

IEEE 802.15.4

Low-Rate Wireless Personal Area Networks : PHY Layer

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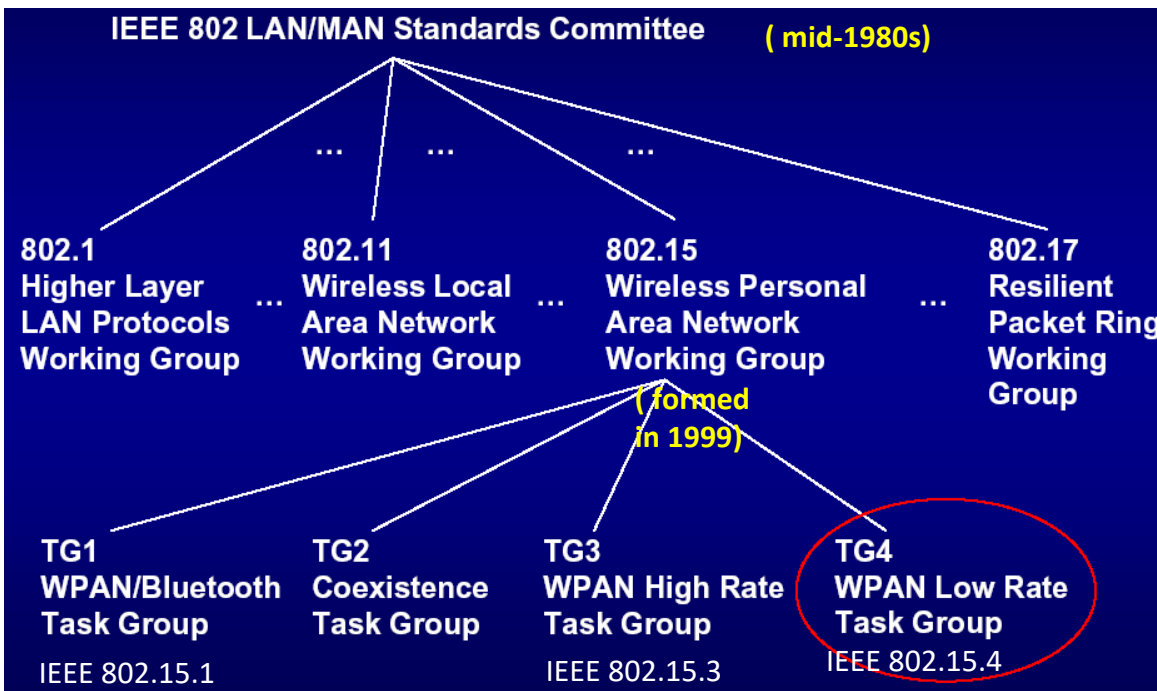
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IEEE 802.15 Working Group



- IEEE 802.11 was concerned with features like
 - Ethernet like speed
 - Medium range (~100 m) communication
 - Seamless roaming
 - Less complex message forwarding
 - Data throughput ~ 2-11 Mbps

- IEEE 802.15 are focused to
 - Short range
 - space around a person or a object (~ 10 m)
 - Low cost
 - Low power
 - Very small packet size



IEEE 802.15 working group mainly defines three standards:

1. High data rate WPAN

- IEEE 802.15.3
- e.g. for multimedia applications

2. Medium rate WPAN

- IEEE 802.15.1 / Bluetooth
- e.g. for device to device communication

3. Low rate WPAN

- IEEE 802.15.4
- e.g. relaxed data rate, and battery powered device

IEEE 802.15 - Task Group 4



- Task Group 4 (TG4) was formed to define
 - low-data-rate PHY and MAC layer specifications for **wireless personal area networks** (WPAN)
- WPAN work group (WG) plans to have the following:
 - span in a **small area**
 - e.g., a private home, an individual workspace
 - **short distance** communication
 - **low-powered** communication
 - e.g. lifetime must be few months or years
 - primarily uses **ad-hoc networking**
 - Generally **wireless**; could be **wired**
 - Intended to serve industrial, residential and medical applications

IEEE 802.15.4 LR-WPAN

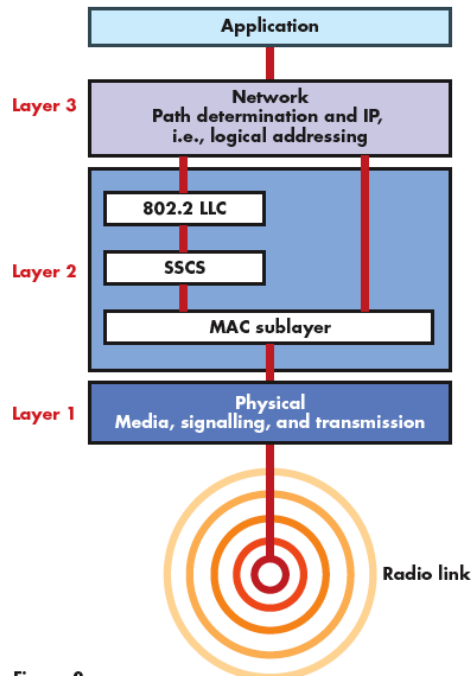


- Low-rate WPAN (LR-WPAN)
 - It is a
 - ✓ simple,
 - ✓ low-cost communication network
 - ✓ that allows wireless connectivity in applications
 - ✓ with limited power and
 - ✓ relaxed throughput requirements.
 - Standard has evolved over time:
 - IEEE 802.15.4-2003
 - IEEE 802.15.4-2006
 - IEEE 802.15.4-2011
 - IEEE 802.15.4-2015
 - IEEE 802.15.4-2020
- 2011 version: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6012487>
2015 version: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7460875>
2020 version: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9144691>
- Few important features of an LR-WPAN are
 - ✓ ease of installation,
 - ✓ reliable data transfer,
 - ✓ extremely low cost,
 - ✓ a reasonable battery life,
 - ✓ while maintaining a simple and flexible protocol.

Reference: IEEE Std 802.15.4™-2020, “IEEE Standard for **Low-Rate Wireless Networks**”,
Developed by the LAN/MAN Standards Committee of the IEEE Computer Society, Approved on 6 May 2020.

IEEE 802.15.4 Stack – PHY & MAC

The OSI model adapted to the IEEE 802.15.4



LLC: Logical Link Control – provides protocol multiplexing

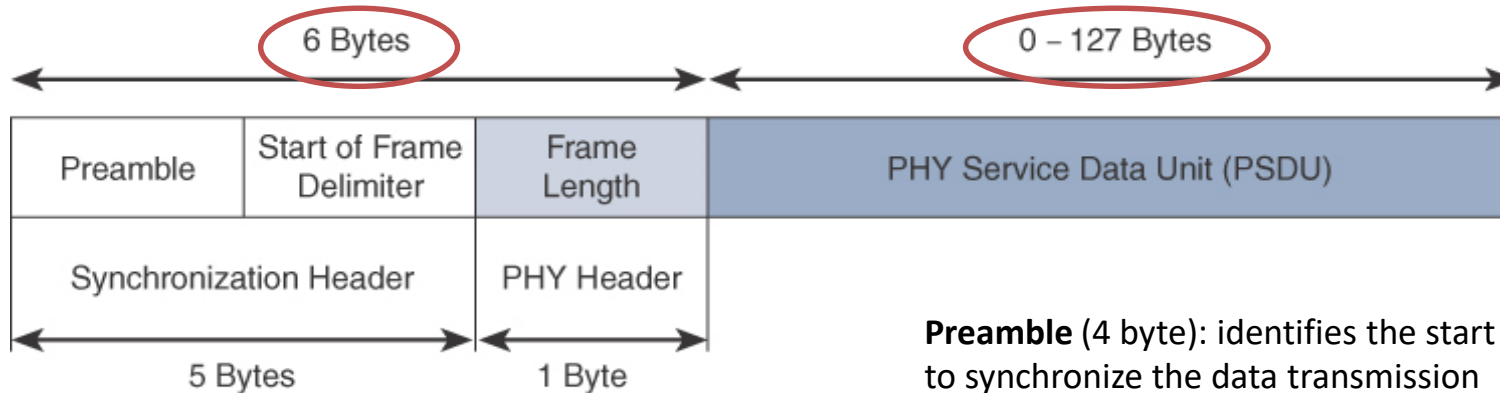
SSCS: Service Specific Convergence Sublayer

- IEEE 802.15.4 standard is limited to the **PHY & MAC** Layers
- IEEE 802.15.4 standard PHY provides the **PHY data service** and **PHY management services**:
 - The **PHY data service** enables the **transmission** and **reception** of PHY protocol data units (PPDU) across the physical radio channel.
 - The **PHY's features** include
 - radio transceiver activation/deactivation,
 - radio channel selection,
 - energy level detection (ED) ,
 - received signal quality (RSI) or link quality indicator (LQI),
 - clear channel assessment (CCA),
 - channel selection
 - transmitting and receiving packets in 2.4-GHz band.

Image Source: <https://www.embedded.com/ieee-802-15-4-zigbee-hardware-and-software-open-the-applications-window/>

IEEE 802.15.4 PHY

IEEE 802.15.4 PHY Layer



IEEE 802.15.4 PHY Frame Format

Preamble (4 byte): identifies the start of the frame; used to synchronize the data transmission

SFD (1 byte): informs the receiver about the starting point of frame content. It shall be formatted as “1110 0101”

PHY functionalities:

- Activation & deactivation of the radio transceiver
- Energy level detection (ED) within the current channel
- Link quality indication (LQI) or received signal quality (RSI) for received packets
- Clear channel assessment (CCA) for CSMA-CA
- Channel frequency selection
- Data packet transmission and reception at given frequency

Spectrum

- Federal Communications of Commissions (FCC) in USA decides frequency bands
- Applications using ISM band do not require a licence for stations emitting less than 1W.

FCC Band	Max. Transmit Power	Frequencies
Industrial Band	< 1 W	902 MHz – 928 M Hz
Scientific Band	< 1 W	2.4 GHz – 2.48 GHz
Medical Band	< 1 W	5.725 GHz – 5.85 GHz
U-NII (Unlicensed National Information Infrastructure)	< 40 mW	5.15 GHz – 5.25 GHz
	< 200 mW	5.25 GHz – 5.35 GHz
	< 800 mW	5.725 GHz – 5.82 GHz

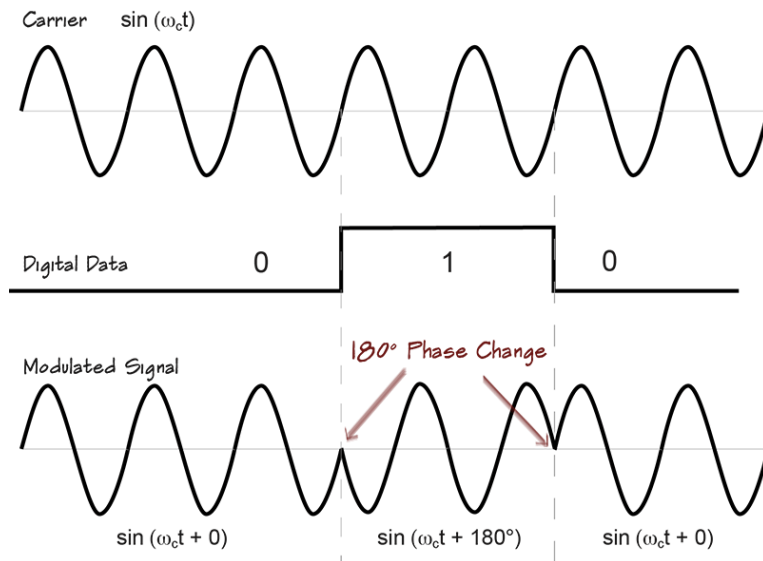
- Physical layer **transmission options** in IEEE 802.15.4-2015
 - 2.4 GHz**, 16 channels, data rate 250 kbps - (This is primary)
 - 915 MHz**, 10 channels, data rate 250 kbps
 - 868 MHz**, 3 channel, data rate 100 kbps

Modulation

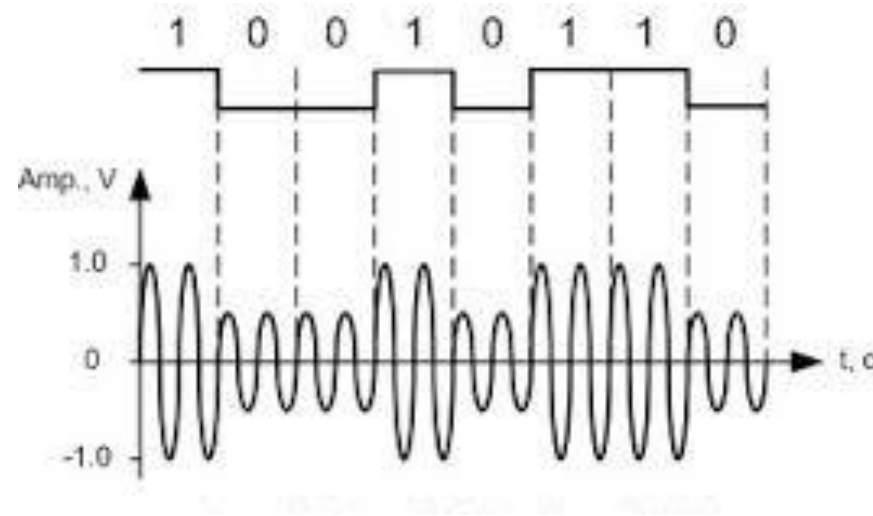
Modulation is the process by which some characteristic of a **carrier wave** is varied in accordance with an information/ **modulating signal**.

Modulation schemes

- **OQPSK PHY** : DSSS PHY employing Offset Quadrature Phase-Shift Keying (OQPSK) – This is Primary Scheme
- **BPSK PHY** : DSSS PHY employing binary phase-shift keying (BPSK)
- **ASK PHY** : PSSS PHY employing Amplitude Shift Keying (ASK) and BPSK

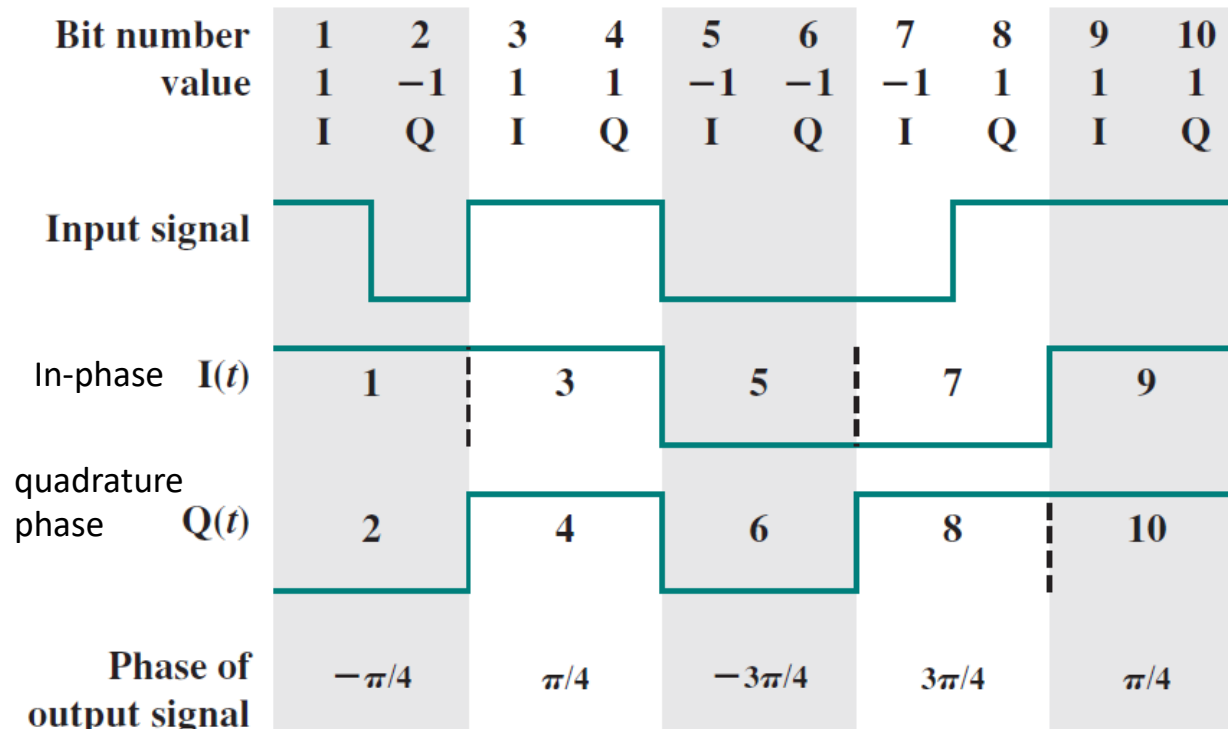
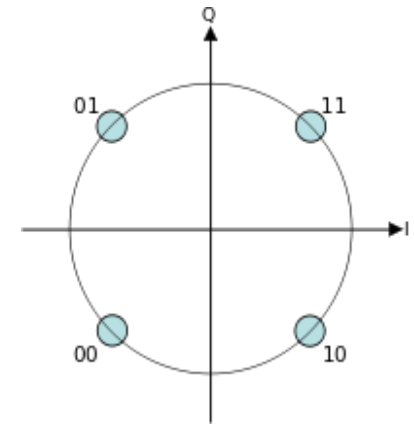


Binary Phase-Shift Keying (BPSK)



Amplitude Shift Keying (ASK)

QPSK



Constellation diagram for QPSK

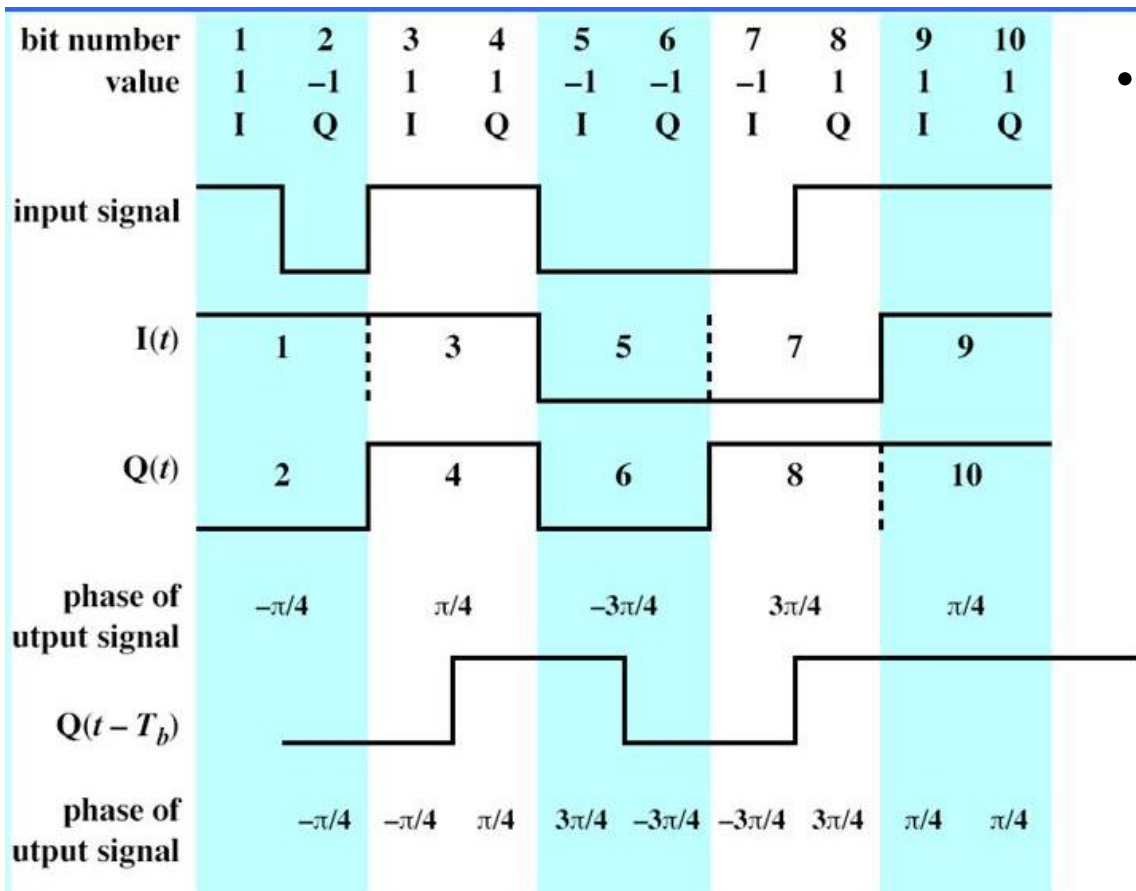
Quadrature Phase-Shift Keying (QPSK)

- More efficient use of bandwidth
 - as each signalling element represents more than one bit.

$$\text{QPSK } s(t) = \begin{cases} A \cos\left(2\pi f_c t + \frac{\pi}{4}\right) & 11 \\ A \cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & 01 \\ A \cos\left(2\pi f_c t - \frac{3\pi}{4}\right) & 00 \\ A \cos\left(2\pi f_c t - \frac{\pi}{4}\right) & 10 \end{cases}$$

Orthogonal QPSK

- **Problem in QPSK:** large phase shift at high transition rate is difficult to perform. Phase shift is 180° in QPSK.



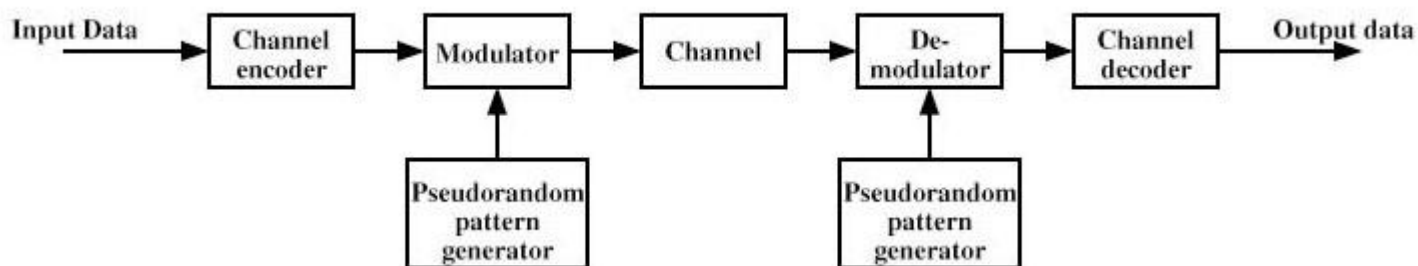
• OQPSK

- ✓ a variation of QPSK known as **offset QPSK** or **orthogonal QPSK**
- ✓ a **delay of one bit time** is introduced in the Q stream of QPSK
- ✓ Its spectral characteristics and bit-error performance are the same as that of QPSK
- ✓ at any time the **phase change** in the combined signal **never exceeds 90° ($\pi/2$)**

Spread Spectrum

Spread Spectrum is a method of spreading a transmitted spectrum over a wide bandwidth, so that the **energy at any particular frequency is not detectable without special foreknowledge** of the spreading technique.

- Spread-spectrum transmission offers many advantages over a fixed-frequency transmission.
 - Spread-spectrum signals are highly resistant to narrow band interference
 - Signals are difficult to intercept, so immune to jamming
- **Types:**
 - direct sequence spread spectrum (**DSSS**)
 - frequency hopping spread spectrum (**FHSS**)



Cont...



- Pseudorandom numbers
 - generated by an algorithm using some initial value called the **seed**
 - produce sequences of numbers that are **not statistically random**, but passes reasonable tests of randomness
 - unless you know the **algorithm** and the **seed**, **it is impractical to predict the sequence**
- **Gain from this apparent waste of spectrum**
 - The signals **gains immunity** from various kinds of noise and multipath distortion.
 - **Immune to** jamming attack
 - It can also be used for **hiding and encrypting signals**.
 - **Several users can independently use** the same higher bandwidth with very little interference. (e.g. CDMA)

- each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code
- spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used

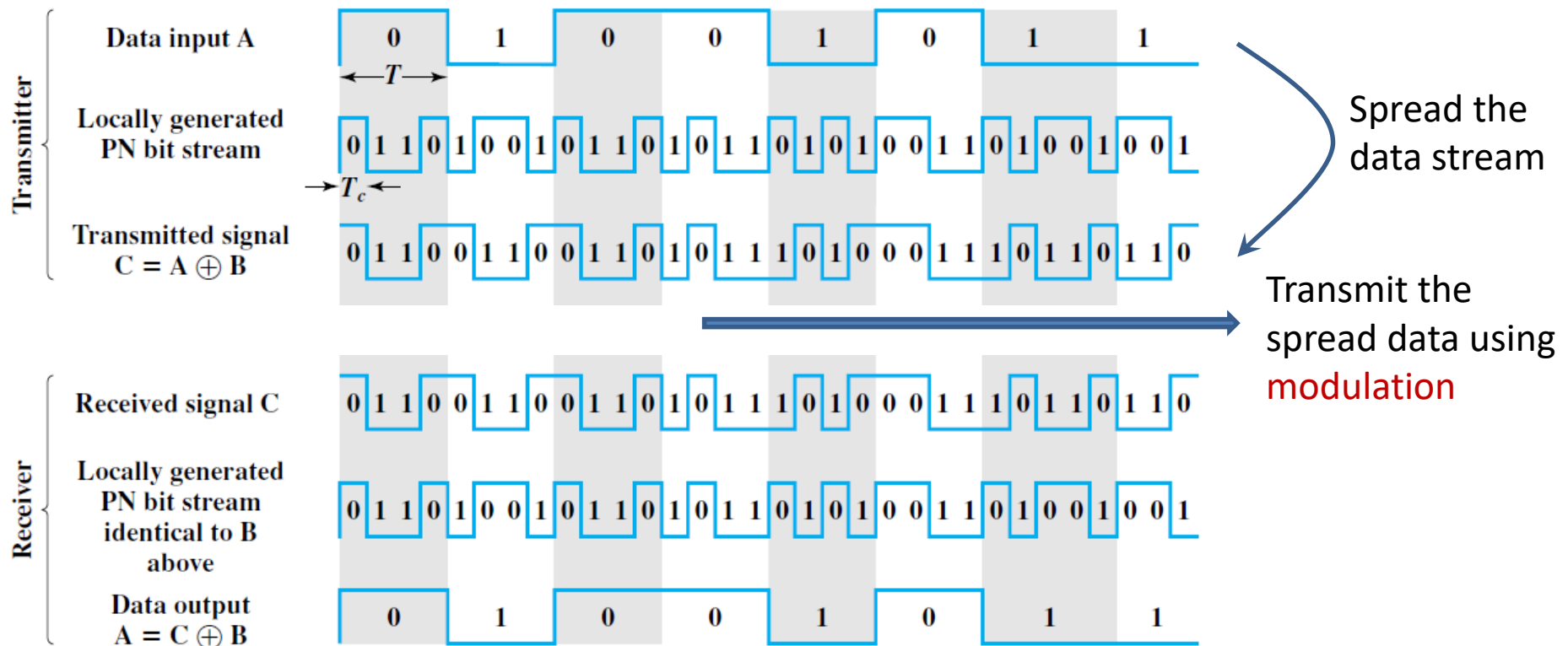
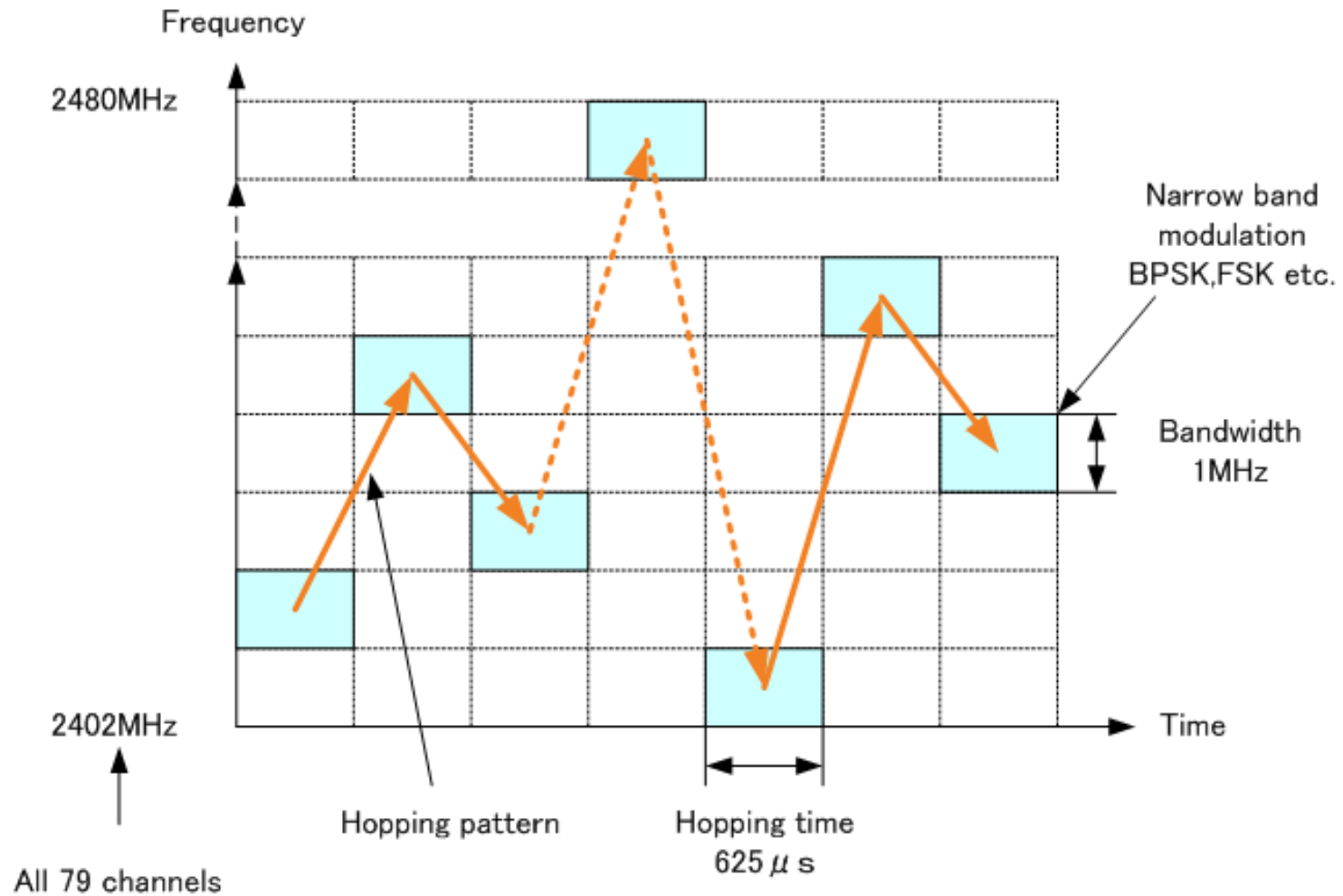
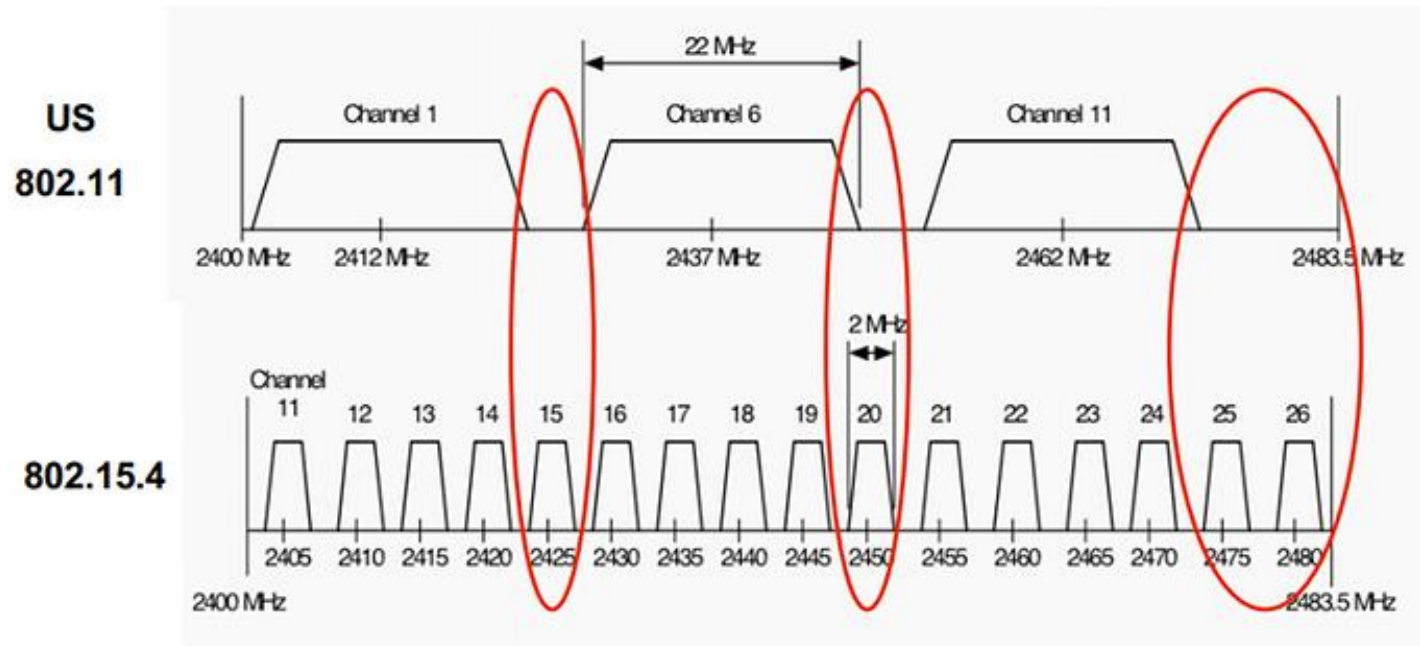


Figure 9.6 Example of Direct Sequence Spread Spectrum

FHSS



Other PHY Attributes



- IEEE 802.15.4 **does not prefer to use frequency hopping** to **minimize energy consumption**.
- To minimize interference in 2.4 GHz band, IEEE 802.15.4 prefer **channel no. 15, 20, 25, 26**
- Transmission power is adjustable from 0.5 mW (min. in 802.15.4) to 1 W (max. in ISM band)
- Transmission power 1 mW provides **theoretical distances** as:
 - Outdoor range **300 m**.
 - Indoor range **100 m**.

- 802.15.4 **PHY** provides **energy detection (ED)** feature
 - **Application** can request to **asses** each channel's **energy level**
 - It is an estimate of the received signal power within the bandwidth of the channel
 - **Coordinator** can make **optimal selection of channel** based on **channels energy level**
- 802.15.4 **PHY** provides **link quality information (LQI)** to **NET and APP layers**
 - The LQI measurement is a characterization of the strength and/or quality of a received packet.
 - The measurement may be implemented using
 - i. receiver ED
 - ii. signal-to-noise ratio (SNR) estimation, or
 - iii. combination of the above methods.
 - Transmitter may **decide to use high transmission power** based on LQI
 - Applications may **dynamically change 802.15.4 channels** based on LQI
- 802.15.4 uses **CSMA/CA** which ask the PHY layer to do CCA
 - **Clear Channel Assessment (CCA)** is performed by any one of the below methods:
 - Energy above ED threshold regardless of modulation
 - Carrier sense only (i.e. based on the detection of a signal with modulation and spreading characteristics)
 - Combination of both the above

Lessons Learned



- ✓ What is IEEE 802.15.4
 - Introduction to IEEE 802.15 WG
 - Genesis of LR-WPAN

- ✓ IEEE 802.15.4. PHY
 - Functionalities
 - Modulation: QPSK, OQPSK
 - Spread Spectrum: DSSS, FHSS

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.
2. Oliver Hersent et al., “The Internet of Things: Key Applications and Protocols”, 2018, Wiley India Pvt. Ltd.