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Wireless communication for Smart Buildings

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1. The Smart Buildings

Before even talking about the wireless communications and its technologies in the Smart Buildings, we should remind the main purpose of making a building “smart”.

The needs can vary depending on the type of the building (commercial, offices, industrial, residential, schools, healthcare, ...) but generally, it is about allowing a better control and monitoring of the building itself and how it is used.

For instance, we may have very disparate use cases:

- A better security with access controls
- A smart HVAC (Heating Ventilation Air Conditioning) management allowing us to have a smoother temperature through the year
- A smart light management to avoid waste of electricity with lights we forgot to switch off
- An Indoor location system
- A room management to know the occupancy, the reservations
- The energy and water consumption monitoring to watch and detect any leak or unusual consumption
- The indoor air quality monitoring
- An elderly care monitoring system

But how do we proceed?

There are a lot of different equipment developed nowadays allowing us to do so. Actuators, automation and control equipment are a part of it but the main components are the sensors. Indeed, we need a lot of sensor throughout the building in order to be able to collect all the information needed and with the appropriate granularity level. For instance, if we want to manage the temperature, we may need a lot of different temperature sensors to get the data and act accordingly (heat up the room if it is too cold for example). The same applies for instance for the precise metering of electricity consumption, in which vase we need to deploy meters not only at building level, but also at room level and in some cases even at plug level or within equipment and appliances.

On the figure below, we gathered some useful equipment (current sensor, air quality monitor, window opening tetector, thermostatic valve, water leak detector, …). All use wireless communication technologies and most work by harvesting energy from their environment (solar, heat, mechanical, induction, ...)

Illustration 1: Several wireless sensors and actuators

2. Smart Buildings and Wireless technologies

Now we have our equipment, the question is how to get the data and communicate with the sensors, actuators and automation and control equipment. There are only two possibilities: with wire or with wireless technologies.

Running cables through all the building would involve an extremely high deployment cost, especially when retro-fitting an existing building. Therefore, the wireless technologies are the only alternative. And their versatility is a strong advantage.

The final goal would be to use only wireless device and run them on batteries for years or with harvesting energy from environment.

On the figure 2, we presented the different wireless technologies according to their operating range and the data rate they can transmit.

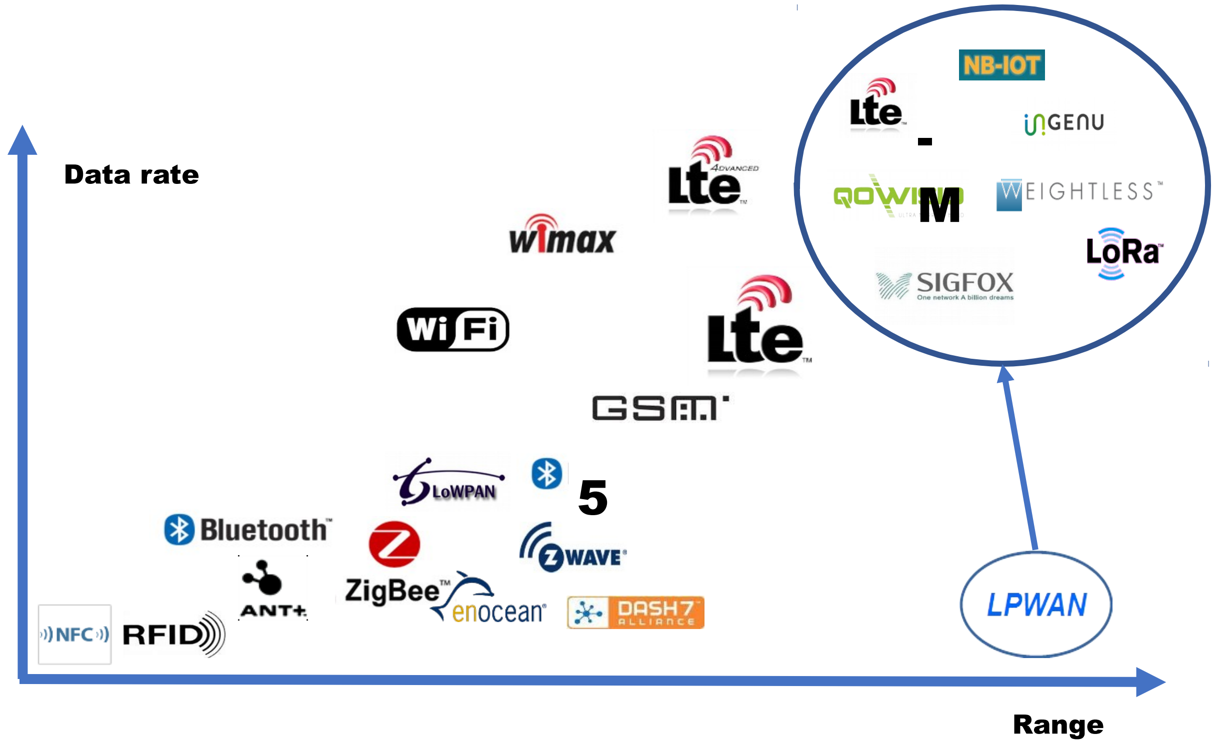


Illustration 2: wireless technologies

As we can see, a lot of technologies already exist. But which one are relevant for the Smart Building?

You may find most of them in Smart Buildings already but some are more appropriate while others tend to disappear quickly in the future. Indeed, expensive and proprietary technologies can't compete that much with cheap emerging technologies promoted by strong consortiums.

The diversity of technologies is also a good point since the needs won't be the same for a Smart Home and a Smart Building. In the case of a Smart Building, the most important characteristics are the following ones:

- The cost
- The power consumption: if we aim devices on battery or energy harvesting.
- **Indoor range**
- Ease of deployment
- Durability

3. The link budget

3.1. Principles

The link budget is a method to compute all kind of gains and losses of a signal sent by a transmitter, through the medium space to the receiver. We will see that this method can give a theoretical estimation of the indoor range, this last point being important in the choice of the wireless technology in Smart Buildings.

Here is the expression of a link budget:

Received Power = Transmitted Power + Gains – Losses

The principle of a wireless communication is the following one: The transmitter sends a message through a signal with a certain power. Then the receiver receives a noisy signal with a certain power. To have a successful communication and get the message inside the signal, the received power of the signal must be greater than the receiver sensitivity. Thus, the sensitivity of a receiver is the ability to extract the transmitted message from the received signal.

This sensitivity depends on the quality of the receiver, in other terms its signal processing electronic, the bandwidth of the signal, the temperature …

It is also important that the signal is above the noise floor. Indeed, it is the physical limit of sensitivity and any signal below the noise floor cannot be measured. We can compute it with the following mathematical expression:

$$\mathbf{P_{dBm} = -174 + 10 \log_{10}(BW)}$$

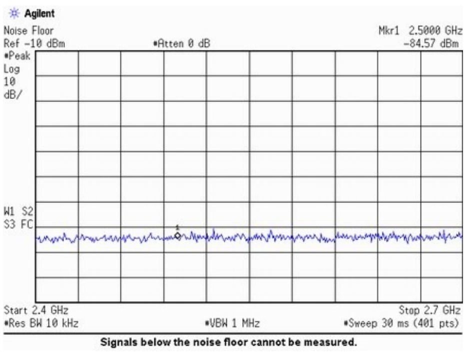


Figure 1. Measurement of a Noise Floor

Bandwith	Noise floor
1 MHz	- 114 dBm
125 kHz	- 123 dBm
200 Hz	- 151 dBm

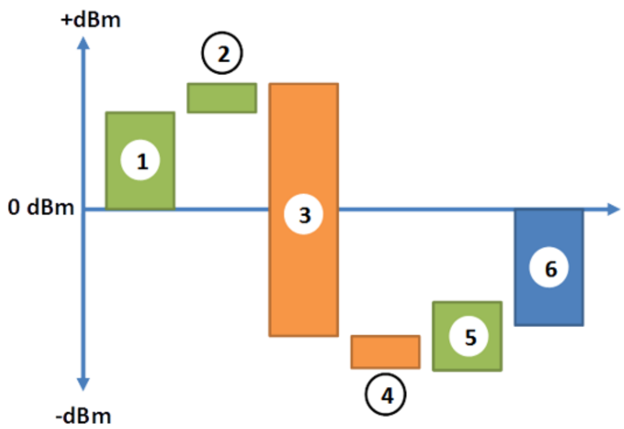
Figure 2. Some values of the Noise Floor according to the bandwidth

In the figure below is listed the sensitivity of some typical receivers for EnOcean, Bluetooth Low Energy, Z-Wave, Sigfox and Lora.

Sensitivity		Receiver
- 96 dBm	$2.5.10^{-10}$ mW	STM300 ENOCEAN ASK
- 97 dBm	2.10^{-10} mW	TI CC2640R2
- 98 dBm	$1.6.10^{-10}$ mW	STM300 ENOCEAN GFSK
- 103 dBm	5.10^{-11} mW	TI CC2640R2 @125kbps / Z-Wave @9.6kbps
-137 dBm	2.10^{-14} mW	RN2483 LoRa@0.25kbps / ATIM Sigfox

Figure 3. Typical Receiver Sensitivity

The life of a signal from the transmitter to the receiver is presented in the figure 5 below.



1. Transmitter output power
2. Transmitter antenna gain
3. Path loss (free space or indoor)
4. Miscellaneous losses
5. Receiver antenna gain
6. Receiver sensitivity

Figure 4. Gains and losses of a signal transmitted

This is a graphical way to present the link budget, with the gains in green and the losses in orange. We can see that it is possible to get some power with antenna gains from the transmitter and the receiver but the main losses come from the path loss. We will see that the distance and the obstacles, such as walls and floors, increase this path loss.

3.2. Maximum link budget

This is why we compute the maximum link budget:

Maximum link budget = Max Output Power – Receiver sensitivity

We computed some of the typical maximum link budget for the different wireless technologies in the figure below. The path loss must be lower than this value.

Standard	Max link budget
Z-Wave (9.6 kb/s)	107 dBm
Bluetooth (125 kb/s)	108 dBm
EnOcean	103 dBm
LoRa (0.25 kb/s)	151 dBm
Sigfox	151 dBm

Figure 5. Typical maximum link budget values

A way to increase the maximum link budget would be to increase the transmit power itself. We can see in the figure below the power gain in dBm from the mW.

Transmit power (mW)	Transmit power (dBm)	Standard
2 mW	4 dBm	Z-Wave
3 mW	5 dBm	Bluetooth
5 mW	7 dBm	EnOcean
25 mW	14 dBm	LoRa & Sigfox
39 mW	16 dBm	Wi-Fi

Figure 6. Power gain in mW and dBm

The negative side of this method is that it leads to higher power consumption. And there are also ISM rules (figure 7) and health norms to respect.

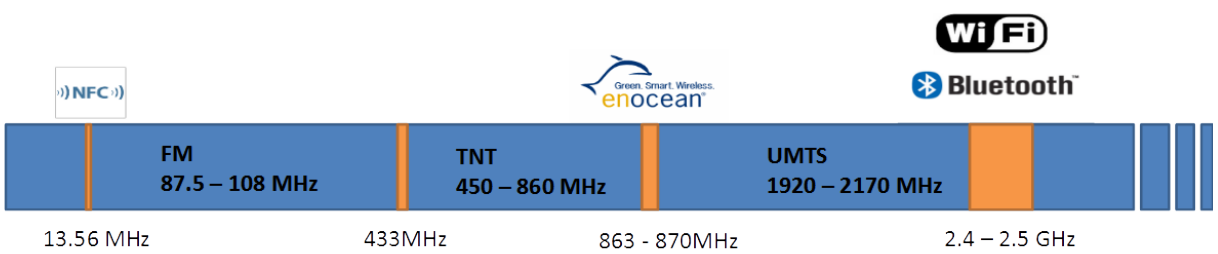


Figure 7. Distribution of the wireless technologies according to the frequency

3.3. Path loss

When the perfect conditions are reunited, in other words in straight line, without obstacle or perturbation, we can get the best ranges of communication. That's what we call the free space. Of course, any signal transmitted in the free space is attenuated. It is known as the free space loss and can be computed with the following expression:

$$\mathbf{FSL = 20\log_{10}(d) + 20\log_{10}(f) - 147.55} \qquad \textit{(d: distance; f: frequency)}$$

We can see in the figure below some values of this free space loss for different distances and frequencies.

Distance	Frequency	Attenuation
10 m	2.4 GHz	60 dBm
100 m	2.4 GHz	80 dBm
1 km	2.4 GHz	100 dBm
1.6 km	2.4 GHz	104 dBm
10 km	868 MHz	111 dBm
960 km	868 MHz	150 dBm

Figure 8. Attenuation of the signal according to the distance and the frequency

In practice, we do not really meet those perfect conditions. The attenuation can be much bigger, especially in a building. The International Telecommunication Union (ITU) developed an indoor propagation model so that we can compute a theoretical value of the indoor path loss:

$$\mathbf{IPL = N\log_{10}(d) + P_f(n) + 20\log_{10}(f) - 147.55}$$

where

N: distance power loss coefficient;
n: number of floors;
$P_f(n)$: Floor
loss penetration factor

The factors and coefficients depends on the building type: a house, an apartment block, an office, a commercial building …

We computed the values for some specific cases in the figure 10. As we can see, the BLE 5.0 would get attenuated by 100 dBm 100 meters around in a one floor residential building. It is less than the 108 dBm presented in the maximum link budget presented in the figure 6 which means the BLE 5.0 would be enough for the case. Now in an office with two floors, the highest distance to stay under the maximum link budget, still for the BLE 5.0, would be 20 meters. The BLE wouldn't be the smartest choice.
However, if we look at the LPWAN technologies (working at 868 MHz), such as LoRa and Sigfox, we can see that we are still under the maximum link budget, in the case of the two floors office and 200m around.

Distance	Frequency	Free space Attenuation	Residential, one floor	Office, two floors
10 m	2.4 GHz	60 dBm	72 dBm	89 dBm
20 m	2.4 GHz	66 dBm	80 dBm	98 dBm
40 m	2.4 GHz	72 dBm	89 dBm	107 dBm
100 m	2.4 GHz	100 dBm	100 dBm	119 dBm
100 m	868 MHz	71 dBm	-	110 dBm
200 m	868 MHz	77 dBm	-	119 dBm

Figure 9. Free Space and Indoor path loss for different cases

4. Wireless technologies

In this section, we will present the main characteristics of each wireless technology in the Smart Building use case.

4.1. LoRa

LoRa, for Long Range, is a LPWAN originally developed by Semtech and now promoted by the LoRa Alliance. This is a technology working on the ISM frequency 868 MHz.

LoRa stands for Long Range modulation. This is a part of the emerging LPWAN (Low Power Wide Area Network) working on the ISF frequency 868 MHz and originally developed by Semtech. It is now promoted by the LoRa Alliance.
On the physical layer which is the LoRa modulation is used the MAC protocol LoRaWAN for high capacity and long-range star network. That MAC protocol is standardized by the LoRa Alliance.

This wireless technology has a low data rate (0.3 to 22 kbps) but has a high range estimated to more than ten kilometers in optimal conditions.
As it uses the entire channel bandwidth, it is less sensitive to noise than the other technologies using the frequency shift keying.
About the power consumption, the devices can last several months to several years since they only send some messages per day.
The network needs Lora Gateway which is multi-channel, multi-modem, transceivers and can demodulate on multiple channel to get all the messages from the different devices.
This is a new technology which is growing really fast thanks to its ecosystem.

Cost	Intermediate, but should decrease rapidly (<12$ for SoC)
Power consumption	Several months to several years on battery (msg / day)
Indoor range	Best solution, several hundred meters, even with 5+ floors
Ease of deployment	Best solution for large buildings, no infrastructure except a base station
Durability	New technology, but very fast growing ecosystem. However, currently relies on one silicon vendor only

Figure 10. Characteristics of LoRa

4.2. Wi-Fi

The Wi-Fi is a standard 802.11 really used today. It works at the ISM frequencies 2.4 and 5 GHz.

The Wi-Fi is a wireless technology well known today. It is protocol based on the standard 802.11 and working at the ISF frequency 2.4 and 5 GHz. This is also a certification gave by the Wireless Ethernet Compatibility Alliance (or Wi-Fi Alliance) which verifies the specifications and interoperability of the devices in accordance with the 802.11 norm.

Indoor, the range of the Wi-Fi is about 40 meters. It keeps improving since we are theoretically above the Gbps with the 802.11ac. The main disadvantage of the technology is that it has a high power consumption. Any device using the Wi-Fi must be plugged.

The Wi-Fi is a really mature technology and has now a large ecosystem which makes this technology reliable with affordable equipment.

Cost	Very cheap (< 2$ for a SoC)
Power consumption	Only days on battery, needs external power
Indoor range	~ 40 meters indoor
Ease of deployment	Depends on whether a local wlan infrastructure may be used
Durability	Mature technology and large ecosystem

Figure 11. Characteristics of the Wi-Fi

4.3. BLE 5.X

Originally developed by Nokia and now promoted by the Bluetooth Special Interest Group. A new version 5 appeared recently and offers interest features, especially in the Smart Houses and Buildings.

It also works at the ISM frequency 2.4 GHz.

The BLE (for Bluetooth Low Energy) or Bluetooth Smart is a wireless personal area network working at the ISF frequency 2.4 GHz. It was originally developed by Nokia. It is now designed, promoted and marketed by the Bluetooth Special Interest Group which is a strong ecosystem.

The previous version BLE 4.X was already featuring a 1mpbs rate, a range of 10 meters and a low power consumption which are nice characteristics for IoT and connected objects.

But a new version emerged recently: The BLE 5.X

It extends the features of the BLE 4.X and is totally compatible with the old devices which were already implementing the BLE.

We can now have up to 2 times the bandwidth (2 Mbps) and reduce the time to transmit data and also up to 4 times the range of BLE 4.2 (depending of course on the strength of the signal).

This is a strong improvement for the Smart Houses and Smart Buildings since it can provide a full coverage of an entire home in order to create home autonomation and security solutions.

Cost	Very cheap (< 2$ for SoC)
Power consumption	Several months to years on battery or energy harvesting
Indoor range	~ 40 meters indoor
Ease of deployment	Ok for smaller & residential buildings otherwise needs complementary infrastructure
Durability	Mature technology and very large ecosystem (mobile), but new for the building

Figure 12. Characteristics of the BLE 5.X

4.4. EnOcean

EnOcean is working on the ISM frequency 868 MHz (in Europe) and was originally developed by an offspring of Siemens. It is also promoted by the EnOcean Alliance.

The EnOcean is a radio frequency technology originally developed by an offspring of Siemens, now by the company having the same name and promoted by the EnOcean Alliance. It works at the ISM frequency 868 MHz. The range indoor is about 40 meters.

This is a proprietary technology with a growing ecosystem but already with a wide variety of equipment.

The principal advantages of EnOcean devices are they have a really low energy consumption since they use photovoltaic cells, piezoelectricity, Thermoelectric effect and they have a strong focus on inter-operability. It can last from several months to several years.

This technology is simple to use for smaller and residential buildings but is quite expensive with a System on Chip for about 20€.

Cost	Quite expensive (<25$ for a SoC)
Power consumption	Several months to years on battery or energy harvesting
Indoor range	~ 40 meters indoor
Ease of deployment	Very simple for smaller & residential buildings. Use repeaters and gateways for larger buildings
Durability	Growing ecosystem, a lot of equipments already. BLE 5 is a serious challenger. One silicon vendor only.

Figure 13. Characteristics of EnOcean

4.5. Z-Wave

Z-wave was developed by a Danish company Zen-Sys. It also works on the ISM frequency 868 MHz in Europe, which makes it a concurrent of EnOcean and BLE 5.X.

The Z-Wave is a radio frequency technology which is also working at the ISM 868 MHz in Europe. It was originally developed by a Danish company Zen-Sys. The range indoor is about 40 meters and the data rate from 9.6 to 100 kbps.

Since it is designed for home autonomation, it is a direct concurrent of EnOcean and BLE 5.X.

At this time, Z-Wave has a well-established ecosystem and already a lot of equipment.

It is simple for smaller and residential buildings and has the possibility to extend the network thanks to the mesh network. However, that kind of network can get quickly complex.

In opposition to his concurrent EnOcean, Z-Wave is cheaper but eats up power and only works on battery, which means it can last several months only.

Cost	Intermediate (<10$ for a SoC)
Power consumption	Several months on battery (mesh networks)
Indoor range	~ 40 meters indoor
Ease of deployment	Simple for smaller & residential buildings. Complexity of mesh networks
Durability	Well established ecosystem, a lot of equipments already, but BLE 5 and EnOcean are serious challengers

Figure 14. Characteristics of Z-Wave

Summary

When retro-fitting existing buildings to make them "smart", deployment and maintenance costs may be strong barrier to adoption. In this context zero zero wire devices (wireless communication + energy harvesting) represent a powerful solution to overcome these barriers.

We presented several wireless technologies, that could be a part of the technological mix needed to achieve zero wire devices. Two of them are for us the most promising technologies: BLE 5 and LoRa.

They are new to the building sector but also the most promising in two different sub-markets: the residential/small buildings in one hand and the large buildings in the other hand.