lumenradio

How to Win at Wireless

The Insider's Guide to Cognitive Coexistence

About the Author

Niclas Norlén is the founder of LumenRadio and a pioneer in the field of wireless technology. He has more than 25 years' experience delivering business-critical wireless connectivity, ranging from major Hollywood productions to large-scale IoT systems.

Niclas won E&Y's Entrepreneur of the Year 2023 award in West Sweden for Best International Growth.

"The demand for connected devices is skyrocketing, yet most products today still rely on cumbersome cables. At LumenRadio, we aim to empower industry professionals by eliminating the time-consuming task of running new cables. Our cutting-edge Cognitive Coexistence wireless technology offers a seamless alternative.

This innovation is especially crucial when upgrading building management systems and industrial automation to enhance energy efficiency. Wireless control emerges as the fastest and most efficient way to meet sustainability goals.

So why did we invest so heavily in developing this unique wireless technology instead of just using standard options like Thread or Bluetooth? The short answer is simple – the standard options don't cut it. The longer answer lies in our commitment to providing a technology you can depend on, one that is also easy to install.

Professionals cannot afford to gamble with unreliable wireless technology. Whether you're handling the Eurovision Song Contest, managing lighting or HVAC systems in commercial buildings, or overseeing street and road lighting controls, reliability is non-negotiable.

Nearly two decades ago, we recognized the challenging path ahead. This realization shaped our company culture, embracing the mantra of 'challenge accepted'. Our advanced technology, detailed in this paper, is a testament to our unwavering promise to you: Wireless Without Worries."

Contents

INTRODUCTION

It´s a Wireless World

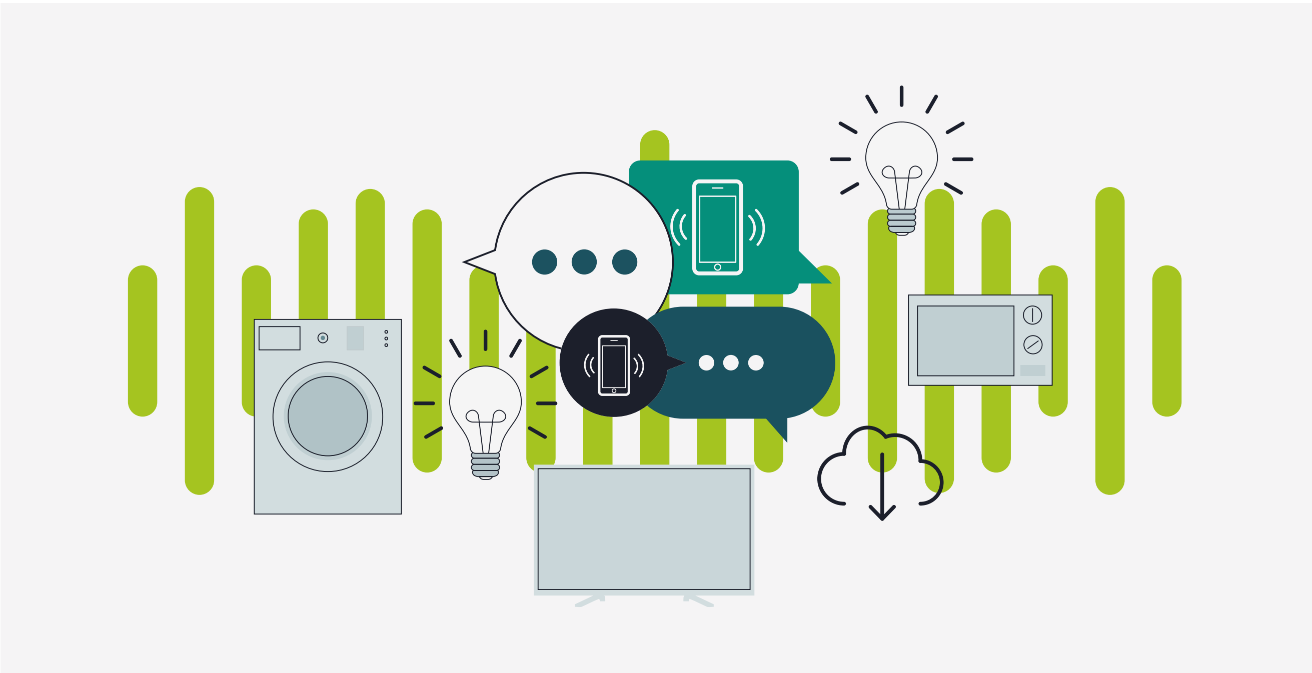
Breaking through the noise has never been harder

According to Transforma Insights[1], there are now in excess of 17 billion wireless devices in the world. This number has doubled in just five years and it is expected to almost double again to reach 30 billion by 2030.

At home we are used to smart versions of everything – doorbells, fridges, ovens, even toasters. And for businesses it is no different. From smart meters and temperature sensors to lighting control and ventilation regulation, the applications are endless. This has already revolutionized many industries, welcoming an age of data-driven decision-making and unprecedented opportunities to make efficiency gains.

But maybe this rapidly expanding Internet of Things should be known as the Interference of Things. With so many devices operating in the same noisy space sending signals on the same narrow frequency band, how can you be sure that your data is getting through?

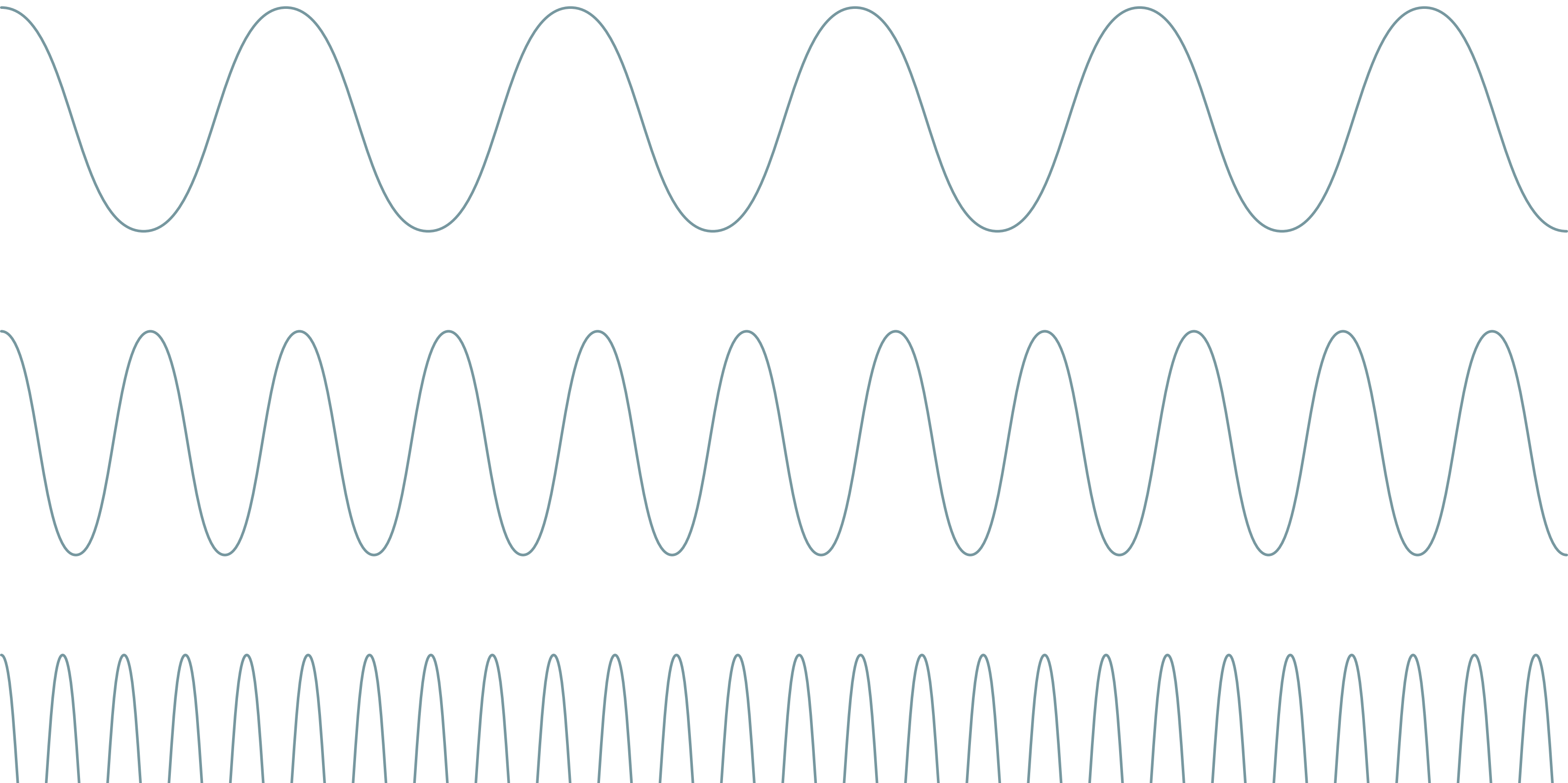
In this piece of knowledge content, we are going to look at the current challenges with wireless communication, give you a better understanding of some of the key science involved and explain the secrets behind the most reliable wireless technology ever created – Cognitive Coexistence.



[1]https://www.statista.com/statistics/802706/world-wlan-connected-device/

CHAPTER ONE

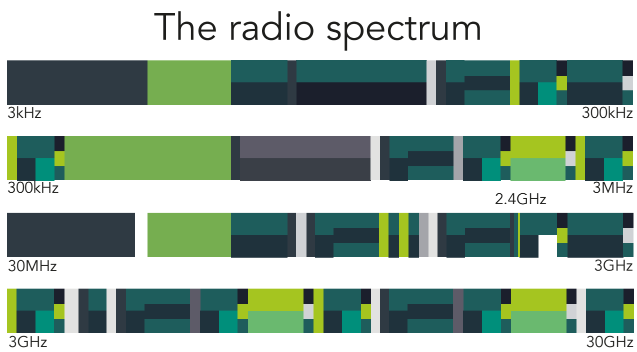
Frequency and the Frequency Spectrum



Navigating a finite resource

The frequency spectrum is fundamental to understanding wireless communication as it is used by all the billions of wireless devices operating around us. But the crazy thing is, this multitude of wireless products are only allowed to utilize a tiny fraction of the frequency spectrum, making it an extremely crowded space. It's time to start thinking of frequencies as a limited natural resource!

Here is the whole frequency spectrum:



At one end are very low frequency radio waves which can have wavelengths over 100,000 meters long. Then there are higher frequency radio waves followed by microwaves. Next on the spectrum is light, moving from infrared light to visible light and then ultraviolet light. At the other end of the spectrum are the highest frequencies which include x-rays, gamma rays and finally cosmic rays.

And this is the small section where wireless devices operate - within the 2.4GHz band:

Why do wireless devices all operate in the same crowded frequency space?

The 2.4GHz band offers a relatively good range for wireless communication. It can penetrate walls and obstacles reasonably well, allowing signals to reach devices even when they are not in direct line-of-sight with the transmitter.

But there is another major reason – unlike much of the frequency spectrum, it is free to use!

Fighting for space

As a band which is globally accessible without buying an expensive license, it is hardly surprising that 2.4GHz is the most popular and most used frequency out there.

The bottom line is that the 2.4GHz band has become overcrowded, resulting in interference, transmission disturbances and degraded wireless performance.

In the next chapters, we will look at an ingenious method of wireless communication which can coexist in this narrow frequency space with other wireless technologies without causing interference or being interfered with.

FREQUENCY ALLOCATION

Frequency allocation is carried out by regulatory bodies such as the Federal Communications Commission (FCC) in the United States or the International Telecommunication Union (ITU) globally.

Once frequency bands are allocated, they are usually licensed or regulated by these authorities. Licensed communication uses dedicated frequency bands and someone like a mobile network operator or a TV broadcaster pays for a license to use them.

Unlicensed frequency bands, on the other hand, do not require an expensive license to operate and are free to use. The 2.4GHz band is an example of an unlicensed band and is utilized by most of the wireless devices on the market.

The 2.4GHz frequency spectrum is an overcrowded space full of traffic where it can be difficult to get through.

CHAPTER TWO

“Normal” Wireless Standards

The problem with single channel systems

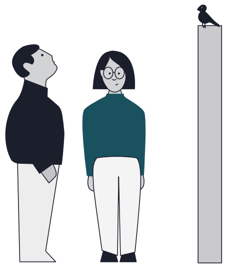
We're all used to using WiFi at home and in the office and we're all used to experiencing interference in the form of slower Internet speeds.

WiFi – and other common wireless standards such as ZigBee and Thread – are **single channel systems** and all have a connection which runs on one specific frequency channel.

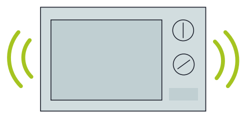
This tends to make the connectivity susceptible to interference from factors such as:

Overlapping networks run by neighboring businesses

Other wireless devices in the same area

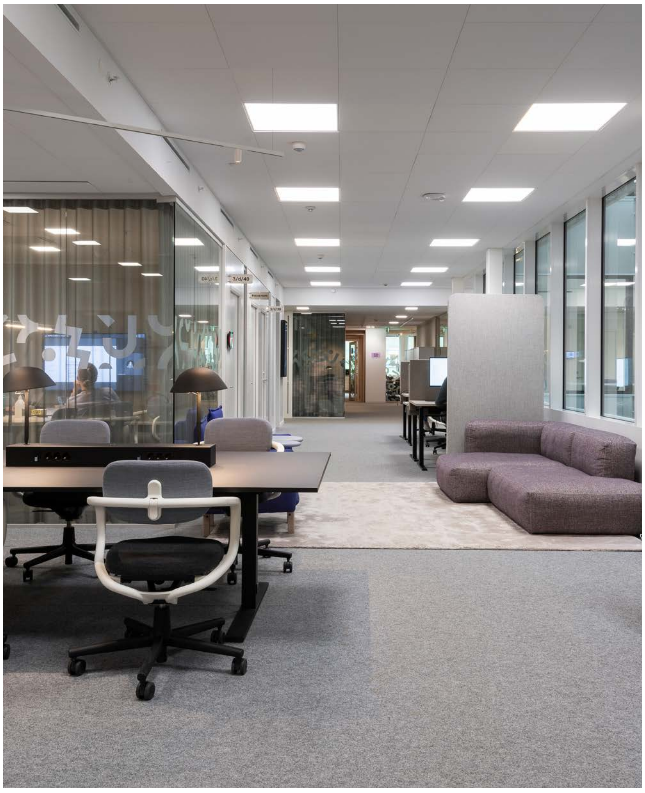


Physical obstructions such as walls and people



Devices generating electromagnetic fields, such as microwaves

We are prepared to tolerate some loss in Internet speed in our home and at the office every now and then during the day, but when you want to wirelessly control systems like lighting, ventilation or heating, this type of single channel wireless standard is simply not up to the job.



SINGLE CHANNEL WIRELESS STANDARDS

WiFi: the most common wireless communication standard technically known as IEEE 802.11. IEEE is the Institute of Electrical and Electronics Engineers – they update the WiFi standard every few years.

Bluetooth: a wireless technology that uses a radio frequency to share data over a short distance, primarily used to wirelessly connect peripherals to mobile phones, desktops and laptops.

ZigBee: an open wireless standard for low-data rate, low-power applications developed to enable machine-to-machine (M2M) and internet of things (IoT) networks.

Thread: another wireless standard designed for low-power, low-bandwidth devices. Thread shares many similarities with ZigBee.

How "normal" wireless standards try to improve reliability

There are a range of methods single channel systems use to try and get their message through when there is a lot of noise.

Let's take a look at them in order of effectiveness, starting with the least effective.

Listen before talk

This type of wireless system listens to the whole channel and only sends data if the channel is free, which makes it extremely vulnerable to degraded performance or a complete loss of service.

So as soon as there is other activity on this channel – from another WiFi network or a microwave oven, for example – it stops sending data and service could be lost for several hours.

Rating ☆☆☆☆☆

Frequency agility

If the system detects that the channel is already being used, it switches to a channel that has less interference.

Frequency agility assumes that there are free channels to switch to and often causes the connection to break while the network is repairing itself after a channel switch. This is because these systems are not designed for changing channel while being used.

For larger networks this can cause errors that are hard to find since they appear in different parts of the network at different times.

Rating ★☆☆☆☆

Frequency hopping

Frequency hopping is an attempt to tackle interference by rapidly switching between different channels. This is not random but is done based on a predefined list known to the receiver and transmitter.

When a signal is sent on a channel which is being used there will be interference, but since the system will soon hop to another channel, the interference should not persist.

Even though this is a better approach, it is not adaptive and it is limited in environments such as dense urban areas where the hopping patterns may not provide sufficient coverage or resistance against interference.

Rating ★★☆☆☆

Adaptive frequency hopping (AFH)

AFH automatically identifies and excludes channels which are in continuous use by other devices. It makes this assessment either by measuring the strength of the received signal or by calculating the packet error rate.

Although this is a more flexible configuration, it relies solely on detected disturbances and still stays away from channels being used by something else. So if a blocked channel becomes free to use, the system will continue to ignore it.

Rating ★★★☆☆

★★★★★

The major problem with all these approaches is that they are too rigid and do not make use of frequency space when it is available. At best they restrict themselves to channels where no interference has been detected, ignoring channels which become free – and at worst they simply stop communicating altogether.

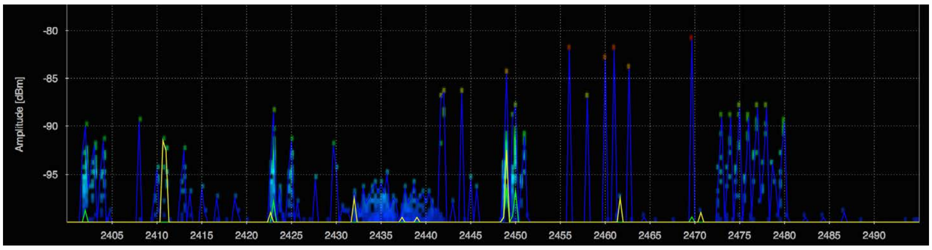
If you want a flawless wireless connection for critical applications in an overcrowded frequency space, **Cognitive Coexistence** is the only five-star option.

Enhancing network reliability through real-time adaption

These screenshots show wireless activity on the 2.4GHz band in an office at different parts of the day. When there is less activity, there will be no interference, but as conditions change, normal wireless signals start to fail.

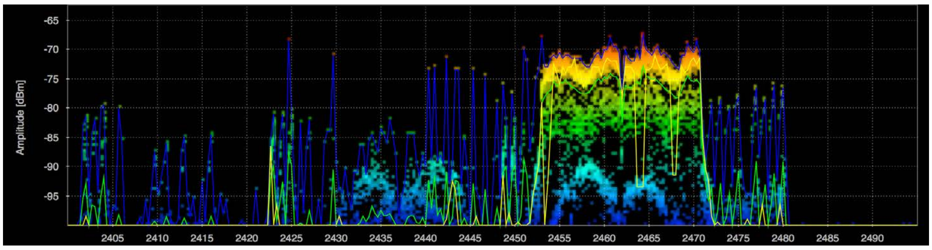
1. Middle of the night

With no one in the office, you can see that there is little wireless activity at all.



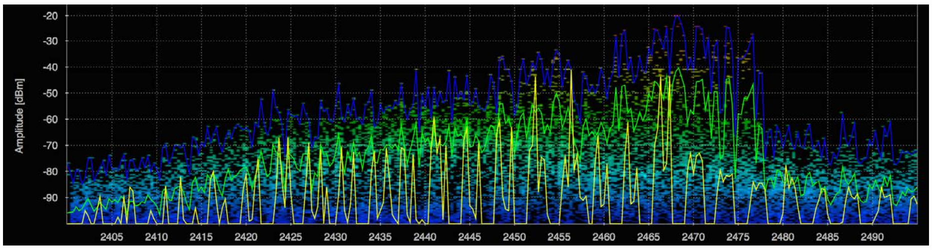
2. Early morning

With almost everyone in the office now active, there is high intensity wireless traffic, which will continue throughout the day until people go home.



3. Lunchtime

This is a period of wireless chaos with noise being created across the entire band from people using microwave ovens and preparing food.



If you want to avoid interference and guarantee network reliability, then you need a wireless solution which will adapt to changing conditions – in real time. We call this Cognitive Coexistence.

CHAPTER THREE

Cognitive Coexistence: the Gamechanger

Making the most of what's available

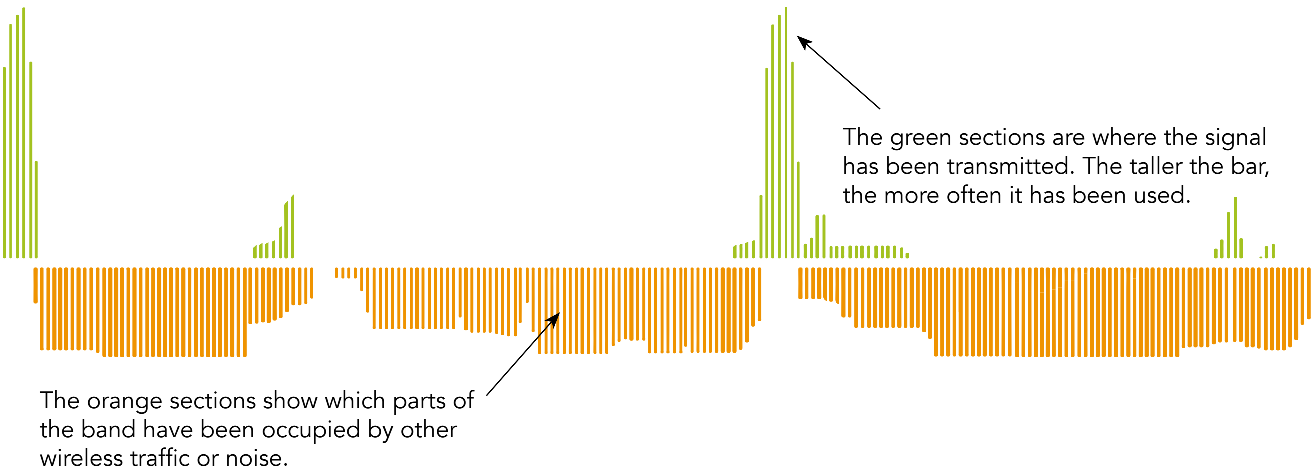
Compared to normal wireless systems, Cognitive Coexistence is much smarter and is much more effective at making use of the gaps on the narrow 2.4GHz frequency.

Unlike other technologies, it does not restrict itself to a single channel nor does it simply exclude sections of the 2.4GHz band from being used. This ensures an exceptionally reliable signal.

Instead it constantly adapts to changing conditions on the network by measuring the quality of channels, identifying which are the best to use and hopping to the ideal channel when required.

It also does this in real-time – every 10 milliseconds – which means it constantly has the most accurate picture of where to transmit based on the most recent input from the devices in the network.

This diagram represents Cognitive Coexistence in action within the 2.4GHz band. Each bar represents a specific 1MHz frequency in the frequency spectrum 2.402GHz - 2.480GHz.



Cognitive Coexistence skillfully utilizes the free sections and adapts to changing conditions to always find the best way through.

Setting the benchmark for wireless reliability

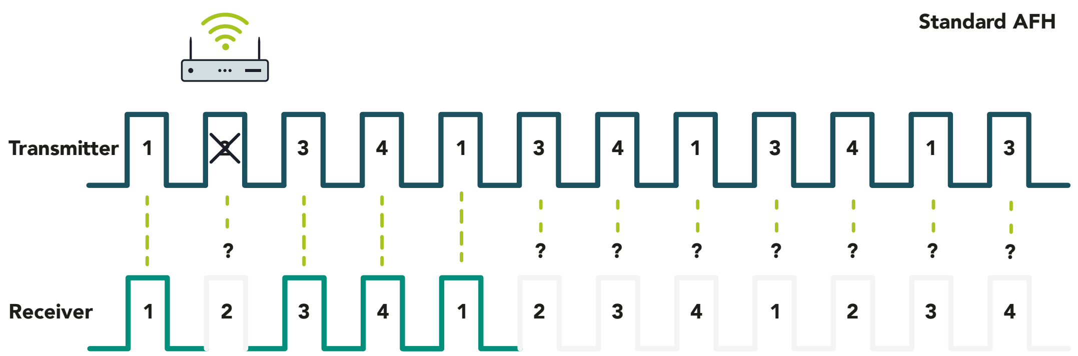
Cognitive Coexistence also improves upon the weaknesses of standard AFH (adaptive frequency hopping) systems by employing "smart blocking" technology.

When standard AFH cycles through its static list of frequencies, it blocks a channel where there is already noise. But as it continues to hop, the predefined sequence no longer syncs up and the receiver expects to hear a signal on a different channel. This increases the likelihood of data loss and network failure.

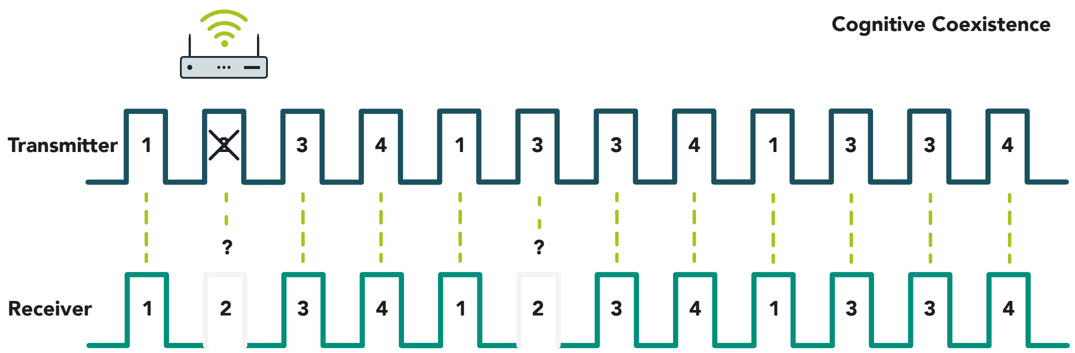
Cognitive Coexistence gets around this issue by replacing the blocked channel with a good channel on the list and ensures that the transmitter and receiver remain in sync.

This makes Cognitive Coexistence the technology of choice for business-critical applications as you can always be sure that it works – even in the most demanding and most crowded environments.

Here we have a simplified channel sequence, represented by the numbers 1-4.



When standard AFH blocks a channel, it breaks the sequence leading to significant data loss.



When Cognitive Coexistence blocks a channel, it replaces it to avoid a mismatch between transmitter and receiver which means the network always remains intact. After it realizes that the signal is not being received on a certain channel and swaps it out to create a new, more reliable sequence.

Where failure is not an option

Normal wireless standards are fine in residential environments or in situations where the occasional loss of a wireless signal can be tolerated. But for tougher applications where there is no room for a loss of performance, there is Cognitive Coexistence.

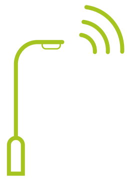
Not only does it coexist in the narrow 2.4GHz frequency space with other wireless technologies but it does so without causing interference or being interfered with.

So for use cases in professional lighting, commercial buildings and industrial automation, Cognitive Coexistence is the only wireless technology which has been designed to succeed.

Typical use cases include wireless control for:

Entertainment lighting

Office lighting



Street lighting

Heating, ventilation and air conditioning systems

Industrial automation

Retrofitting a building's lighting or HVAC system is a costly and time-consuming exercise when you have to run new cables, but wireless control eliminates the need for construction, making it a very cost-effective and convenient alternative.

Cognitive Coexistence: Making the impossible possible

In 2012, the organizers of Coachella – one of the world's largest music festivals – had a simple yet challenging request: sync the lighting on the stage with a set of huge searchlights right at the back of the site over half a kilometer away.

There was no way cables could be laid over that distance through the entire crowd to the stage, so LumenRadio was asked to link the lights wirelessly. In this instance, we are talking about replacing DMX cables – the standard protocol for entertainment lighting – with a wireless DMX signal.

Wireless lighting control over that distance is one challenge. But it becomes even more testing when you add tens of thousands of people in between, all with smart phones – and all using a free WiFi service which was not allowed to be interfered with.

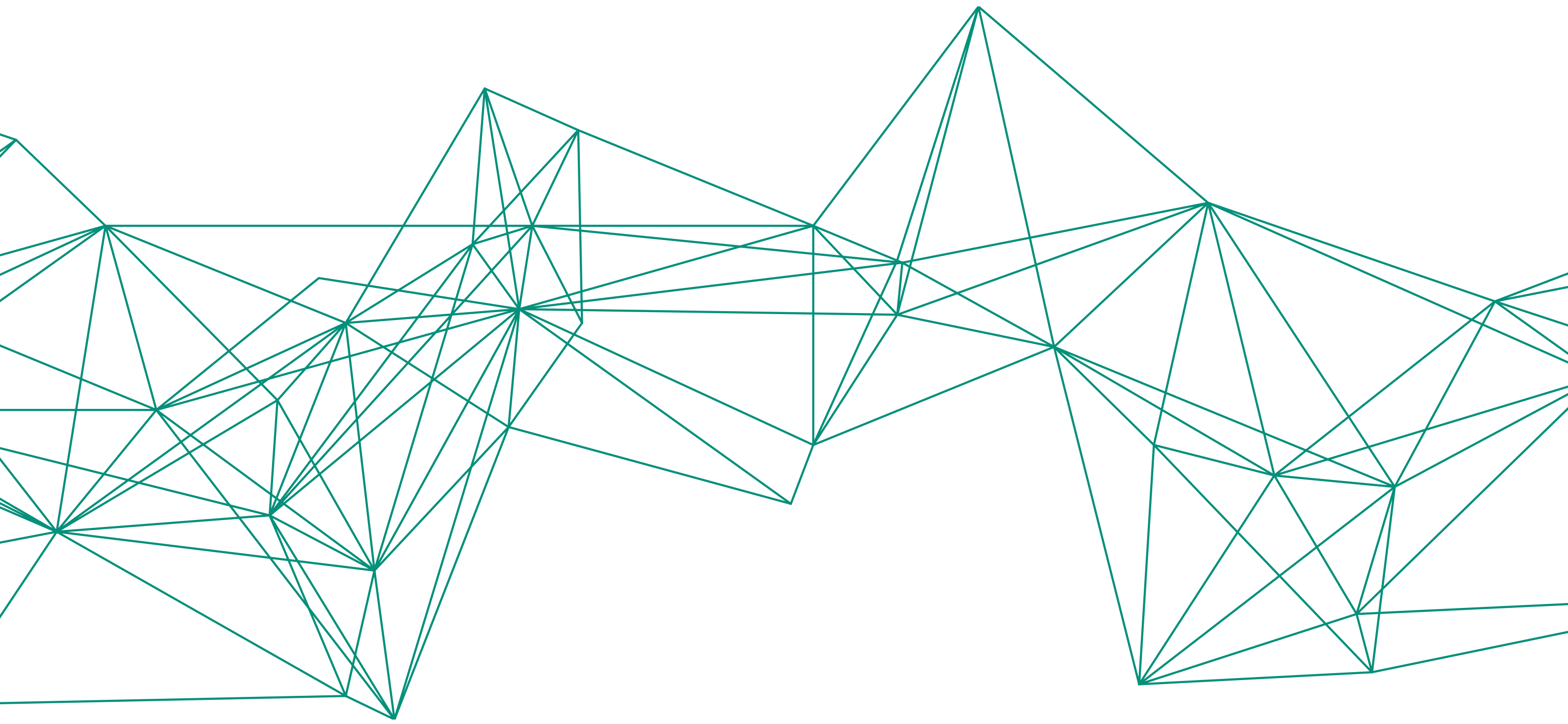
Thanks to Cognitive Coexistence technology, LumenRadio was able to offer an alternative to those DMX lighting cables with a wireless signal which did not fail. Not only did it sync the lighting to fractions of a second in locations hundreds of meters apart, but it did so in an area completely crowded with other wireless traffic and without causing any interference to other devices.

This launched Cognitive Coexistence as the benchmark for reliability in the entertainment lighting world.

And that same Cognitive Coexistence technology – which enabled interference-free, rock-solid wireless performance at Coachella – is the platform on which all LumenRadio's wireless solutions are built, from wireless control for office lighting and street lighting to wireless control for HVAC systems and industrial automation.

CHAPTER FOUR

Wireless Mesh



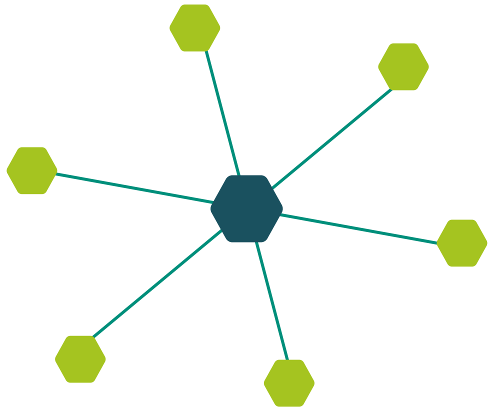
An introduction to mesh networks

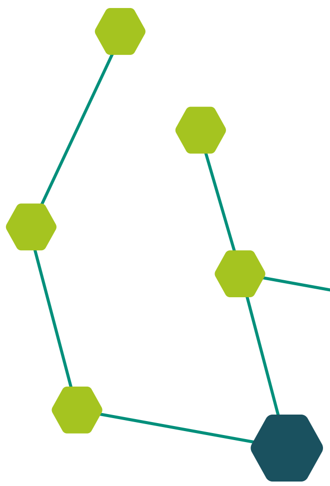
To explain what a wireless mesh network is, it's helpful to first look at what a **star network** is.

In a star network each device (or node) is connected to a central device (or hub). The hub controls the network and there is a single path for data to travel from the hub to a node.

It's technically simple and very reliable but the network can be affected when devices are added or removed, and it is completely dependent on the central hub.

In a **mesh network**, each device is directly or indirectly connected to every other device in the network. Each node can act as a repeater for the signal and there are multiple paths for the data to travel. The network gets its name from the mesh structure which is created as a result.

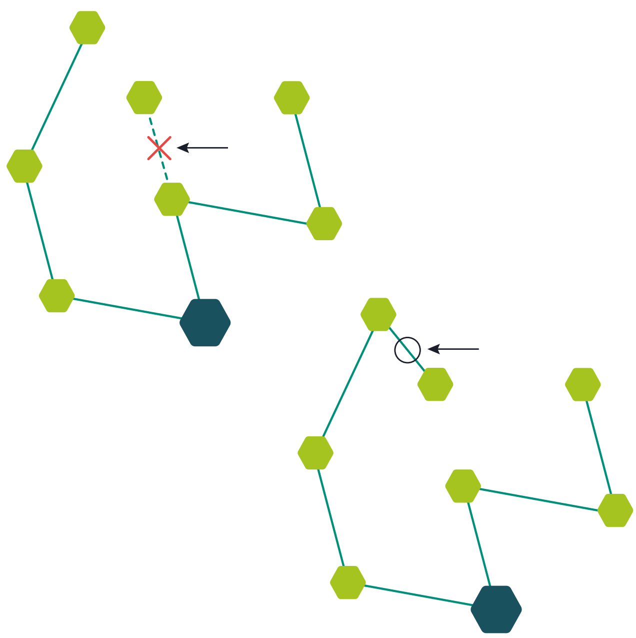

Star network


Mesh network

The self-healing, self-configuring network

The beauty of wireless mesh is that it is self-healing – if one link fails, the network still carries on working and it does so without manual intervention. When a node becomes unreachable, the network can dynamically reroute traffic through alternate paths to maintain connectivity.

This is because it is not dependent on any one point in the network. Any node can send information to any other node making wireless mesh extremely flexible and resilient across a large area.



Where normal wireless mesh is weak

Mesh does have its downside – even though it is self-healing, it is not invulnerable. In fact it can be considered sensitive to interference. Take Thread in an office, for example. Turning on a microwave can be enough to block all the nodes in that room creating a dropout large enough to collapse the entire network.

Mesh networks with Cognitive Coexistence, however, remove this Achilles heel.

Taking wireless mesh to the next level

Despite being more technically complex, mesh is easier for professionals to install than a star network. With Cognitive Coexistence you get that ease of installation plus a mesh system which is just as reliable as a star network.

Cognitive Coexistence is constantly scanning the network – every 10 milliseconds – and decisions on which section of the 2.4GHz band to use are taken based on the most recent input from the devices in a network.

As a system with only a few pre-defined rules, it has the freedom to be completely flexible and react to changing conditions in real-time, hopping to the optimal channel for transmission whenever needed.

LOW ENERGY MESH

In many circumstances, it is advantageous to utilize low energy mesh for low-power, short-range communication between devices.

Low energy mesh is ideal for applications where power consumption is critical and is a key enabler for battery-operated wireless products used in industrial applications.

LumenRadio holds the unofficial record for lowest amount of energy used, having reduced the power consumption for meshing nodes to less than 16uA, which enables more than 15 years of operation in routing mode from an AA-sized battery.

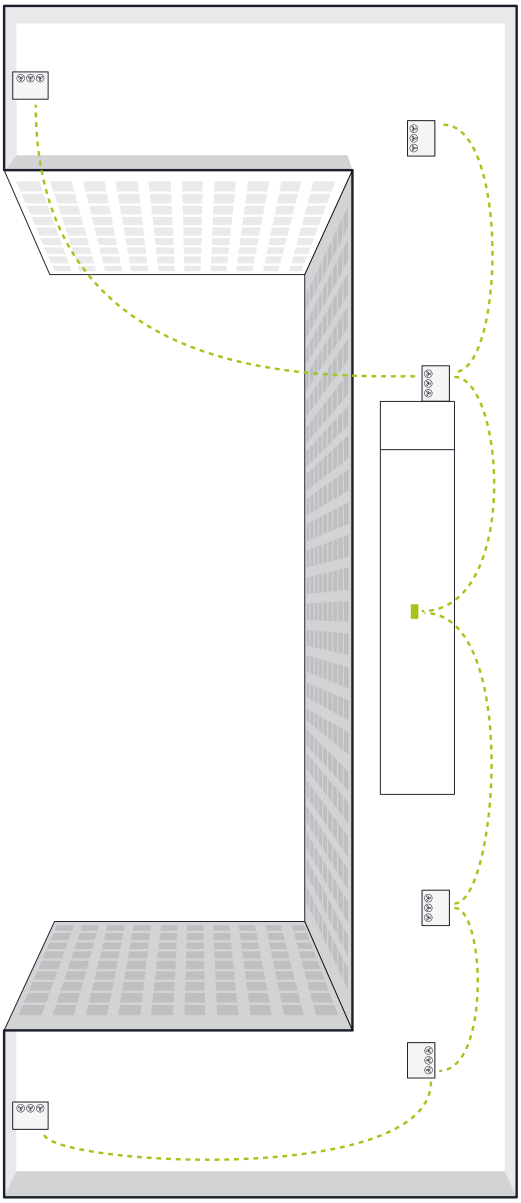
This is significantly better than any other competing wireless technology. It enables battery-powered products to run on the same battery throughout their entire lifecycle and means that building-wide batterypowered meshing connectivity is achievable.

Redundancy and extended range

In a mesh network, nodes can work as repeaters, sending data across the network. Consequently, multiple paths exist between each two nodes. This redundancy enhances network resilience because if one route fails, an alternative path can be found.

With nodes acting as repeaters, even nodes not directly within range of each other can communicate via intermediate router nodes. This is a major advantage of mesh networking in IoT applications because it allows a user to extend the range of the network.

And for more on the topic of wireless range, you can turn to our final chapter.



CHAPTER FIVE

Wireless Range

Measuring wireless range

Range is a common parameter when assessing which wireless technology is fit for the job and on the face of it, this is a pretty straightforward measurement to understand.

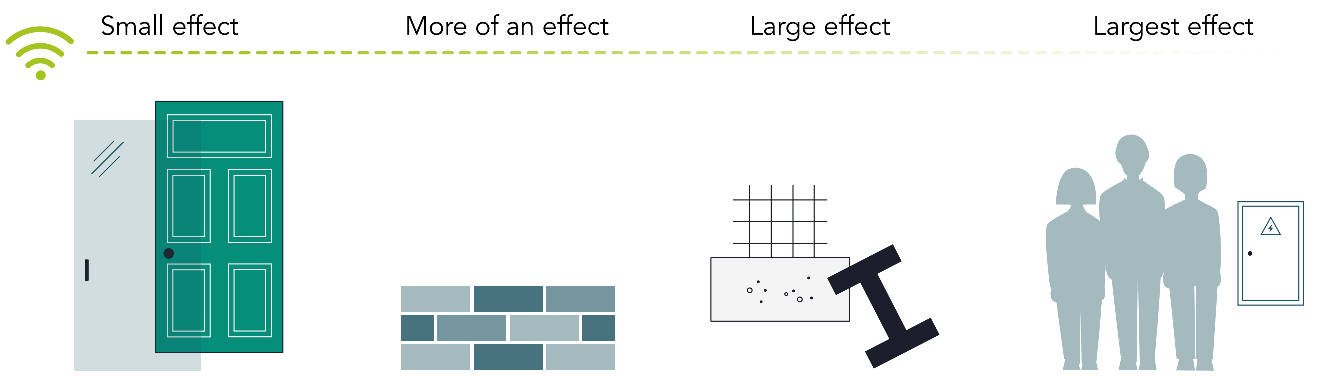
One wireless device may specify a range of 80 meters and another 50 meters. So the first has a better range than the second, right? Not necessarily because really you cannot be sure what that data actually means.

Often that data will come with a caveat like "80 meters in appropriate settings". That means there is a maximum range of 80 meters in free air with no physical obstacles or other wireless interference. It's a best-case scenario – and rarely the reality.

What affects wireless range the most?

A common mistake is to set up and test a wireless network in an empty building only to find that performance is seriously impacted once it is full of objects and people.

Different materials affect the wireless signal to varying degrees.



Interior drywalls, glass and wood doors

Brick walls and masonry blocks

Steel and reinforced concrete

Sealed steel compartment and people

Be aware of your range budget

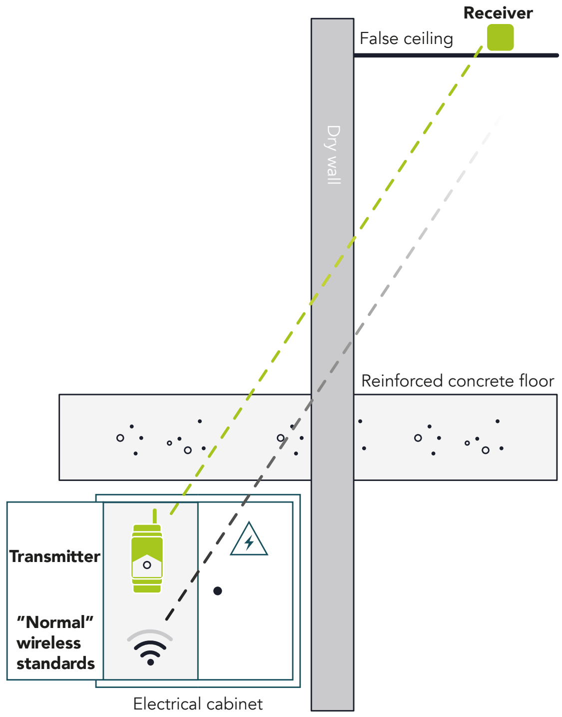
The impact of various materials – such as doors, walls and floors – on the range of a wireless signal can be calculated and an additional margin must be included. Without a sufficient margin, the system might work during installation, often during renovation or construction, but fail once the project is completed and the tenant moves into the premises.

For all products using Cognitive Coexistence, tools are available to calculate your range budget by simply entering the types and amounts of materials the wireless signal must pass through.

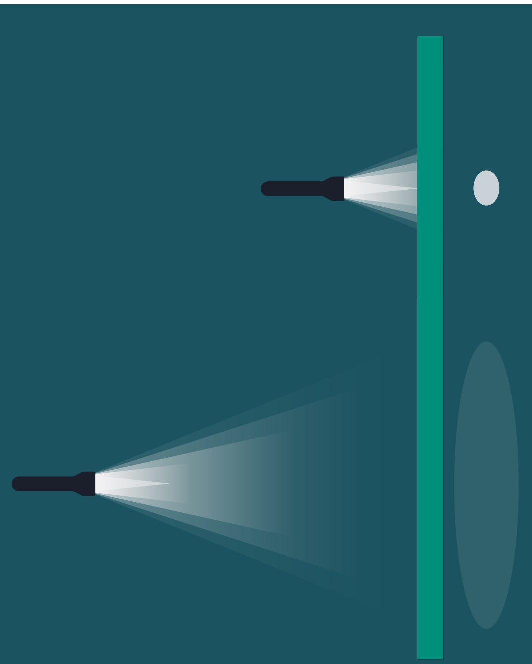
Making best use of limited resource

Adding a margin is crucial to account for interference. Cognitive Coexistence not only enhances reliability and minimizes interference with other systems but also allows for smaller margins - up to 10 times smaller than other technologies.

This technology also significantly extends range. Other technologies may offer a range of up to 80 or 100 meters. In contrast, Cognitive Coexistence products from LumenRadio offer a range from 500 to 1500 meters.



For example, W-DALI, W-BACnet and W-Modbus products have a range of 500 meters. This might seem excessive for an indoor mesh network with a high node density. However, this design ensures that the first hop from the technical room – where control units for lighting or HVAC are often installed – can reach another floor, as shown in the illustration on the right. With other technologies, the signal might be too weak to be received or the margin too small, resulting in a poorly functioning wireless system.



FREE PATH SPACE LOSS (FPSL)

When a signal travels from a transmitter to a receiver through open space without any obstacles, the signal gets weaker. This is called free space path loss (FSPL).

This is similar to using a flashlight. If you hold it close to a wall, there is an intense patch of light, but the further you draw the flashlight away from the wall, the more the light spreads out over a wider area and the weaker the effect becomes.

FSPL helps us figure out how far a signal can travel from a sending device to a receiving device. Integral to this is the strength of signal sent by the transmitter and the sensitivity of the device receiving the signal.

Summary

A transformative solution in wireless communication

The global surge in wireless devices is showing no sign of slowing down and as this growth intensifies, it poses serious challenges for reliable communication, most notably in the overcrowded 2.4GHz band.

Common wireless standards like Thread and Bluetooth struggle to break through the noise and while they use various methods to enhance reliability, they often fall short due to rigidity and limited adaptability.

Cognitive Coexistence technology addresses these issues by dynamically adapting to changing network conditions, offering superior performance and more robust connectivity compared to traditional standards.

Not only does it coexist in the narrow 2.4GHz frequency space with other wireless technologies but it does so without causing interference or being interfered with.

Additionally, Cognitive Coexistence enhances the effectiveness of the mesh network and its sensitivity to even the weakest of signals improves wireless range.

This makes Cognitive Coexistence the technology of choice for business-critical applications as you can always be sure that it works – even in the most demanding conditions.

Wireless Without Worries

Want to learn more about frequency-friendly, rock-solid wireless technology?

LumenRadio offers pre-certified radio modules ready for integration to give your devices the most reliable wireless connectivity. We also have end-user products which replace some of the most used cable standards with a more convenient wireless alternative – from Wireless DMX and W-DALI to W-BACnet and W-Modbus.

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