# Internet Applications

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# Chapter 2

# Smart Objects Things in IOT

# Connecting Smart Objects

Currently, the number of technologies connecting smart objects is quite extensive, but you should expect consolidation, with certain protocols eventually winning out over others in the various IoT market segments. The discussion of technologies for connecting sensors to the ones that seem to be most promising going forward in the IoT marketplace. Other technologies are mentioned in context when applicable.

In the world of connecting "things," a large number of wired and wireless access technologies are available or under development. Before reviewing some of these access technologies, it is important to talk about the criteria to use in evaluating them for various use cases and system solutions. Wireless communication is prevalent in the world of smart object connectivity, mainly because it eases deployment and allows smart objects to be mobile, changing location without losing connectivity.

# Communications Criteria

**1- Range:** How far does the signal need to be propagated? That is, what will be the area of coverage for a selected wireless technology? Should indoor versus outdoor deployments be differentiated? Very often, these are the first questions asked when discussing wired and wireless access technologies. The simplest approach to answering these types of questions is to categorize these technologies

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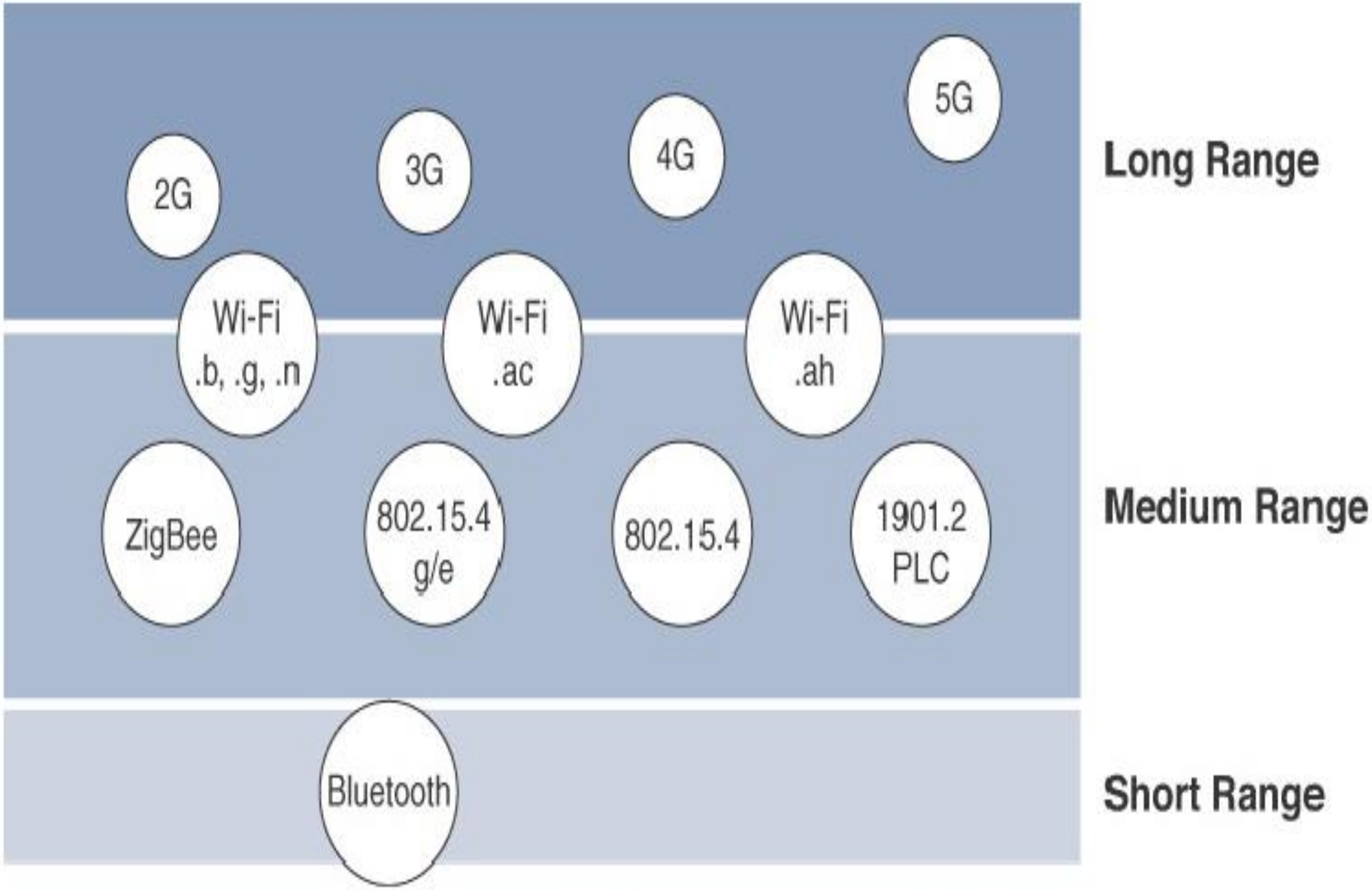



*Wireless Access Landscape*

- **Short range:** The classical wired example is a serial cable. Wireless short-range technologies are often considered as an alternative to a serial cable, supporting tens of meters of maximum distance between two devices. Examples of short-range wireless technologies are IEEE 802.15.1 Bluetooth and IEEE 802.15.7 Visible Light Communications (VLC). These short-range communication methods are found in only a minority of IoT installations.

- **Medium range:** This range is the main category of IoT access technologies. In the range of tens to hundreds of meters, many specifications and implementations are available. The maximum distance is generally less than 1 mile between two devices, although RF technologies do not have real maximum distances defined, as long as the radio signal is transmitted and received in the scope of the applicable specification. Examples of medium-range wireless technologies include IEEE 802.11 Wi-Fi, IEEE 802.15.4, and 802.15.4g WPAN. Wired technologies such as IEEE 802.3 Ethernet and IEEE 1901.2 Narrowband Power Line Communications (PLC) may also be classified as medium range, depending on their physical media characteristics.

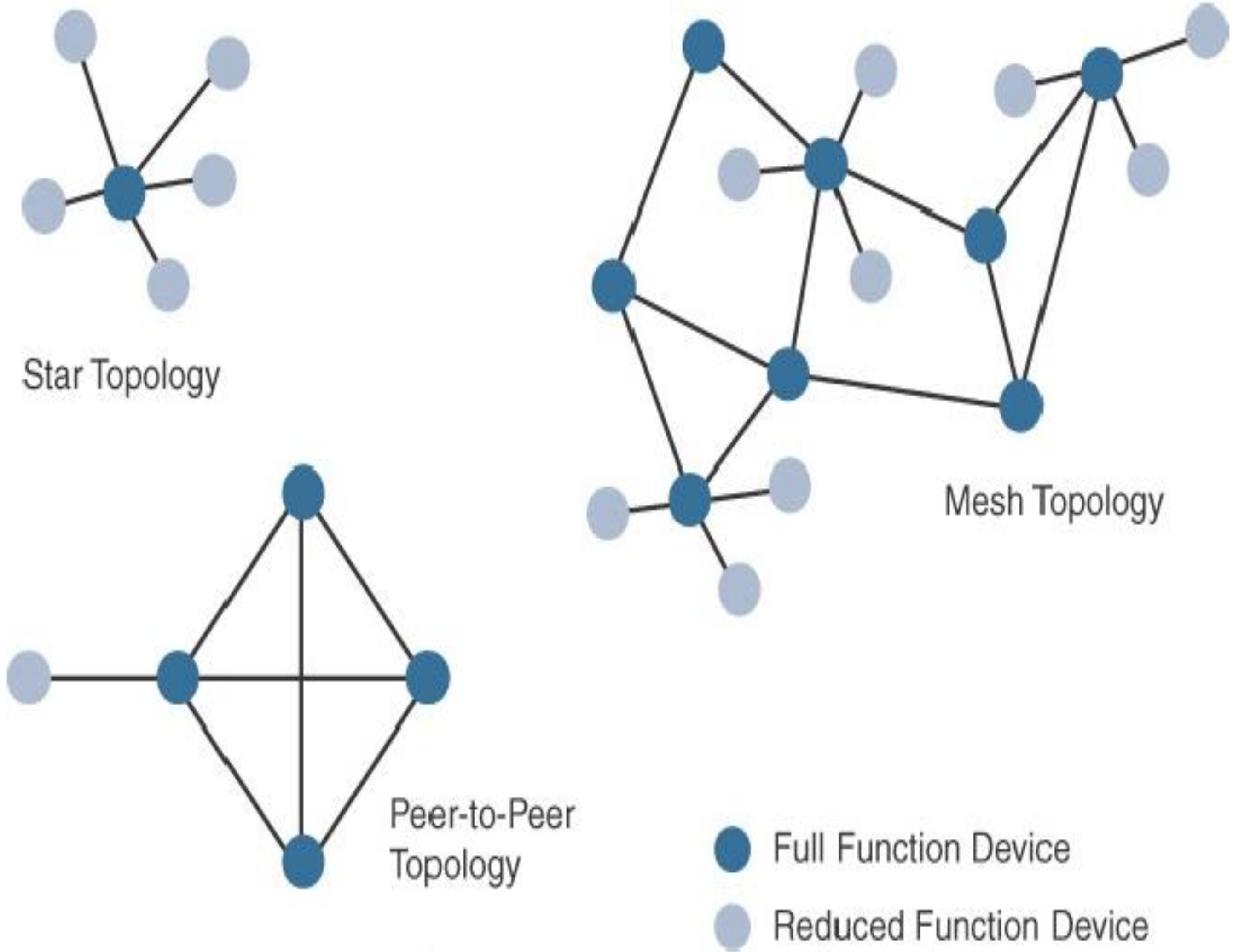
- **Long range:** Distances greater than 1 mile between two devices require long-range technologies. Wireless examples are cellular (2G, 3G, 4G) and some applications of outdoor IEEE 802.11 Wi-Fi and Low-Power Wide-Area (LPWA) technologies. LPWA communications have the ability to communicate over a large area without consuming much power. These technologies are therefore ideal for battery powered IoT sensors. Found mainly in industrial networks, IEEE 802.3 over optical fiber and IEEE 1901 Broadband Power Line Communications are classified as long range but are not really considered IoT access technologies.

**2- Frequency Bands:** Radio spectrum is regulated by countries and/or organizations, such as the International Telecommunication Union (ITU) and the Federal Communications Commission (FCC). These groups define the regulations and transmission requirements for various frequency bands. For example, portions of the spectrum are allocated to types of telecommunications such as radio, television, military, and so on. Around the world, the spectrum for various communications uses is often viewed as a critical resource. For example, you can see the value of these frequencies by examining the cost that mobile operators pay for licenses in the cellular spectrum.

**3- Power Consumption:** While the definition of IoT device is very broad, there is a clear delineation between powered nodes and battery-powered nodes. A powered node has a direct connection to a power source, and communications are usually not limited by power consumption criteria. However, ease of deployment of powered nodes is limited by the availability of a power source, which makes mobility more complex.

Battery-powered nodes bring much more flexibility to IoT devices. These nodes are often classified by the required lifetimes of their batteries. Does a node need 10 to 15 years of battery life, such as on water or gas meters? Or is a 5- to 7-year battery life sufficient for devices such as smart parking sensors? Their batteries can be changed or the devices replaced when a street gets resurfaced. For devices under regular maintenance, a battery life of 2 to 3 years is an option.

**4- Topology:** Among the access technologies available for connecting IoT devices, three main topology schemes are dominant: star, mesh, and peer-to-peer. For long-range and short-range technologies, a star topology is prevalent, as seen with cellular, LPWA, and Bluetooth networks. Star topologies utilize a single central base station or controller to allow communications with endpoints. For medium-range technologies, a star, peer-to-peer, or mesh topology is common.




*Star, Peer-to-Peer, and Mesh Topologies*

Peer-to-peer topologies allow any device to communicate with any other device as long as they are in range of each other. Obviously, peer-to-peer topologies rely on multiple full-function devices. Peer-to-peer topologies enable more complex formations, such as a mesh networking topology. For example, indoor Wi-Fi deployments are mostly a set of nodes forming a star topology around their access points (APs). Meanwhile, outdoor Wi-Fi may consist of a mesh topology for the backbone of APs, with nodes connecting to the APs in a star topology.

**5- Constrained Devices:** While categorizing the class of IoT nodes is a perilous exercise, with computing, memory, storage, power, and networking continuously evolving and improving, RFC gives some definitions of constrained nodes. These definitions help differentiate constrained nodes from unconstrained nodes, such as servers, desktop or laptop computers, and powerful mobile devices such as smart phones. Constrained nodes have limited resources that impact their networking feature set and capabilities. Therefore, some classes of IoT nodes do not implement an IP stack.

| Class | Definition |
|---|---|
| Class 0 | This class of nodes is severely constrained, with less than 10 KB of memory and less than 100 KB of Flash processing and storage capability. These nodes are typically battery powered. They do not have the resources required to directly implement an IP stack and associated security mechanisms. An example of a Class 0 node is a push button that sends 1 byte of information when changing its status. This class is particularly well suited to leveraging new unlicensed LPWA wireless technology. |
| Class 1 | While greater than Class 0, the processing and code space characteristics (approximately 10 KB RAM and approximately 100 KB Flash) of Class 1 are still lower than expected for a complete IP stack implementation. They cannot easily communicate with nodes employing a full IP stack. However, these nodes can implement an optimized stack specifically designed for constrained nodes, such as Constrained Application Protocol (CoAP). This allows Class 1 nodes to engage in meaningful conversations with the network without the help of a gateway, and provides support for the necessary security functions. Environmental sensors are an example of Class 1 nodes. |
| Class 2 | Class 2 nodes are characterized by running full implementations of an IP stack on embedded devices. They contain more than 50 KB of memory and 250 KB of Flash, so they can be fully integrated in IP networks. A smart power meter is an example of a Class 2 node. |

**Table** *Classes of Constrained Nodes, as Defined by RFC 7228*

**6- Constrained-Node Networks:** While several of the IoT access technologies, such as Wi-Fi and cellular, are applicable to laptops, smart phones, and some IoT devices, some IoT access technologies are more suited to specifically connect constrained nodes. Typical examples are IEEE 802.15.4 and 802.15.4g RF, IEEE 1901.2a PLC, LPWA, and IEEE 802.11ah access technologies. Constrained-node networks are often referred to as low-power and lossy networks (LLNs). Low-power in the context of LLNs refers to the fact that nodes must cope with the requirements from powered and battery-powered constrained nodes.

Lossy networks indicates that network performance may suffer from interference and variability due to harsh radio environments. Layer 1 and Layer 2 protocols that can be used for constrained-node networks must be evaluated in the context of the following characteristics for use-case applicability: data rate and throughput, latency and determinism, and overhead and payload.

# IOT Access Technologies

**IEEE 802.15.4** is a wireless access technology for low-cost and low-data-rate devices that are powered or run on batteries. In addition to being low cost and offering a reasonable battery life, this access technology enables easy installation using a compact protocol stack while remaining both simple and flexible. Several network communication stacks, including deterministic ones, and profiles leverage this technology to address a wide range of IoT use cases in both the consumer and business markets.

IEEE 802.15.4 is commonly found in the following types of deployments:

- Home and building automation
- Automotive networks
- Industrial wireless sensor networks
- Interactive toys and remote controls

**IEEE 802.15.4g and 802.15.4e** The IEEE frequently makes amendments to the core 802.15.4 specification, before integrating them into the next revision of the core specification. When these amendments are made, a lowercase letter is appended. Two such examples of this are 802.15.4e-2012 and 802.15.4g-2012, both of which are especially relevant to the subject of IoT. Both of these amendments were integrated in IEEE 802.15.4-2015 but are often still referred to by their amendment names.

The IEEE 802.15.4e amendment of 802.15.4-2011 expands the MAC layer feature set to remedy the disadvantages associated with 802.15.4, including MAC reliability, unbounded latency, and multipath fading. In addition to making general enhancements to the MAC layer, IEEE 802.15.4e also made improvements to better cope with certain application domains, such as factory and process automation and smart grid. Smart grid is associated with the modernization of the power grid and utilities infrastructure by connecting intelligent devices and communications.

This technology applies to IoT use cases such as the following:

- Distribution automation and industrial supervisory control and data acquisition (SCADA) environments for remote monitoring and control.
- Public lighting
- Environmental wireless sensors in smart cities
- Electrical vehicle charging stations
- Smart parking meters
- Microgrids
- Renewable energy

**IEEE 1901.2a:** While most of the constrained network technologies relate to wireless, IEEE 1901.2a-2013 is a wired technology that is an update to the original IEEE 1901.2 specification. This is a standard for Narrowband Power Line Communication (NB-PLC). NB-PLC leverages a narrowband spectrum for low power, long range, and resistance to interference over the same wires that carry electric power.

NB-PLC is often found in use cases such as the following:

- **Smart metering:** NB-PLC can be used to automate the reading of utility meters, such as electric, gas, and water meters. This is true particularly in Europe, where PLC is the preferred technology for utilities deploying smart meter solutions.
- **Distribution automation:** NB-PLC can be used for distribution automation, which involves monitoring and controlling all the devices in the power grid.

- **Public lighting:** A common use for NB-PLC is with public lighting—the lights found in cities and along streets, highways, and public areas such as parks.
- **Electric vehicle charging stations:** NB-PLC can be used for electric vehicle charging stations, where the batteries of electric vehicles can be recharged.
- **Microgrids:** NB-PLC can be used for micro grids, local energy grids that can disconnect from the traditional grid and operate independently.
- **Renewable energy:** NB-PLC can be used in renewable energy applications, such as solar, wind power, hydroelectric, and geothermal heat.

**IEEE 802.11ah:** In unconstrained networks, IEEE 802.11 Wi-Fi is certainly the most successfully deployed wireless technology. This standard is a key IoT wireless access technology, either for connecting endpoints such as fog computing nodes, high-data-rate sensors, and audio or video analytics devices or for deploying Wi-Fi backhaul infrastructures, such as outdoor Wi-Fi mesh in smart cities, oil and mining, or other environments. However, Wi-Fi lacks sub-GHz support for better signal penetration, low power for battery-powered nodes, and the ability to support a large number of devices.

For these reasons, the IEEE 802.11 working group launched a task group named IEEE 802.11ah to specify a sub-GHz version of Wi-Fi. Three main use cases are identified for IEEE 802.11ah:

- Sensors and meters covering a smart grid: Meter to pole, environmental/agricultural monitoring, industrial process sensors, indoor healthcare system and fitness sensors, home and building automation sensors
- Backhaul aggregation of industrial sensors and meter data: Potentially connecting IEEE 802.15.4g subnetworks
- Extended range Wi-Fi: For outdoor extended-range hotspot or cellular traffic offloading when distances already covered by IEEE 802.11a/b/g/n/ac are not good enough

**Lora WAN:** In recent years, a new set of wireless technologies known as Low-Power Wide-Area (LPWA) has received a lot of attention from the industry and press. Particularly well adapted for long-range and battery-powered endpoints, LPWA technologies open new business opportunities to both services providers and enterprises considering IoT solutions. This section discusses an example of an unlicensed-band LPWA technology, known as LoRa WAN, and the next section, "NB-IoT and Other LTE Variations," reviews licensed-band alternatives from the 3rd Generation Partnership Project (3GPP).

| 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 Data Rate Example*