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IEEE 802.11 (WiFi)

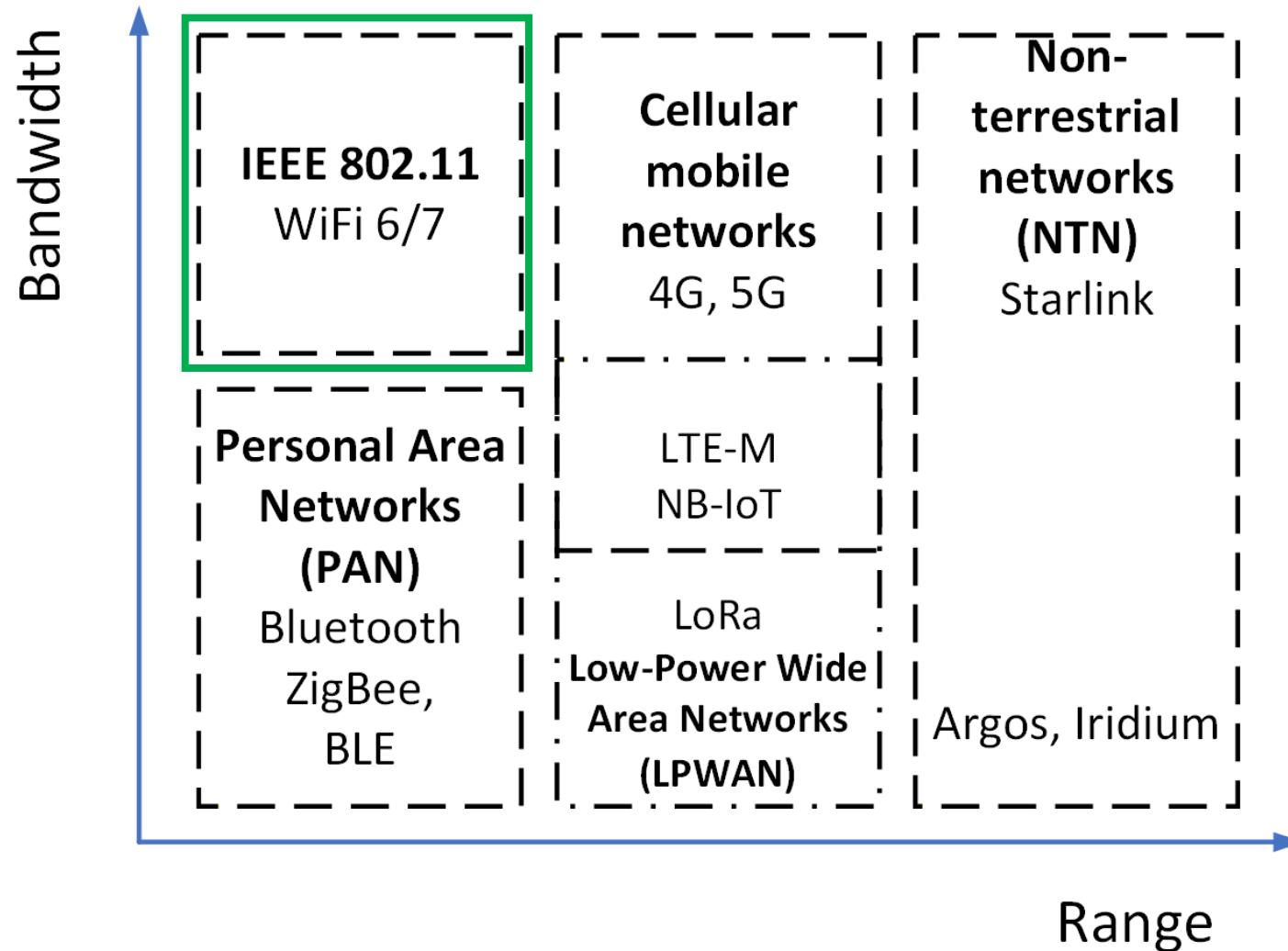
MARIA KIHLM



Literature

- D. Lopez-Perez et. al, “IEEE 802.11be Extremely High Throughput: The Next Generation of Wi-Fi Technology beyond 802.11ax”, IEEE Communications Magazine, 2019.
 - The whole article

Today's lecture



Today's scenario: Helsingborg West Harbour

Your task is to help Helsingborg West Harbour with their project on self-driving trucks. The trucks will move containers within the harbour area. The trucks will be controlled by a software application placed in a back-end server. The software application will send instructions to the trucks about their path trajectory, so that the trucks' movements are optimized.

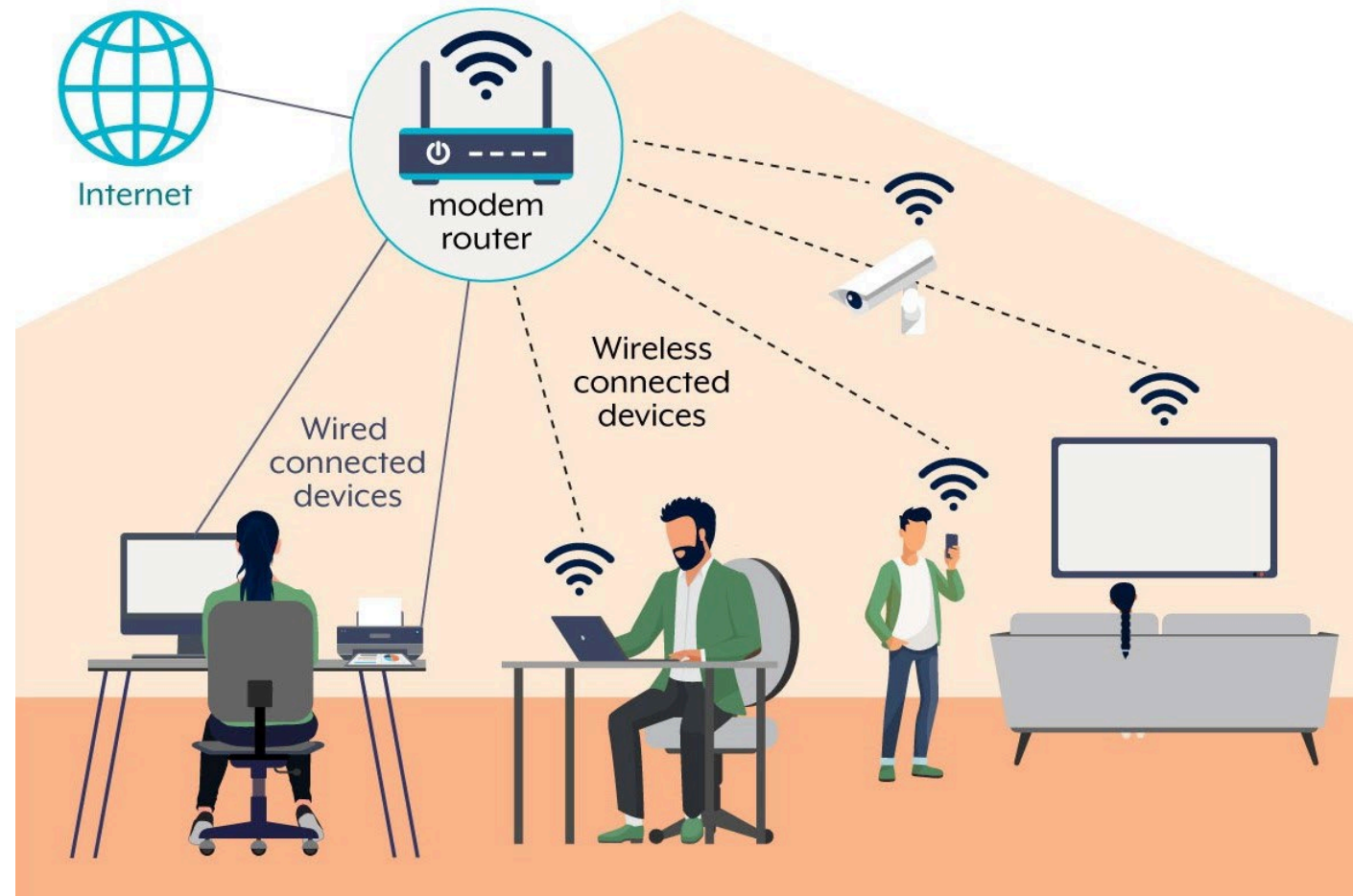
The trucks will continuously send information about their current position to the software application. As a fall-back solution, the trucks will have their own internal collision-avoidance mechanism so that they do not collide into each other or other things.

Your task is to propose a complete network system design for this self-driving application. The image shows Helsingborg West Harbour.



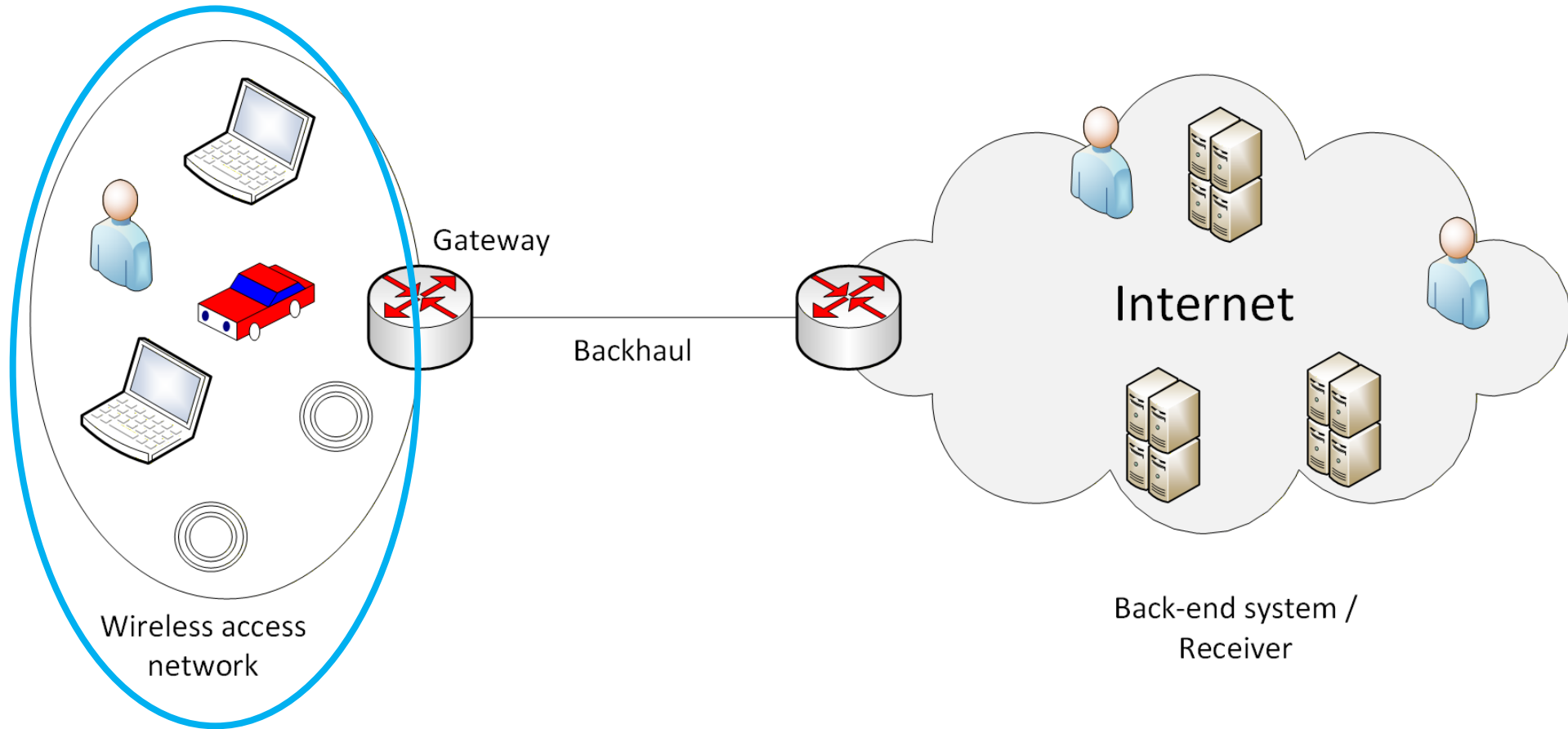
IEEE 802.11 (WiFi)

You should have basic knowledge of the WiFi standard IEEE 802.11 from your previous courses.



IEEE 802.11- Physical and Data link layer protocols

The IEEE 802.11 standards define protocols for the physical and data link layers, i.e. the intranet communication protocols.



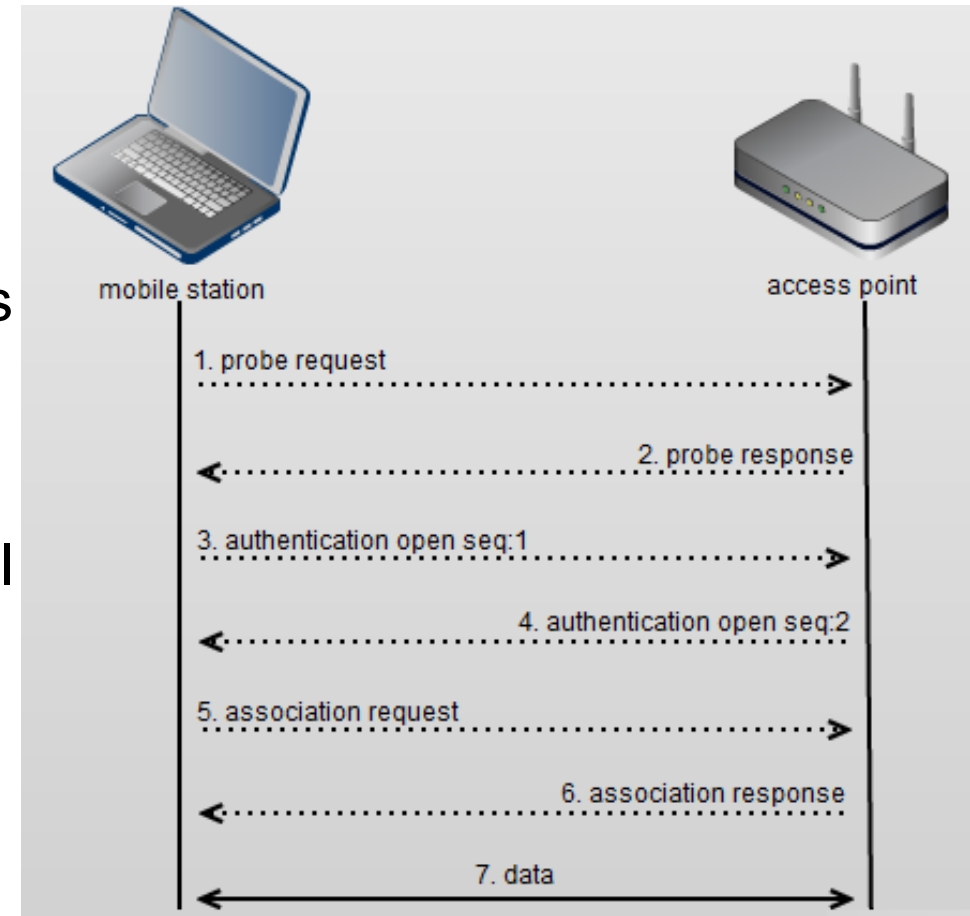
IEEE 802.11

- IEEE 802.11 exists in numerous standards with different **unlicensed frequency bands** and physical layer technologies.
- A device is identified with its **MAC address** and its **service set**. A service set is a group of wireless network devices which share a **service set identifier (SSID)**.
- "Traditional" IEEE 802.11 uses a combination of a **contention-based MAC** protocol, CSMA/CA, combined with a reservation based MAC protocol (contention-free).
- IEEE 802.11ax (WiFi 6), IEEE 802.be (WiFi 7) and forward can use a **contention-free MAC** to achieve higher bit rates and more stable connections.

IEEE 802.11 Node Association Process

Before a terminal can send traffic through an AP, it must be in the appropriate connection state.

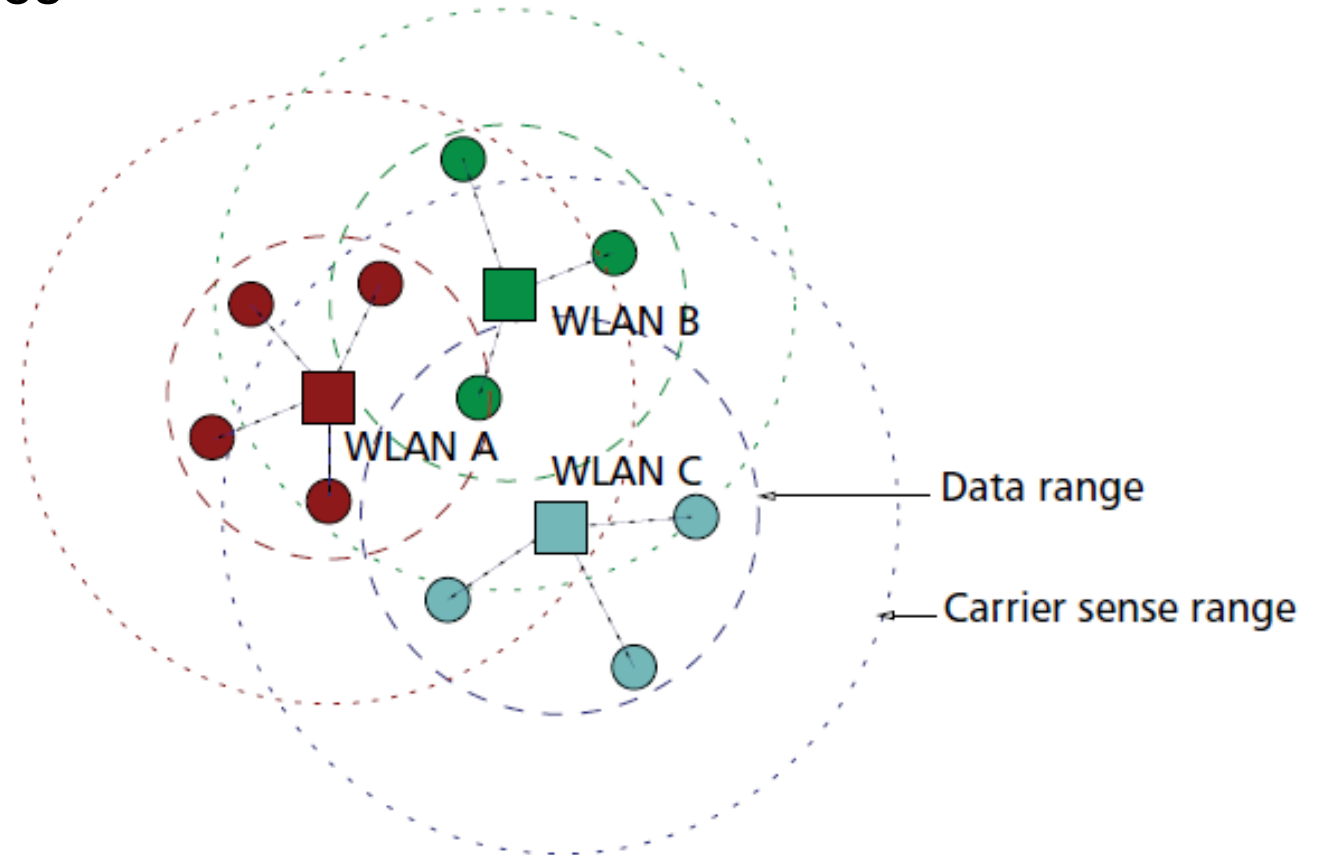
- A terminal sends probe requests to discover 802.11 networks within its proximity. Probe requests advertise the terminal's supported data rates and its 802.11 capabilities (i.e which 802.11 standards the terminal has capability for.)
- Because the probe request is sent from the terminal to the layer-2 address ff:ff:ff:ff:ff:ff, all AP's that receive it will respond.
- A terminal then chooses compatible networks from the probe responses it receives.



Interfering networks

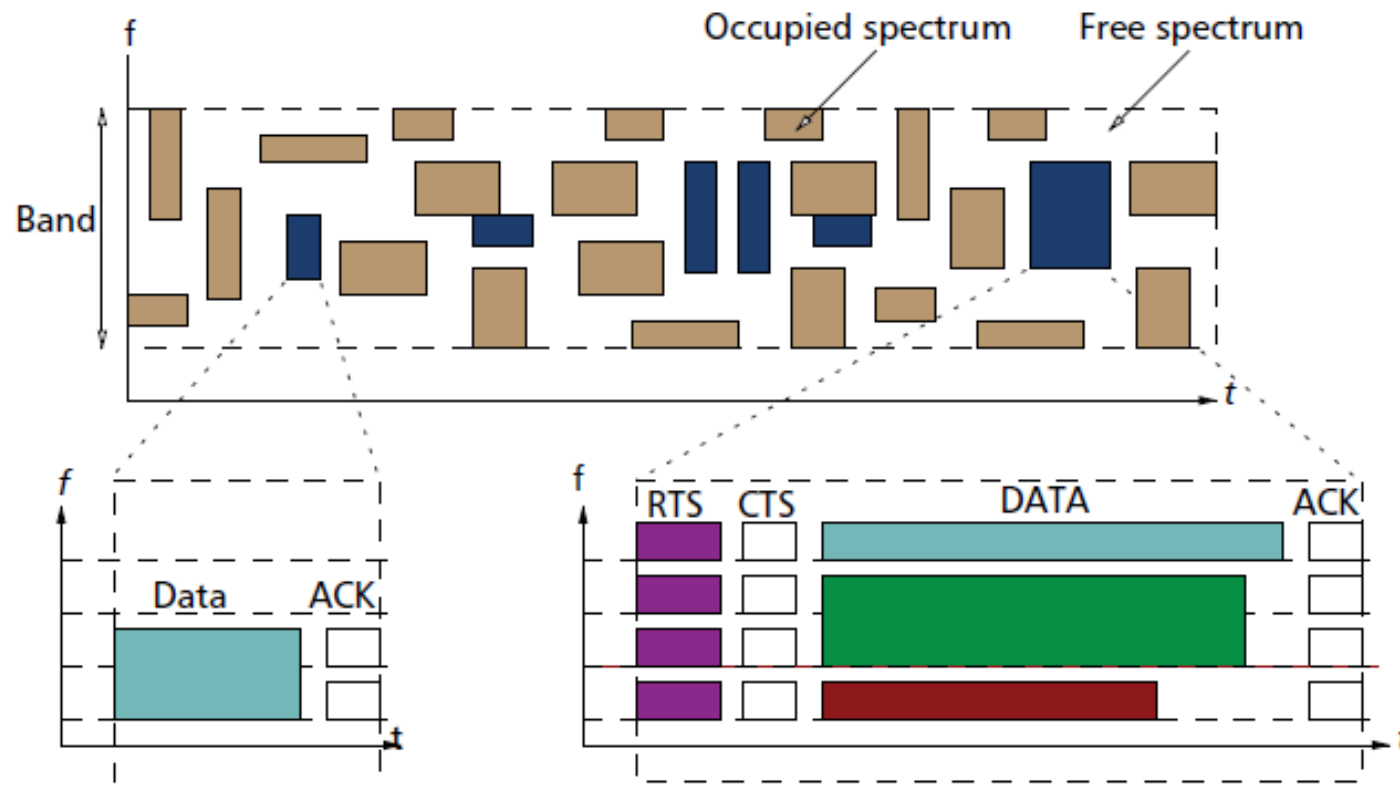
In dense use cases and high bit rates, several WLANs can interfere with each other due to the unlicensed frequency bands.

- Newer versions of IEEE 802.11 includes several mechanisms for handling this interference.
- Examples are improved coding, so called **OFDMA dynamic channel bonding** and different types of multiple antenna techniques called **Multi-User Multiple-Input-Multiple-Output (MU-MIMO)**.



OFDMA and dynamic channel bonding

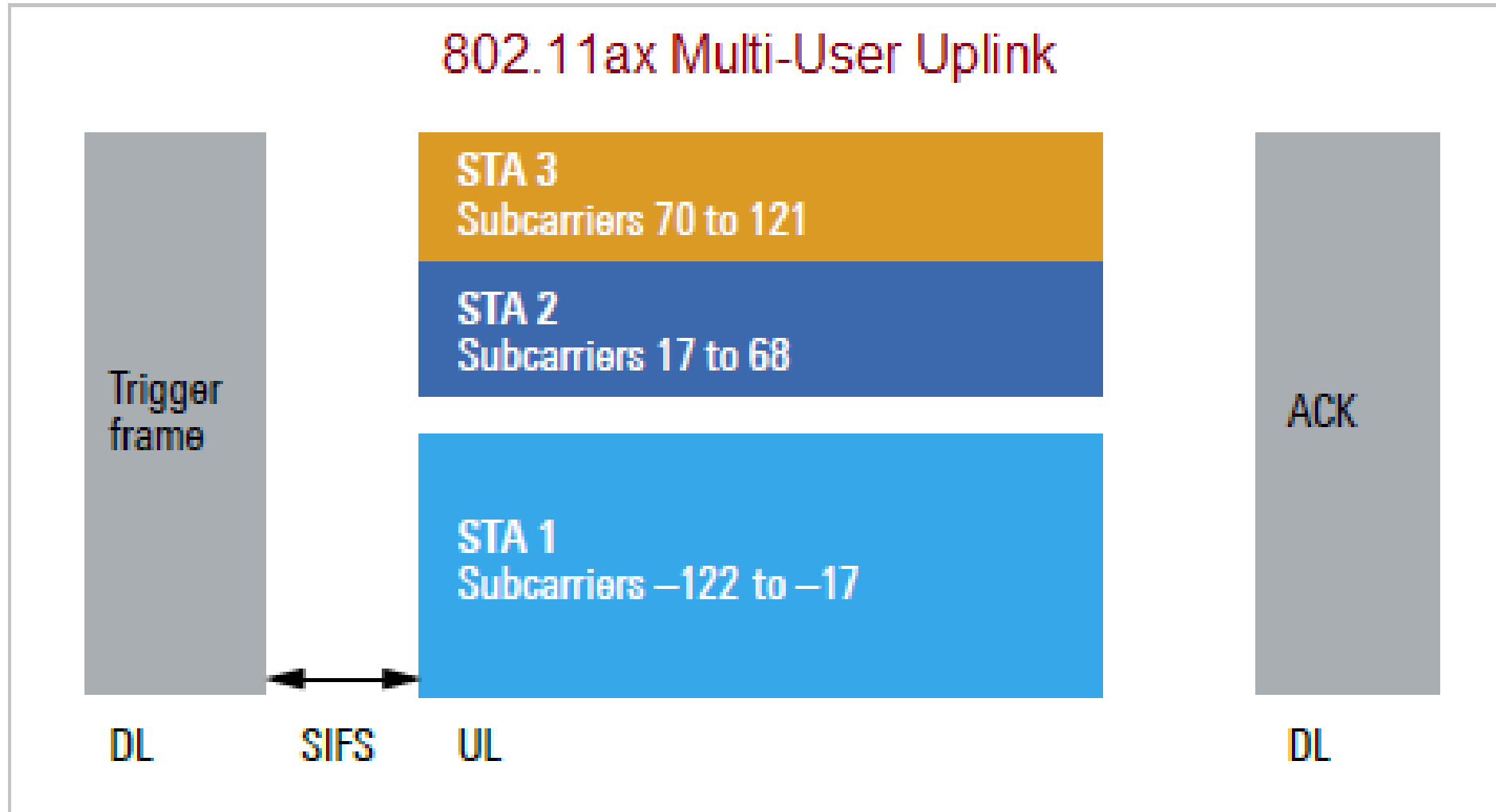
With OFDMA and dynamic channel bonding, multiple WLANs can dynamically occupy different parts of the available time-frequency space.



Uplink multi-user MIMO

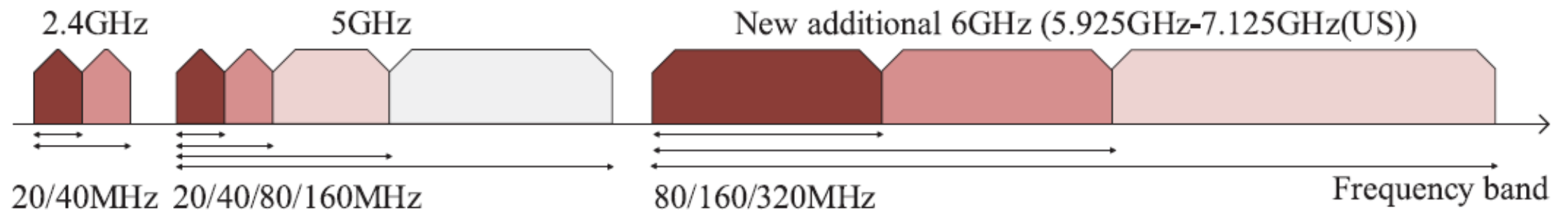
- All the **users transmit simultaneously over uplink** using OFDMA technique when they are triggered by the AP.
- In order to avoid collisions, **each user is pre-assigned with their share of allocations in the OFDMA time-space spectrum in units** (Resource Units, RUs). Also, they have been assigned with power levels and how much data to be transported in the packet.
- The **AP first send out trigger frames** to all devices. This trigger frame contains configuration parameters including payload length, bandwidth, RU allocation, modulation mode etc.
- All the **devices start their transmissions after a predefined time interval** (i.e. SIFS).

Uplink MAC illustration



IEEE 802.11be – WiFi 7

- Development from WiFi 6.
- Added frequency band: 6 GHz
- Better modulation technique: 4096-QAM, enables each symbol to carry 12 bits instead of 10 bits in WiFi 6 (1024-QAM)

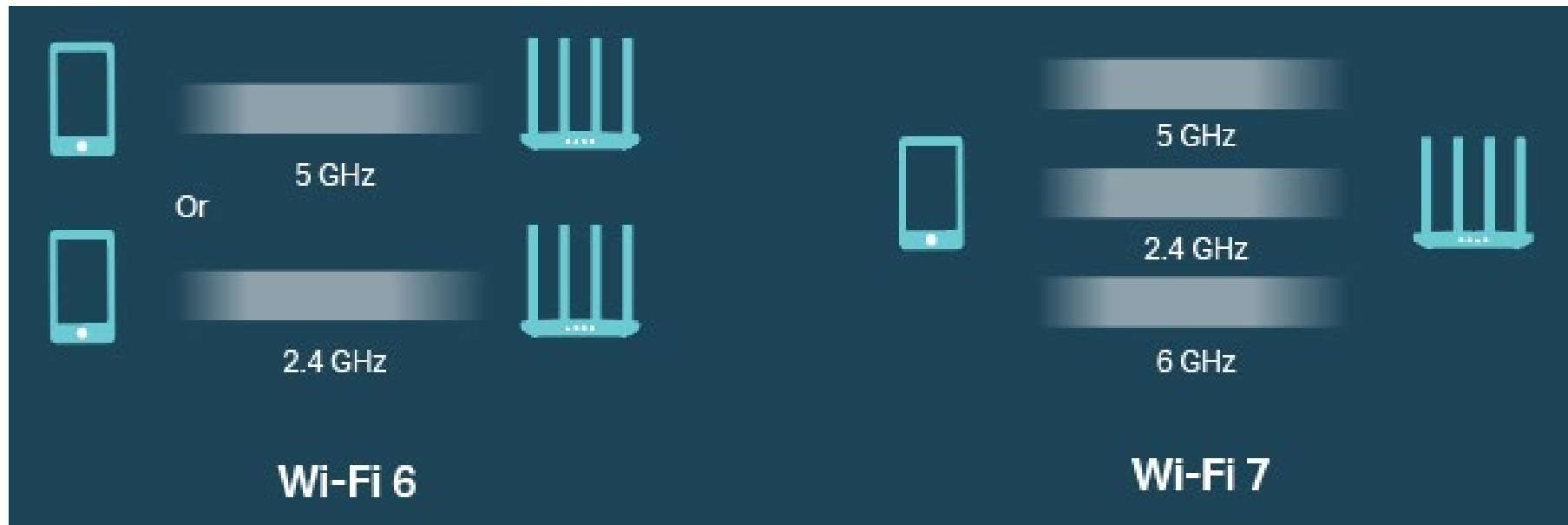


Sources: IEEE 802.11be Wi-Fi 7: New Challenges and Opportunities

https://en.wikipedia.org/wiki/IEEE_802.11be

WiFi 7 – Multi-link operation

Multi-Link Operation (MLO) is a core new feature that increases capacity and robustness by simultaneously sending and receiving data across different frequency bands and channels. (2.4GHz, 5GHz, 6GHz).



WiFi 6/7

You can buy high-capacity multiple-antenna Wifi 6/7 routers in the stores. The radio range for high-speed connectivity is limited and depends on the environment and which frequency band that is used.



WiFi 6/7 mesh

A mesh protocol standard: IEEE 802.11s

- IEEE 802.11s extends the IEEE 802.11 MAC standard by defining a mesh architecture and protocols. When using the Mesh extension for IEEE 802.11, there are two MAC protocols in the network at the same time:
- The **ordinary MAC protocol** used for the specific IEEE 802.11 standard where the mesh is incorporated.
- A **deterministic channel access mechanism**, Mesh Coordinated Channel Access (MCCA), where **Mesh nodes can reserve channel capacity and communicate with each other with less contention.**

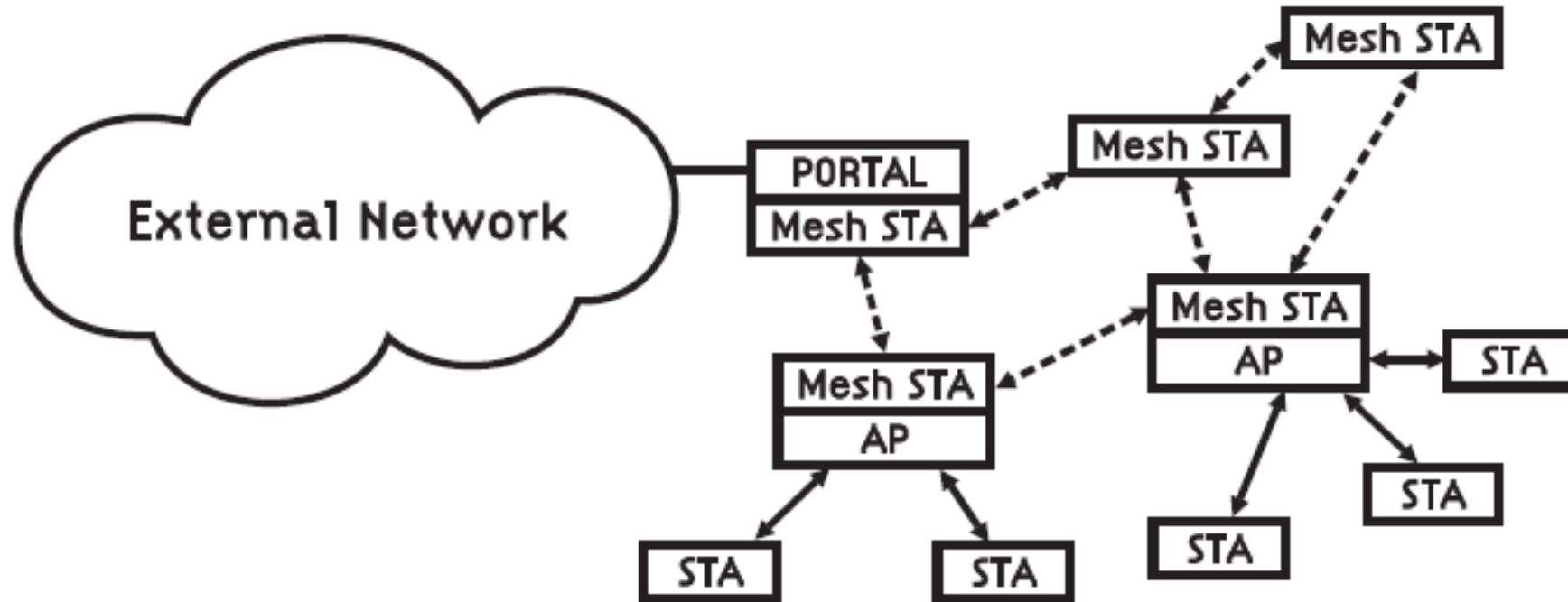
WiFi 6/7 with mesh

Today, you can buy WiFi 6/7 with a mesh solution in the electronic stores.



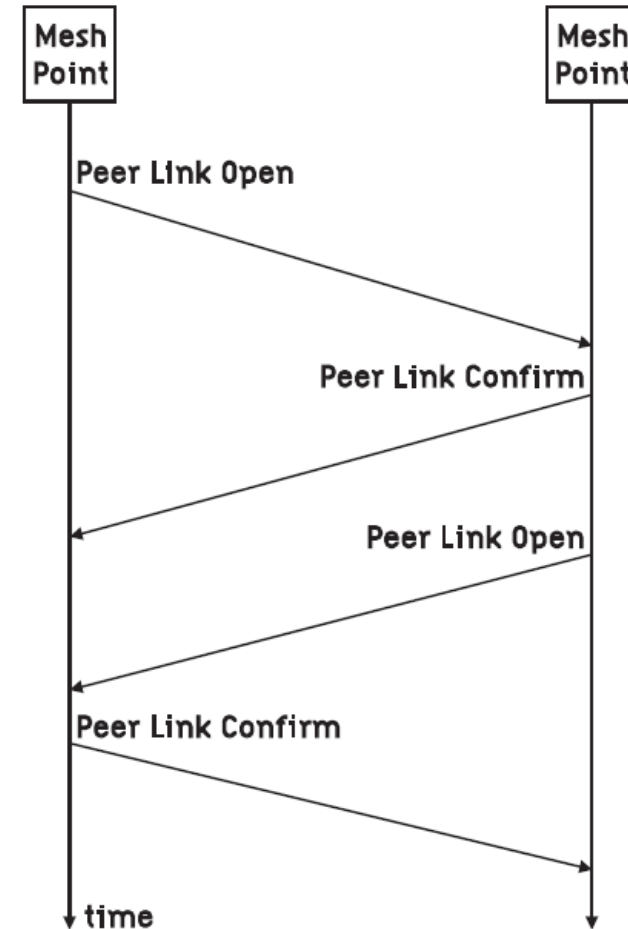
Network architecture for IEEE 802.11s

Mesh STAs are individual devices using mesh services to communicate with other Mesh STAs in the network, i.e they are the mesh routers. A Mesh STA can also collocate with **802.11 Access Points (APs)** that provide access to Internet (via the mesh network) to **802.11 stations (STAs)**.



Mesh ID

- 802.11 beacon frames are used to announce a Mesh ID.
 - Beacon frames are transmitted periodically, they serve to announce the presence of a wireless LAN and to synchronize the members of the Service set.
- To establish a link between two Mesh STAs (peer link), the Mesh STAs exchange Peer Link Open and Peer Link Confirm frames.



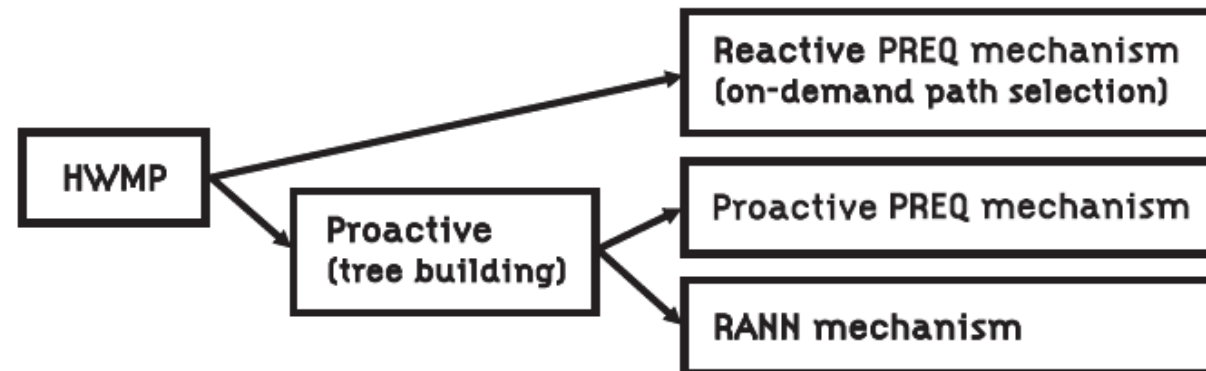
Portal: gateway to the Internet

- At least on Access Point is a Portal, that is, have connectivity to the rest of the Internet (i.e. it is the Gateway).
- The portal has to be announced for other Mesh STAs to benefit from its connectivity (node discovery protocol).
 - Once configured as a Portal, a node spreads the news sending a Portal Announcement (PANN) frame.
 - A Mesh STA that receives a PANN frame registers the Portal MAC address and the associated path and then broadcasts the PANN frame again (so that it can reach other Mesh STAs).

Path selection protocol: HWMP

The path selection protocol in IEEE 802.11 mesh networks is **Hybrid Wireless Mesh Protocol (HWMP)**. HWMP provides both Proactive and Reactive path selections that can co-exist in the same network.

- The reactive approach is based on a peer-to-peer on-demand mechanism based on AODV.
- **The proactive approach is an tree-based approach where one Mesh STA is root (for example the Portal).**
 - Used in the solutions that you buy in the store.



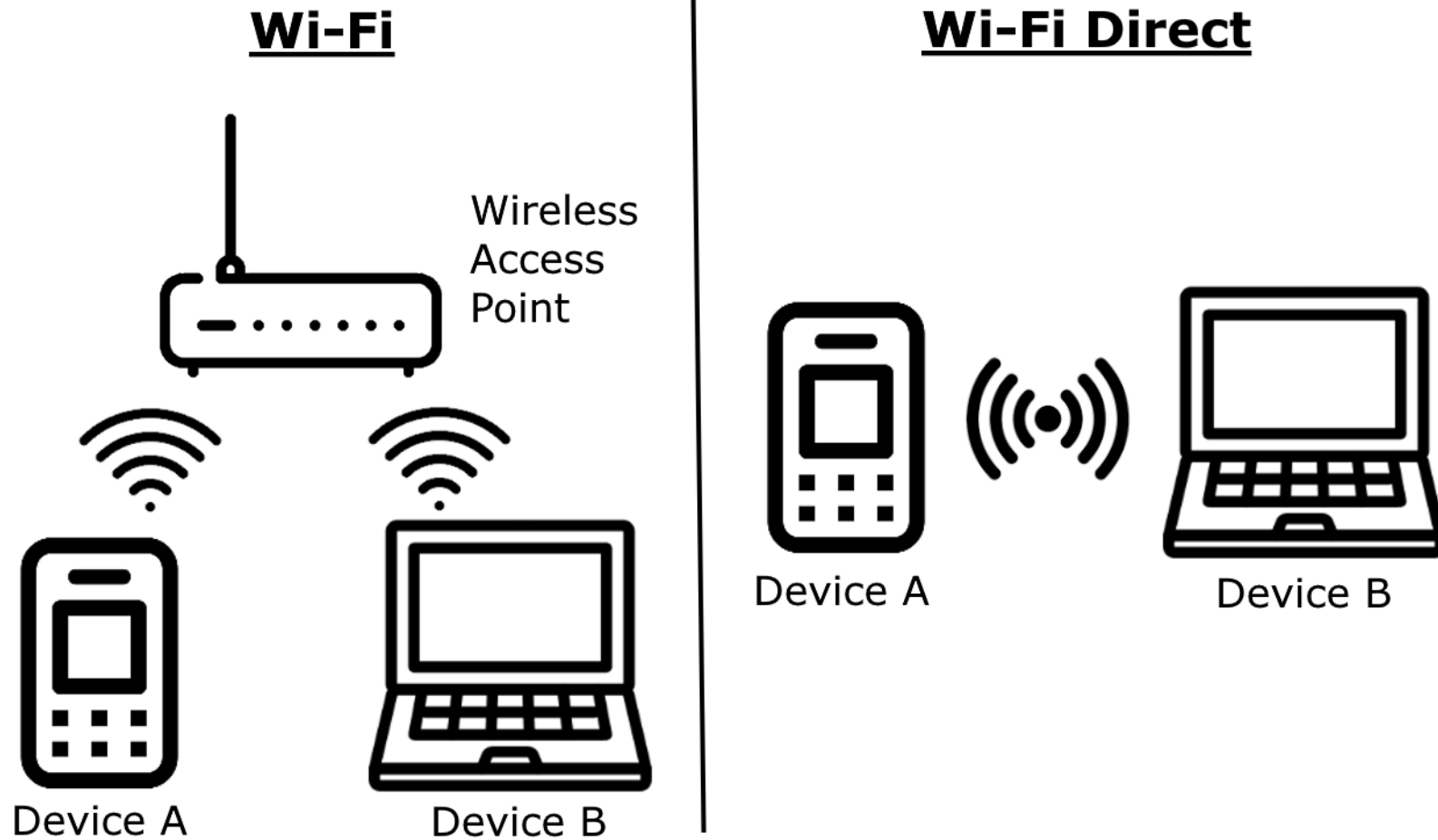
WiFi-Direct

Wi-Fi Direct

- Wi-Fi Direct enables mobile phones, cameras, printers, PCs, and gaming devices to create their own Wi-Fi networks without an Internet connection.
- Wi-Fi Direct essentially embeds a software access point ("Soft AP") into any device that supports Wi-Fi Direct.
- Only one of the Wi-Fi devices needs to be compliant with Wi-Fi Direct to establish a **peer-to-peer connection** that transfers data directly between them.
- The protocols are the same as for ordinary **IEEE 802.11** networks.
- **If you set up a WiFi-hotspot on your phone, your cellular connection will usually become the backhaul link.**



WiFi v. WiFi Direct



WiFi 6/7?

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Helsingborg Harbour - Solution suggestion – WiFi 6/7

Scenario conditions and requirements:

- This is an outdoor scenario in Helsingborg.
- Each truck will continuously receive instructions from a back-end server, and continuously send location information to the server.
- The dialogue between a truck and the back-end server is time-critical, which means that this is a time-critical application.

System design:

- WiFi 6/7 may not be the best choice for this scenario, since the harbour covers a rather large geographic area.
- However, depending on the size of the harbour, a WiFi mesh network could be deployed, with several mesh nodes spread out in the harbour area.
- In this case, the back-end server can either be accessed via the Internet or via the harbour's internal network (it will not be connected via WiFi).
- We can use a public (requiring Internet access) or a private cloud solution.



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