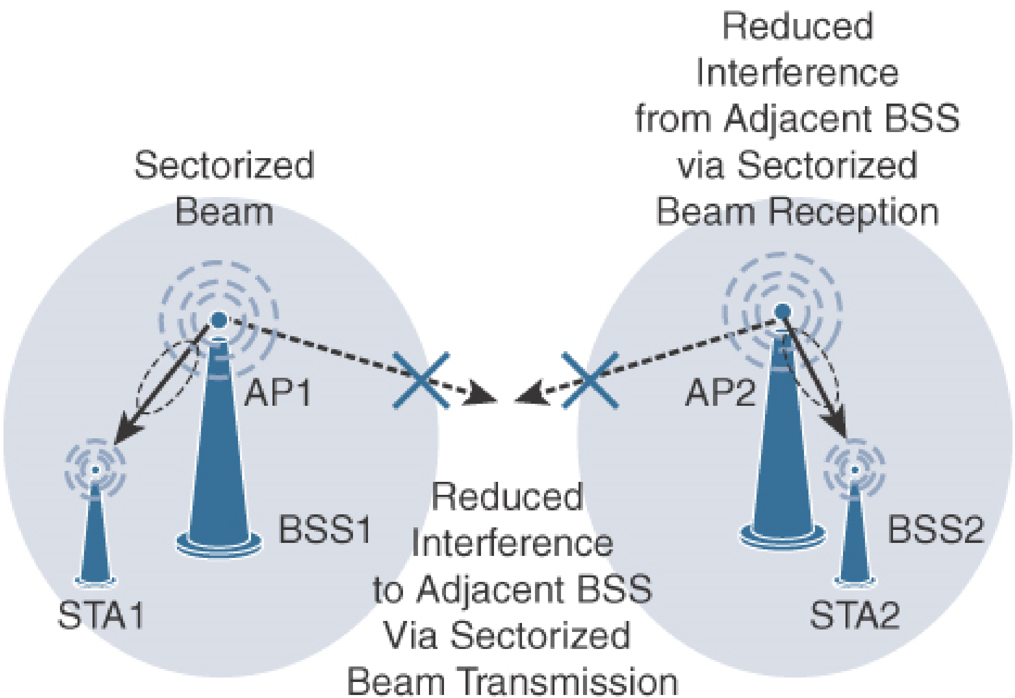
- Restricted access window (RAW): increase throughput and energy efficiency by
  - dividing stations into different RAW groups.
  - Only the stations in the same group can access the channel simultaneously.

- Sectorization: partition the coverage area of a Basic Service Set (BSS) into sectors, each containing a subset of stations. it uses an antenna array and beam-forming technique.
  - reduces contention by restricting which group, in which sector, and at which time window.
  - to mitigate the hidden node problem; to eliminate the overlapping BSS problem.

- Target wake time (TWT): allows an AP and STAs to "wake up" at negotiated times

- Speed frame exchange: Enables an AP and endpoint to exchange frames during a reserved transmit opportunity (TXOP)
  - TXOP is the amount of time a station can send frames when it has won contention for the medium

802.11ah Topology



- Star topology
- Includes simple hops relay to extend its range
  - Max 2 hops
  - Client handle the relay operation

NB-IoT

NB-IoT

- Well-known Cellular Technology
  - GSM: Global System for Mobile Communications
  - GPRS: General Packet Radio Service
  - CDMA: Code Division Multiple Access
  - EDGE: Enhanced Data Rates for GSM Evolution
  - 3G/UMTS: Universal Mobile Telecommunications System
  - 4G/LTE: Long-Term Evolution
- Disadvantage
  - Not adapted to battery-powered small devices like IoT smart objects

- In 2015, 3GPP approved a proposal to standardize a new narrowband radio access technology called Narrowband IoT (NB-IoT)
- It address the requirement:
  - massive number of low-throughput devices,
  - low device power consumption,
  - extended coverage – rural and deep indoors
  - optimized network architecture.
- NB-IoT is addressing the LPWA IoT market opportunity using licensed spectrum
  - New physical layer signals and channels are designed
- NB-IoT can co-exist with 2G, 3G, and 4G mobile networks

Thanks!

Figures and slide materials are taken from the following sources:

1. David Hanes *et al.*, "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", 1st Edition, 2018, Pearson India.