3. Wireless communication standards and techniques

Radio communication standards, IEEE 802.x

Wireless sensor networks

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Radio communication

❏ radio (wireless) communication have its specifics against wired communication

❏ we will always talk about transmission of digital data (binary)

❏ different signal implications

❏ we use broadband transmission
   ❏ baseband direct digital transmission is ineffective

❏ shift keying (modulation)

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Wireless communication

Categorization

- ❏ by mobility
  - ❏ fixed (static)
  - ❏ mobile (dynamic)
- ❏ by transmission band
  - ❏ wide (wideband, broadband)
  - ❏ ultra wide (ultra wideband)
  - ❏ narrow (narrowband)
- ❏ by medium type
  - ❏ radio
  - ❏ optical (light)
  - ❏ infrared (IrDa)
- ❏ by purpose and area
  - ❏ WLAN – Wireless Local Area Network
  - ❏ WPAN – Wireless Personal Area Network
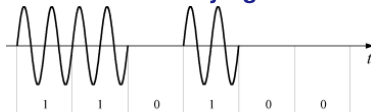 - ❏ WBAN – Wireless Body Area Network
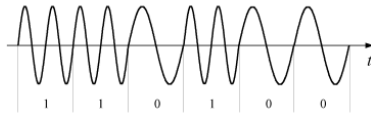
Radio communication

Shift keying

- ❏ *Shift keying*
- ❏ technique to modulate digital (discrete) signal to a wave
- ❏ different combination of wave parameters represents a different discrete symbol
- ❏ base wave equation: $y = A \cdot sin(\omega t + \Phi)$
  - ❏ A – amplitude shift keying (ASK)
  - ❏ ω – frequency shift keying (FSK)
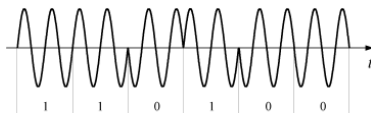 - ❏ Φ – phase shift keying (PSK)

Radio communication

Shift keying

Figure: Example of amplitude (a), frequency (b) and phase (c) shift keying
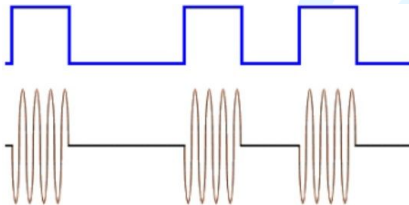
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Shift keying

❑ Amplitude Shift Keying (ASK)

    ❑ simple

    ❑ prone to noise

    ❑ rapidly fades with distance

❑ Frequency Shift Keying (FSK)

    ❑ requires broader frequency band

    ❑ more resistant to noise and jamming

❑ Phase Shift Keying (PSK)

    ❑ complex hardware

    ❑ best resistance to noise and jamming

Radio communication

Shift keying examples

❑ On-Off Keying (OOK)
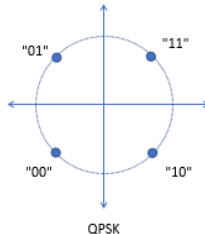 ❑ special case of 2-ASK
  ❑ two states of signal
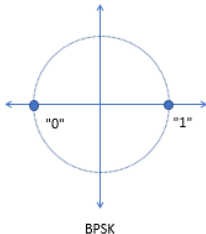
Symbol	A
0	0
1	A_1

Radio communication

Shift keying

❑ Binary Phase Shift Keying (BPSK)

  ❑ special case of 2-PSK
  ❑ two states of signal

❑ Quadrature Phase Shift Keying (QPSK)

  ❑ special case of 4-PSK
  ❑ four states of signal

BPSK

QPSK

Radio communication

Shift keying

❑ we often use a combination

❑ a common combination is phase and amplitude

❑ depicted as a constellation diagram

  ❑ distance from origin = amplitude

  ❑ angle = phase shift

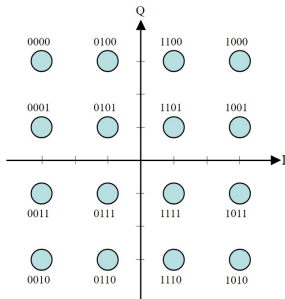**Figure:** 16-QAM constellation diagram

Radio communication

Band width

❑ Wideband (broadband)
  ❑ a result of shift keying in a wide frequency band
  ❑ small energy density
  ❑ very resistant to noise and jamming

❑ Narrowband
  ❑ a result of shift keying in a narrow frequency band
  ❑ large energy density
  ❑ very prone to noise and jamming

Figure: Energy density diagram
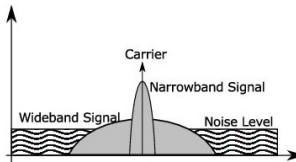
Radio communication

Spectrum spreading

❑ ways to spread the spectrum
  ❑ Direct Sequence Spread Spectrum (DSSS)
    ❑ transmitting data in pre-defined *chips*
    ❑ implicitly spreads the frequency spectrum
  ❑ Frequency Hopping Spread Spectrum (FHSS)
    ❑ switching between frequency channels during transmission
    ❑ may also increase security by pseudo-randomly changing the sequence
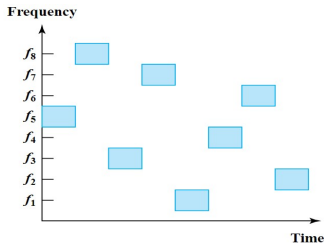
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Spread spectrum

❑ FHSS
  ❑ Slow (SFH) – change channel after a few bytes (bits)
  ❑ Fast (FFH) – change channel during bit transmission
❑ Bluetooth uses FFH

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Radio communication

Shared medium

❑ Wireless transmissions may share the medium

❑ different streams may use multiplexing

   ❑ TDMA – Time Division Multiple Access

      ❑ synchronous
      ❑ asynchronous

   ❑ FDMA – Frequency Division Multiple Access
   ❑ CDMA – Code Division Multiple Access

      ❑ synchronous
      ❑ asynchronous

❑ same streams may use CSMA

   ❑ Carrier Sense Multiple Access
   ❑ e.g., CSMA-CA in 802.11 (RTS, CTS, ...)

❑ we will talk about them later

Wireless communication standards

❑ to allow all developers around the world to connect their devices to a large networks, standards are required

❑ local standards and norms
  ❑ CSN (Czech), CEN (Europe), ...
  ❑ often just regulates specific aspects
  ❑ e.g., how often the node may communicate, ...

❑ global standards
  ❑ ISO – international, often standardizes concepts and architectures
  ❑ RFC – de facto standards formed by the community
  ❑ IEEE – de jure standards formed by working groups of experts

Wireless communication standards
RFC

❑ RFC – Request For Comments

❑ managed by IETF (Internet Engineering Task Force)

❑ community-driven standards

❑ an expert (or group of experts) solves a problem

❑ result is a protocol / technique, which is then offered to a publication as a RFC

❑ if the proposal is verified successfully, it is published as a RFC

❑ RFC is more of a recommendation, than a standard

Wireless communication standards

RFC

❑ standardized in the RFC:
  ❑ ASCII
  ❑ TCP, UDP
  ❑ IPv4, IPv6, ICMP
  ❑ ARP, DNS
  ❑ IRC, HTTP
  ❑ LDAP
  ❑ NTP
  ❑ I'm a Teapot, IP over Avian Carriers, ... (April fools RFC)
  ❑ and many, many more...

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Wireless communication standards
RFC

- ❑ RFCs for WSNs
- ❑ just "a few", e.g.,
    - ❑ RFC 4944 – Transmission of IPv6 Packets over IEEE 802.15.4 Networks
    - ❑ RFC 5673 – Industrial Routing Requirements in Low-Power and Lossy Networks
    - ❑ RFC 7668 – IPv6 over BLUETOOTH Low Energy
    - ❑ RFC 8272 – TinyIPFIX – wireless protocol for metering data transmission
    - ❑ and more...
- ❑ usually standardizes a very specific scenario – e.g., transmitting IPv6 over Bluetooth Low Energy, etc.

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Wireless communication standards
IEEE

❑ IEEE – Institute of Electrical and Electronics Engineers

❑ apart from other things, it consists of working groups

❑ every working group solves a specific problem domain

❑ for us, the most relevant is the 802 working group

❑ every group has its subgroups

Wireless communication standards

IEEE 802

❑ IEEE 802 subgroups:
  ❑ 802.1 – Higher Layer LAN protocols
  ❑ 802.2 – Logical Link Control (disbanded)
  ❑ 802.3 – Ethernet
  ❑ 802.4 – Token Bus (disbanded)
  ❑ 802.5 – Token Ring (disbanded)
  ❑ 802.6 – Metropolitan Area Network (disbanded)
  ❑ 802.7 – Broadband TAG (disbanded)
  ❑ 802.8 – Fiber Optic TAG (disbanded)
  ❑ 802.9 – Isochronous LAN (disbanded)
  ❑ 802.10 – Security (disbanded)
  ❑ ...

Wireless communication standards
IEEE 802

❑ IEEE 802 subgroups (part 2):

  ❑ ...
  ❑ **802.11** – Wireless LAN
  ❑ 802.12 – 100BaseVG (disbanded)
  ❑ 802.13 – not used, reserved for Fast Ethernet
  ❑ 802.14 – Cable modems (disbanded)
  ❑ **802.15** – Wireless PAN
  ❑ 802.16 – Broadband Wireless (WiMAX) (inactive)
  ❑ 802.17 – Resilient packet ring (disbanded)
  ❑ 802.18 – Radio Regulatory Advisory Group
  ❑ 802.19 – Wireless coexistence
  ❑ etc.

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Wireless communication standards
IEEE 802.11

❑ IEEE 802.11

❑ Wireless Local Area Network (WiFi)

❑ specifies media access and logical link control protocols (data link layer)

❑ also specifies physical layer protocols

❑ initially not foreseen to be the host technology for WSN's

❑ there are a set of standards, that allows for WSN operation over 802.11
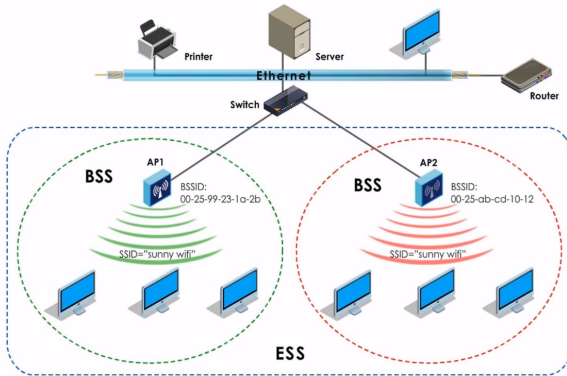
Wireless communication standards
IEEE 802.11

❑ Service set – a group of devices sharing the same service set identifier (SSID)

❑ Service set identifier (SSID) – a human-readable identifier of service set

❑ Base Service Set (BSS) – a subgroup of service set sharing the same physical area and characteristics (frequency, modulation scheme, security, ...)

❑ Extended Service Set (ESS) – a group of BSS providing the same service set

❑ Access Point (AP) – base service set provider

❑ Station (STA) – node connected to BSS provider (AP)

Wireless communication standards
IEEE 802.11

❑ 802.11 distribution system

Wireless communication standards
IEEE 802.11

❑ IEEE 802.11s (2011)

❑ mesh network amendment for 802.11

❑ allows for mesh topology (physical) for 802.11-enabled devices

   ❑ partially- or fully-connected

❑ since this standard, we can built other than point-to-point and star topologies in WSN

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Wireless communication standards
IEEE 802.11

❑ 802.11ah (2017)

❑ WiFi HaLow amendment for 802.11

❑ 802.11 operation on 900 Mhz frequency band

❑ extended range, lower power consumption

❑ relatively high data rate when compared to Bluetooth

❑ changes modulation and coding depending on the amount of data and requested transmit rate

   ❑ Modulation and Coding Scheme (MCS)

Wireless communication standards
IEEE 802.11

❑ 802.11ba (2021)

❑ Wake-Up Radio Operation

❑ extremely low power operation of WiFi

❑ the primary connectivity radio (PCR) unit can sleep, while the Wake-Up Radio unit (WUR) listens for wake-up frames

❑ the wake-up frame is modulated using On-Off-Keying (OOK)

❑ the PCR might not even be an 802.11 radio

Wireless communication standards
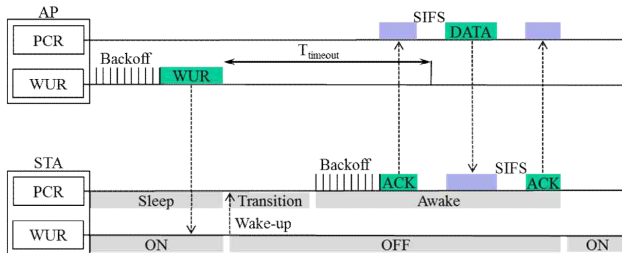
❑ 802.11ba (2021)

Figure: 802.11ba Wake-Up Radio operation

Wireless communication standards
802.15

- ❏ 802.15 – Wireless PAN
- ❏ very important working group for sensor networks
- ❏ subgroups:
    - ❏ 802.15.1 – Bluetooth
    - ❏ 802.15.2 – 802.15 and 802.11 coexistence
    - ❏ 802.15.3 – High-Rate Wireless PAN
    - ❏ 802.15.4 – Low-Rate Wireless PAN
    - ❏ 802.15.5 – WPAN Mesh Networking
    - ❏ 802.15.6 – Body Area Network (BAN)
    - ❏ 802.15.7 – Visible Light Communications

Wireless communication standards

802.15.1

- ❑ 802.15.1 – Bluetooth
- ❑ cheap, fast, potentially power-saving
- ❑ long history in mobile phones
- ❑ supports data and multimedia transfer
- ❑ encryption
- ❑ device pairing
- ❑ based on the Piconet architecture – 1 master and up to 7 slaves
    - ❑ originally supported Scatternet architecture – a network of Piconets
- ❑ sub-standard: Bluetooth Low Energy (since version 4.0)

Wireless communication standards

802.15.1

❑ Versions
- ❑ 1.0, 1.0B, 1.2
- ❑ 2.0, 2.1 – EDR mode (Enhanced Data Rate)
- ❑ 3.0 – HS mode (High-Speed)
- ❑ 4.0, 4.1, 4.2 – includes Bluetooth Low Energy (BLE)
- ❑ 5.0, 5.1, 5.2, 5.3, 5.4 – current, improvements focused on IoT applications
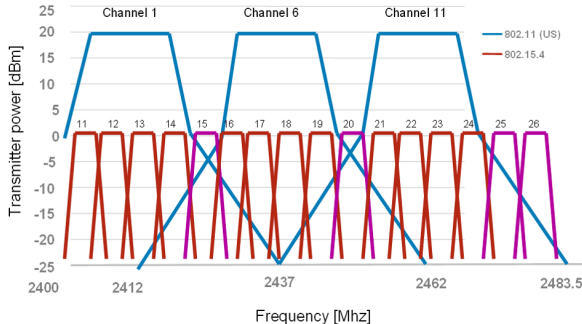
Wireless communication standards

802.15.1

❑ Bluetooth Low Energy (BLE)

❑ interesting technology for WSN

❑ very low power consumption

❑ very cheap

❑ wide support

❑ operates in 2.4Ghz frequency band (ISM)

❑ up to 1Mbps transfer rate

❑ distance: up to 50-150 meters

Wireless communication standards

802.15.2

❑ Coexistence between 802.15 and 802.11 (shares the same frequency band)

Wireless communication standards

802.15.4

❑ 802.15.4 – Low-Rate WPAN

❑ interesting for WSN applications

❑ matches the requirements

❑ defines the physical and data link layers

❑ protocols built on top of 802.15.4

    ❑ Zigbee
    ❑ WiHART
    ❑ MiWi
    ❑ Thread
    ❑ 6LoWPAN

Wireless communication standards

802.15.4
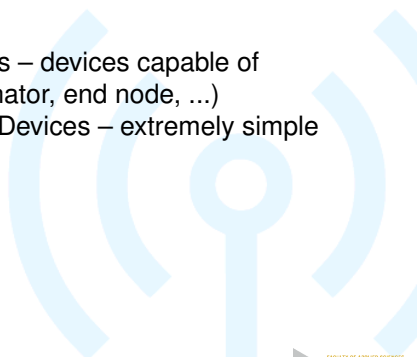
❏ transmission characteristics
  ❏ DSSS
  ❏ 4-bit symbols
  ❏ 32-bit ortogonal sequencies
  ❏ 2Mbps transmission rate
  ❏ CSMA/CA

Wireless communication standards

802.15.4

❑ topology
  ❑ star topology
  ❑ coordinator node – central node
❑ node types
  ❑ FFD – Fully-Functional Devices – devices capable of operating in all modes (coordinator, end node, ...)
  ❑ RFC – Reduced-Functionality Devices – extremely simple devices, end nodes

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Wireless communication standards

802.15.4

❑ we will talk about 802.15.4 more later

❑ particularly, Zigbee protocol will be of interest

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