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Personal Area Networks (PANs)

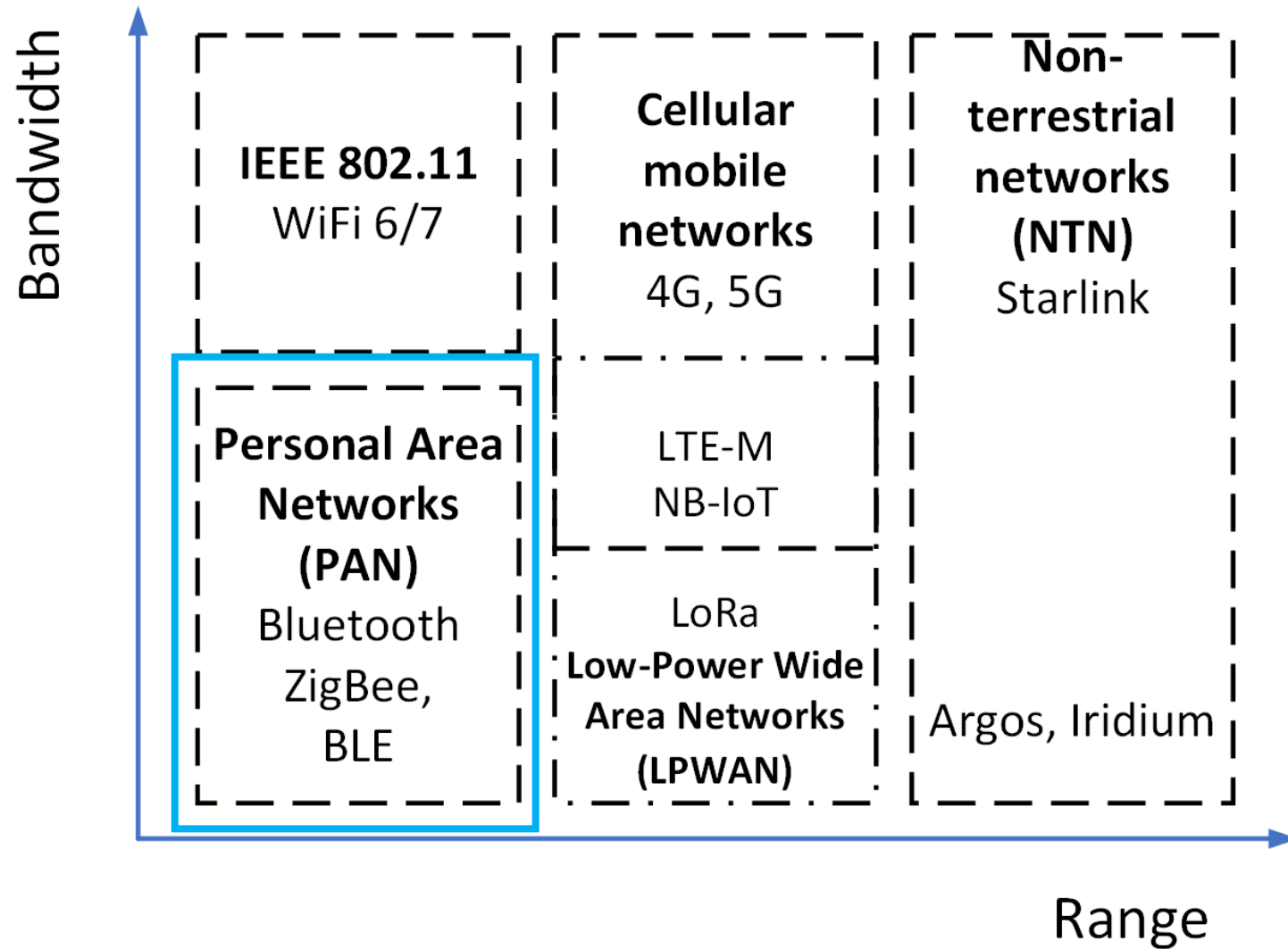
MARIA KIHLM



Literature

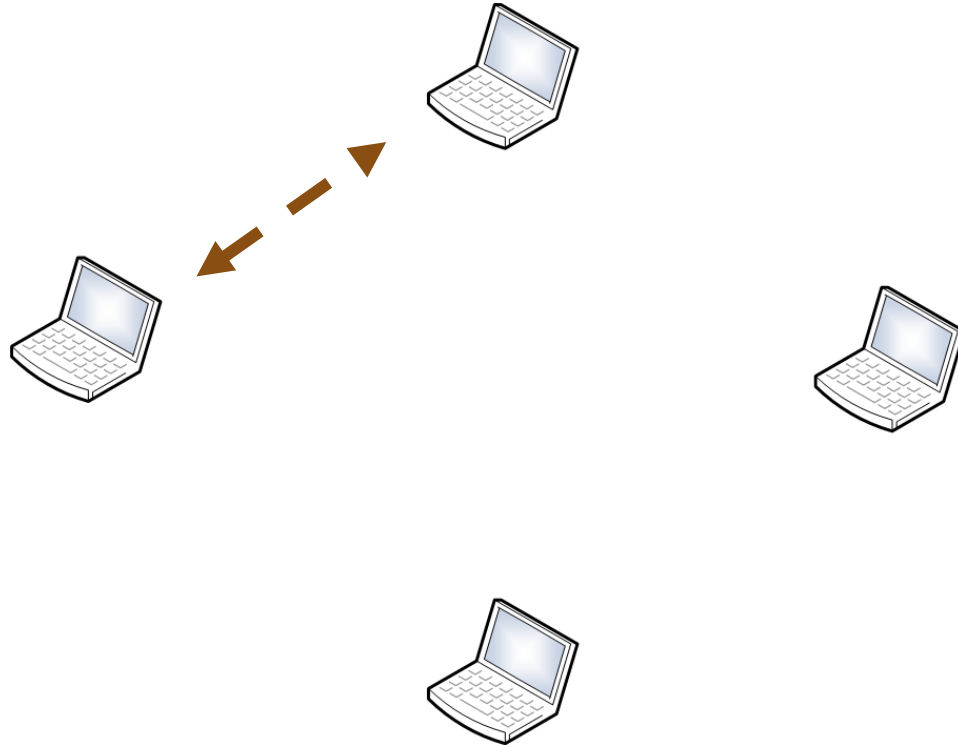
- <https://en.wikipedia.org/wiki/Bluetooth>
- https://en.wikipedia.org/wiki/Bluetooth_Low_Energy
- <https://en.wikipedia.org/wiki/Zigbee>

Lecture today



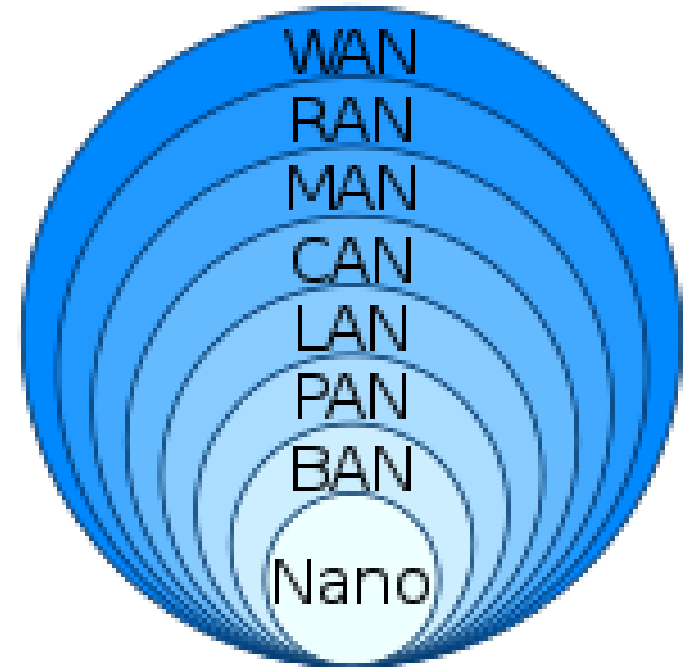
Recap: Ad-hoc connections (peer-to-peer connections)

Using an **ad-hoc** / **peer-to-peer connection**, two nodes can connect directly with each other, without the control of a base station.



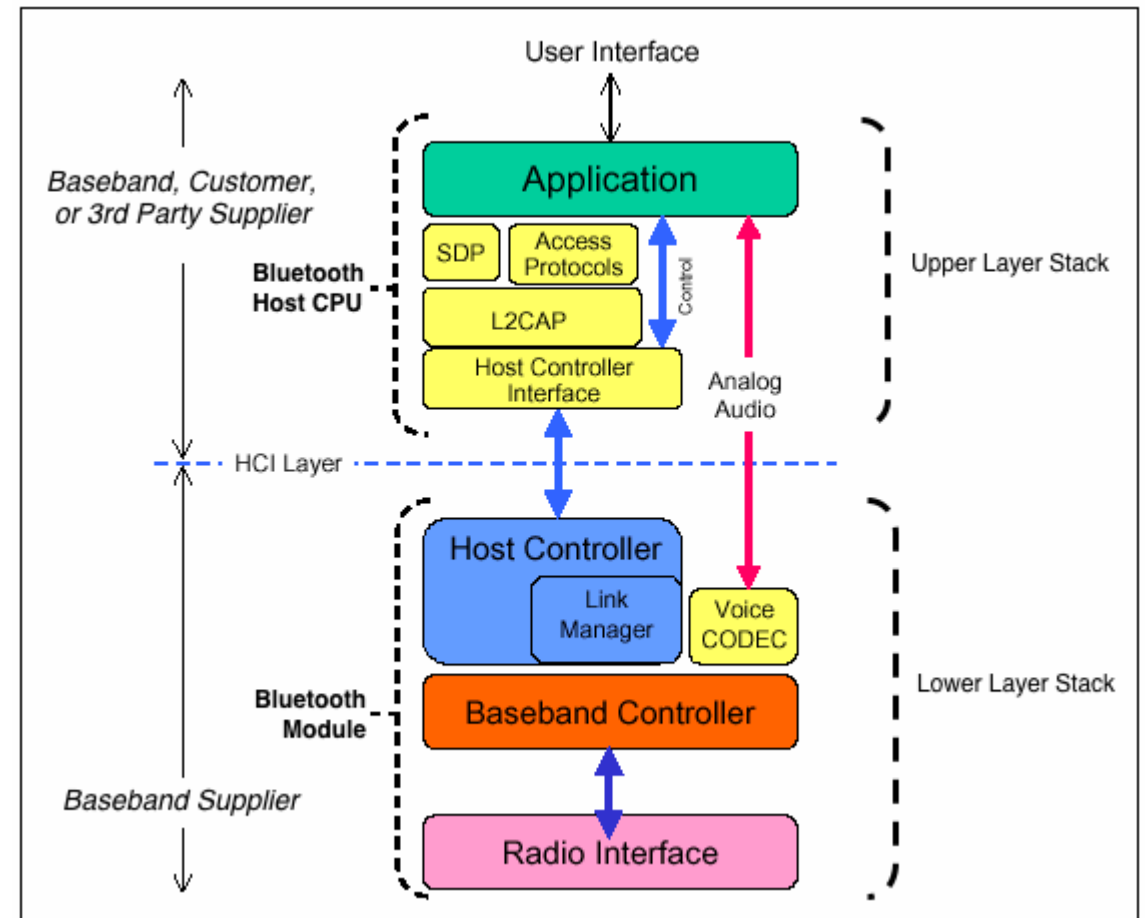
Wireless Personal Area Networks (WPAN)

- A **Personal Area Network (PAN)** is a computer network for interconnecting electronic devices within an individual person's workspace.
- A **Wireless personal area network (WPAN)** is a PAN carried over a low-powered, short-distance wireless network technology.
- There are several technologies for WPAN, for example, irDA, Wireless USB, and **Bluetooth**.

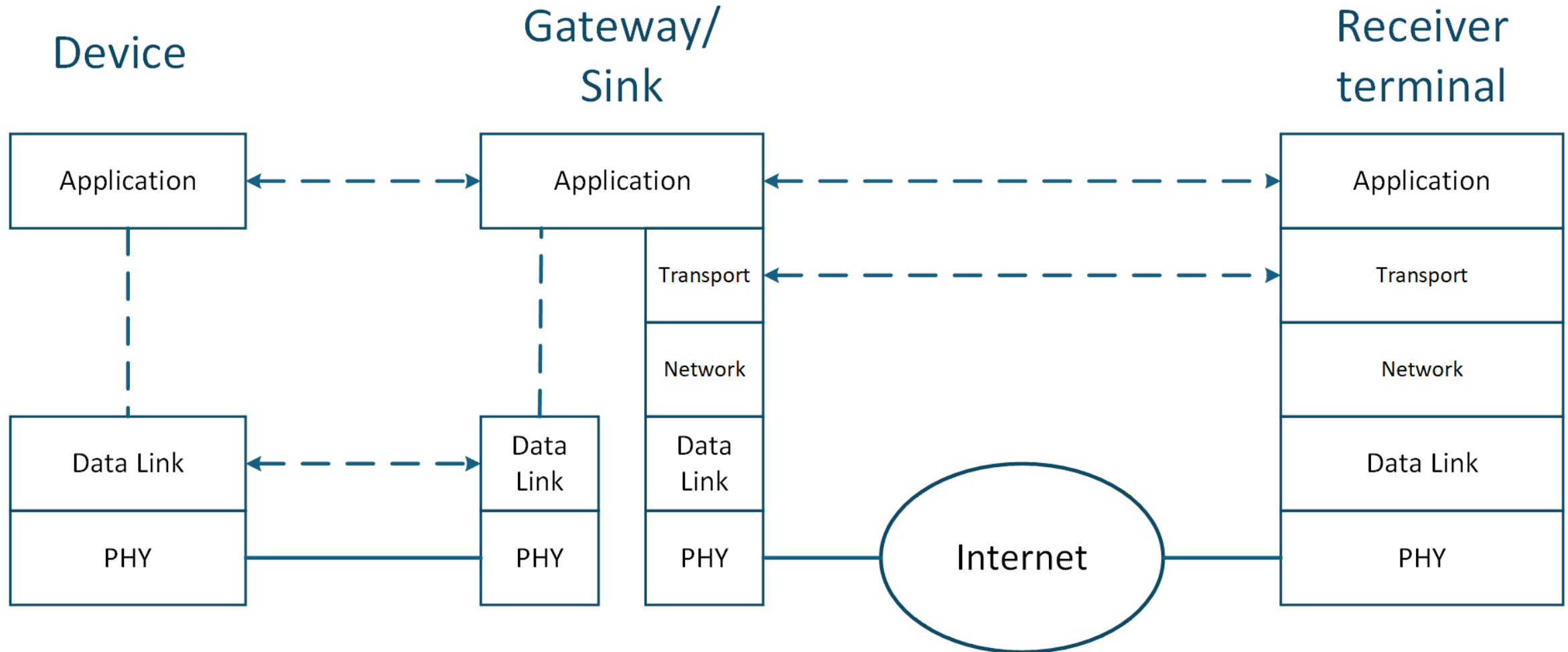


Basic protocol stack for PAN devices

- The PAN technology defines the **physical and data link layer protocols** (Bluetooth in the image).
- This means that a **PAN device normally does not have an IP address**.
- Instead it needs to connect (single-hop or multi-hop) with a device that act as the gateway.



Recap: Protocol stack for non-critical applications



Use case example: WPANs

- Smart home devices, for example light switches, often use a PAN technology.
- Using your smart phone, you connect directly with the light switch with, for example Bluetooth.
- You control the light switch with an Internet-based app on your phone. Your smart phone act as the Gateway.



Bluetooth

Bluetooth

- Developed in Lund, with the first commercial solution in 1997.
- Operates on the **license-free frequency band** on 2.4 GHz.
- Devices have a **48-bit physical address** (IEEE MAC address).
- The radio range depends on the power output and communication conditions.

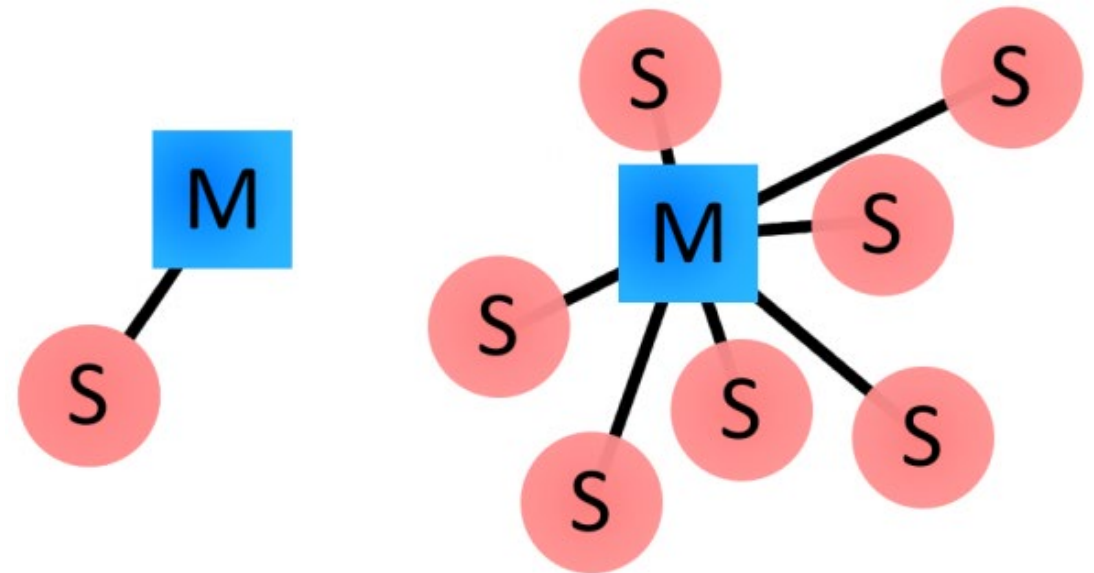
The most widely used mode gives a maximum radio range of about 100 meters.

- Also, there is a standard called **Bluetooth Low Energy (BLE)**, described later.



Bluetooth network architecture

- Bluetooth uses a hierarchical network architecture (still called master/slave, but this terminology is heavily questioned), so called **piconets**.
- The **primary (master) node controls the piconet**, and synchronizes the communication. The **secondary nodes (slaves) can send data to the primary node at specific time slots**.
- Two nodes can **switch roles** at any time.
For example, a headset pairing with a mobile phone starts as a primary node (initiates the connection), but then becomes a secondary node after pairing.

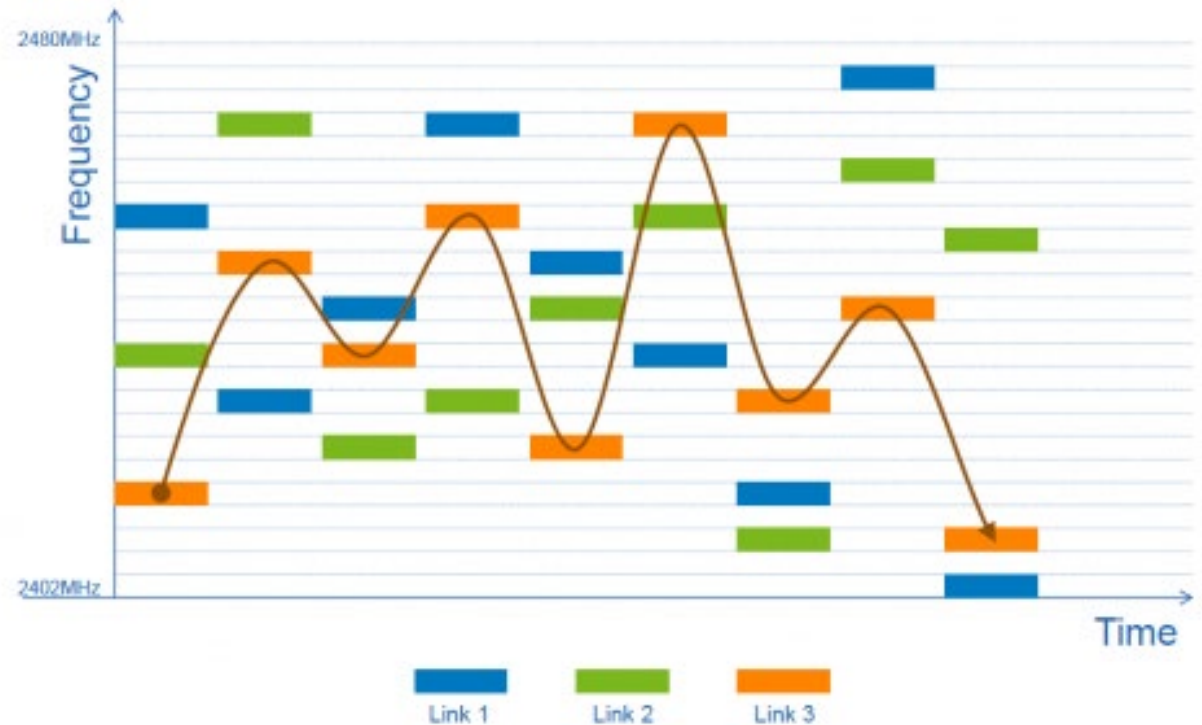


Bluetooth – node discovery and pairing

- A device can initiate connections with other devices with so called **bonding** and **pairing**.
- A device can perform an inquiry to find other devices to connect to (node discovery), and any device can be configured to respond to such inquiries.
- Any Bluetooth device in **discoverable mode** transmits its name and technical information on demand.
- For security reasons, Bluetooth uses a process called **bonding**, and a bond is generated through a process called **pairing**.
- **Pairing often involves some level of user interaction.**
 - This user interaction confirms the identity of the devices.
 - When pairing completes, a bond forms between the two devices, enabling those two devices to connect in the future without repeating the pairing process to confirm device identities.

Bluetooth data communication

- Bluetooth uses **Frequency-hopping spread spectrum** in order to minimize interference and disturbances on the license-free band.
- A data packet is sent over 79 different radio channels in a pre-defined changing pattern.
- If there are more disturbances on some channels, these channels can be avoided.



Bluetooth?

You have been given the task to help a friend that wants to install a smart lighting system for their greenhouse. The system includes about 10 sensors distributed in the greenhouse. Also, the system includes smart lamps that can be controlled via the Internet. The sensors collect and send data to a back-end server system.

The back-end server system includes an AI system that processes the data and then adjusts the lamps in the greenhouse so that the plants always have optimal light.

Your task is to suggest a solution for the complete networked system.

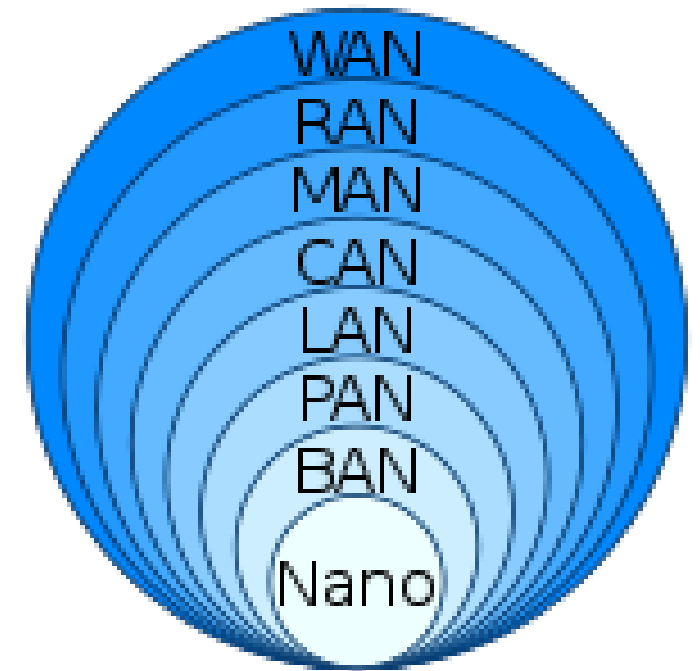


Solution suggestion – Greenhouse - Bluetooth

- Bluetooth could be used, but ordinary Bluetooth is probably not the most suitable technology in this scenario.
- If Bluetooth is used, your friend needs to install a gateway to which the sensors and lamps can be connected.
- The gateway connects with the back-end server.

Low-power Personal Area Networks (LP-PAN)

- WPANs specifically tailored for low-power operation of the sensors are sometimes also called **Low-Power PANs (LP-PANs)** or **Low-rate Wireless PANs (LR-WPAN)** to better distinguish them from LP-WANs.
- **IEEE 802.15.4** is a technical standard for LP-PANs.
 - There are several commercial solutions that are based on IEEE 802.15.4, for example **ZigBee**, WirelessHART, and 6LowPAN.
- **Bluetooth Low Energy (BLE)** is another LP-PAN technology.



Bluetooth Low Energy (BLE)

Bluetooth Low Energy Mesh (BLE Mesh)

- **Bluetooth Low Energy** uses the same 2.4 GHz radio frequencies as classic Bluetooth, which allows dual-mode devices to share a single radio antenna but uses a simpler modulation system.
 - Current Bluetooth standards allow devices to have both ordinary Bluetooth and BLE implemented at the same time.
- **Bluetooth Low Energy Mesh (BLE Mesh)** is a wireless communication protocol and network topology that is built on top of BLE technology.
 - It is designed for creating large-scale mesh networks that consist of numerous interconnected BLE devices.
- BLE Mesh is useful for applications like smart home automation, industrial IoT (Internet of Things), and building automation, where multiple devices need to communicate with each other.

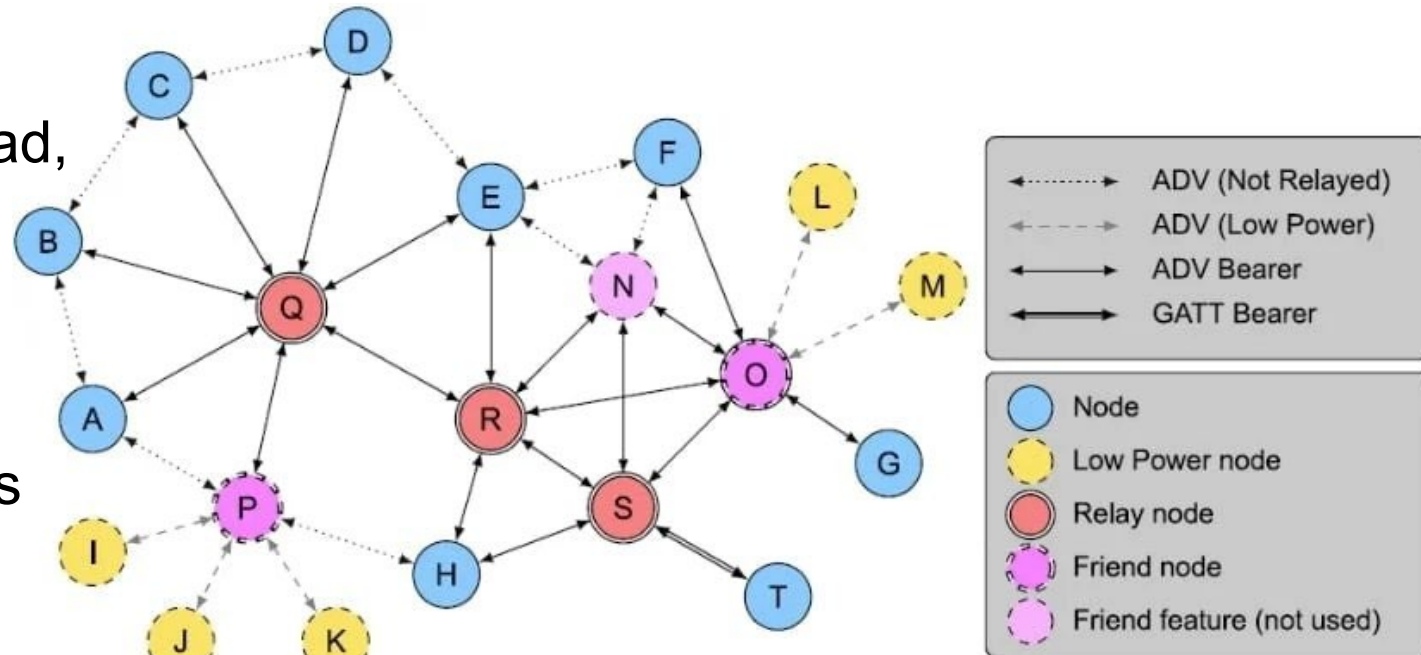


BLE Mesh – Basic network infrastructure

In a BLE Mesh network, there is no central hub or master device. Instead, all devices are equal peers that can communicate directly with one another.

However, nodes have different roles and capabilities:

- **Nodes** can send and receive data.
- **Relay nodes** are nodes that also can forward messages.
- **Low Power nodes** are nodes that have a limited power supply.
- **Friend nodes** are nodes that can help Low power nodes, by for example, storing data for them when they sleep.



BLE Mesh Relay nodes

- The relay nodes play a crucial role in routing messages within the mesh.
- Each relay node handles the creation and maintenance of **routing tables**, ensuring that messages can be efficiently relayed through the mesh.
- Relay nodes contribute to a **self-healing** capability by helping to reroute messages when there are changes in the network, such as when a node becomes unreachable or fails.
- One of the core concepts in BLE Mesh is the **publish-subscribe** model.
 - Nodes can subscribe to certain types of messages, indicating their interest in receiving specific data.
 - Nodes that produce data, known as publishers, send their messages to a group of subscribers who have expressed interest in that data.

ZigBee

ZigBee

- **Zigbee** is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create LP-PANs.
- ZigBee's low power consumption **limits transmission distances to 10–100 meters line-of-sight**, depending on power output and environmental characteristics.
- Zigbee devices can transmit data over long distances by passing data through a **mesh network of intermediate devices** to reach more distant ones.
- The **routing protocol** is performed on the ZigBee network layer (not IP network layer), and it is **based on AODV**.



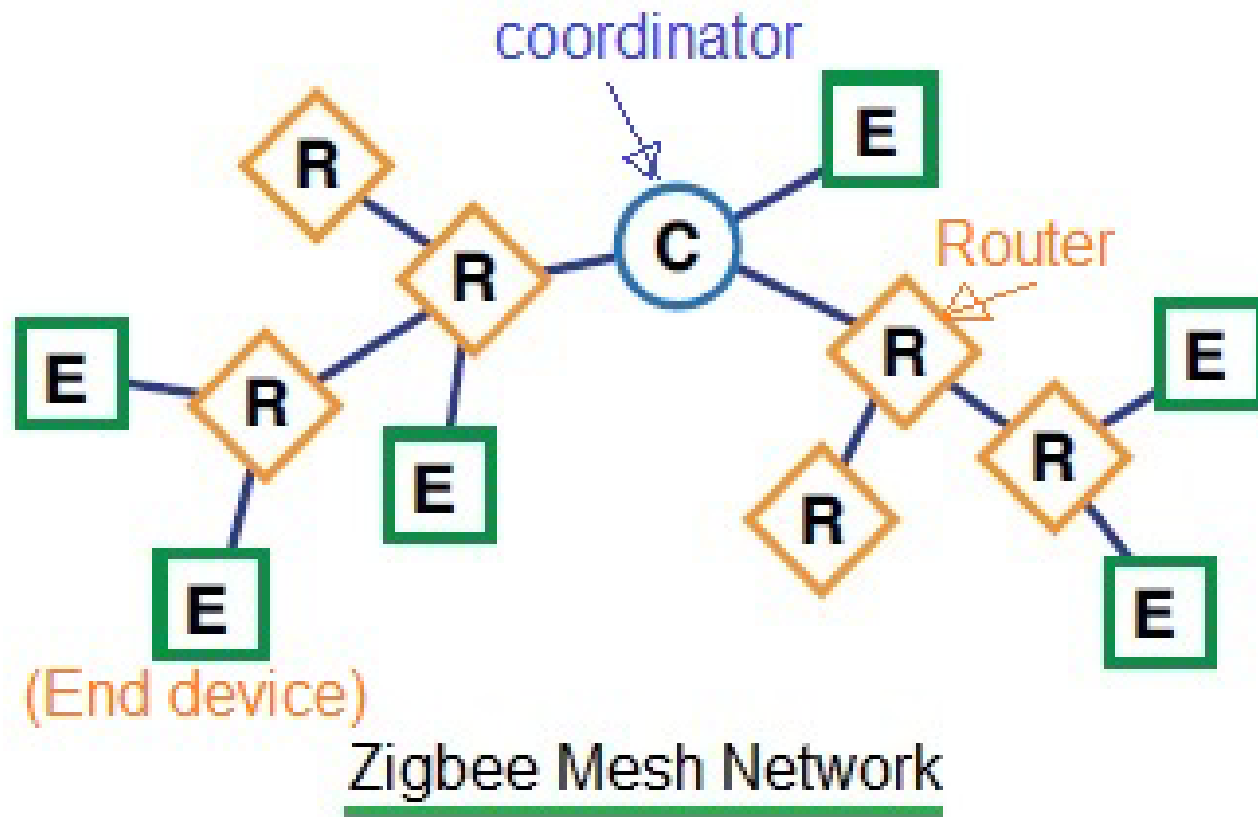
Node types in ZigBee

There are three classes of Zigbee devices:

- ***Zigbee coordinator (ZC)***: The coordinator forms the root of the network tree and may bridge to other networks. There is one Zigbee coordinator in each network. The ZC stores information about the network, including acting as the trust center and repository for security keys.
- ***Zigbee router (ZR)***: A Zigbee router is a host that can act as an intermediate router, passing data on from other devices. The forwarding is performed on the Zigbee network layer.
- ***Zigbee end device (ZED)***: A Zigbee end device contains just enough functionality to talk to the parent node (either the coordinator or a router); it cannot relay data from other devices. This relationship allows the node to be asleep a significant amount of the time thereby giving long battery life.

A ZigBee mesh network

The ZigBee mesh network is based on a tree structure, where the ZC acts as root.



MAC protocol in ZigBee

ZigBee allows for two types of MAC protocols:

- **Beacon-enabled Communication**

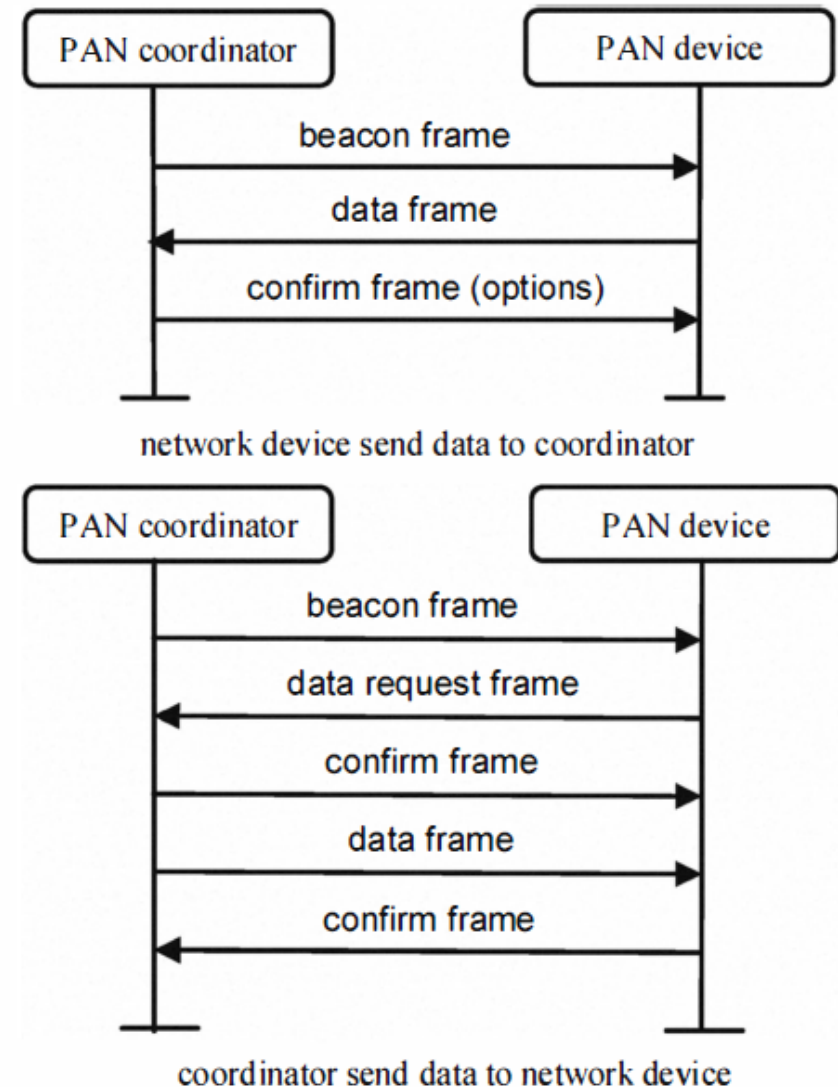
- In beacon-enabled network, the network coordinator periodically broadcasts beacon frames (polling), and devices in the PAN network are synchronized according to the beacon frames from coordinator.

- **Non-beacon-enabled Communication**

- For non-beacon enabled network, the network coordinator randomly sends beacon frames from time to time. The uplink communication is using a CSMA/CA based MAC protocol.

Beacon-enabled communication

- In beacon-enabled communication, the coordinator periodically sends out beacons for synchronization and control.
- **Uplink:** The device can only send a data frame when it has received a beacon from the coordinator.
- **Downlink:** The beacon frame includes information about data to a device. The device can then request this data in a time period after the beacon frame.



Non-beacon-enabled communication

- For non-beacon enabled network, **the network coordinator sends beacon frames from time to time for synchronization.**
- **Uplink (CSMA/CA):** Whenever the device is about to send data, firstly, it has to wait for a random length of time, and then begin to detect the channel state, if idle, the device starts to send data; if busy, the device need to wait for another period, and re-testing channel until the channel is available to send data.
- **Downlink:** The beacon frame includes information about data to a device. The device can then request this data in a time period after the beacon frame.

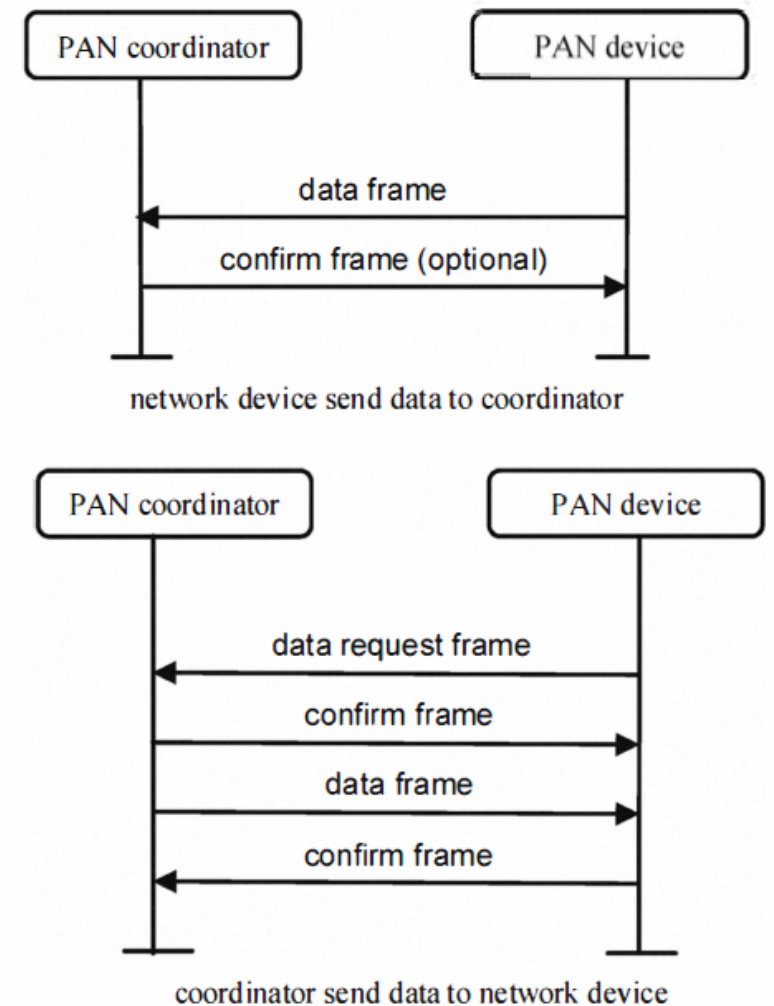


Fig. 2 data transmission model of non-beacon-enabled

BLE or ZigBee?

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The back-end server system includes an AI system that processes the data and then adjusts the lamps in the greenhouse so that the plants always have optimal light.

Your task is to suggest a solution for the complete networked system.



Solution suggestion – Greenhouse – BLE and ZigBee

- BLE or ZigBee is suitable for this scenario.
 - The nodes are stationary.
 - Some nodes are mains powered.
- Your friend can install a ZigBee or BLE network.
- In this case, one of the nodes must be a Gateway/Coordinator.
- The lamps should act as ZigBee routers or BLE Relay nodes, since they are mains powered.
- The sensors and lamps use multi-hop data forwarding to send and receive data.

Alternative solutions?

You have been given the task to help a friend that wants to install a smart lighting system for their greenhouse. The system includes about 10 sensors distributed in the greenhouse. Also, the system includes smart lamps that can be controlled via the Internet. The sensors collect and send data to a back-end server system.

The back-end server system includes an AI system that processes the data and then adjusts the lamps in the greenhouse so that the plants always have optimal light.

Your task is to suggest a solution for the complete networked system.



Greenhouse – Other solution suggestions

- Connect sensors and lamps via WiFi.
 - Requires mains powered sensors.
- Use a wired solution, for example Ethernet.
 - Sensors can use a Power over Ethernet solution.



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