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Wireless Mesh Decoded

The Ultimate Beginner's Guide

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Part of the *How to Win at Wireless* series

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.

"Mesh is a real buzzword these days in the wireless industry and is much vaunted in the fields of industrial IoT and smart infrastructure. I've been working with meshing technology for many years and have been instrumental in developing LumenRadio's own MiraMesh.

Done right, meshing technology can be transformative for a wireless product. Paired with our best-in-class wireless range and Cognitive Coexistence, MiraMesh outperforms other technologies. It covers vast areas, even meshing through reinforced concrete in the most crowded wireless spaces.

This translates to minimal effort needed for planning, installation and maintenance, whereas other competing meshing technologies often cause frustration and require extra work, contradicting the promise of user-friendly tech.

In this paper, I'll delve into why MiraMesh is a cornerstone for some of our products and why we've opted out for others. It's a behind-the-scenes look at our technology and why we confidently say we deliver Wireless Without Worries."

Contents
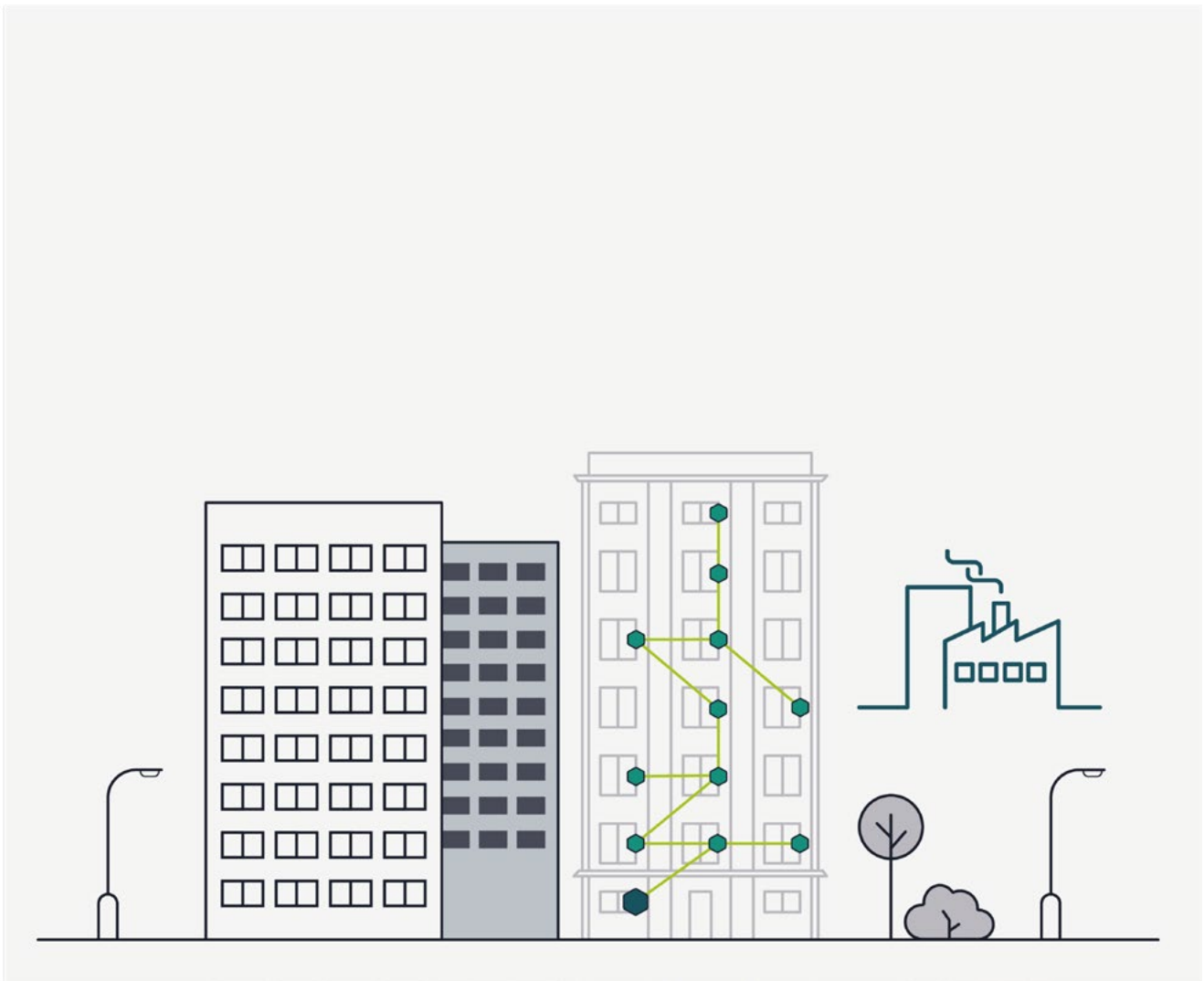
INTRODUCTION

The Rise of Mesh

A transformative technology

Wireless mesh networks (WMNs) have revolutionized the way we achieve reliable, flexible and cost-effective connectivity over large areas.

This has made them particularly suited to providing the infrastructure necessary to support the huge number of connected devices in IoT ecosystems. And they are equally integral to the development of smart city projects, enabling city-wide connectivity for various applications like surveillance, traffic management and public Wi-Fi.

Mesh networks extend wireless range by allowing each node to relay data to the next, effectively creating a vast, interconnected web. This structure not only enhances reliability but is also much simpler to deploy than the traditional cabled alternative, not to mention cheaper to install and maintain.

In this piece of knowledge content, we're going to be looking at the fundamentals of wireless mesh, before lifting the lid on how LumenRadio has succeeded in taking meshing technology to the next level.

What is Wireless Mesh?
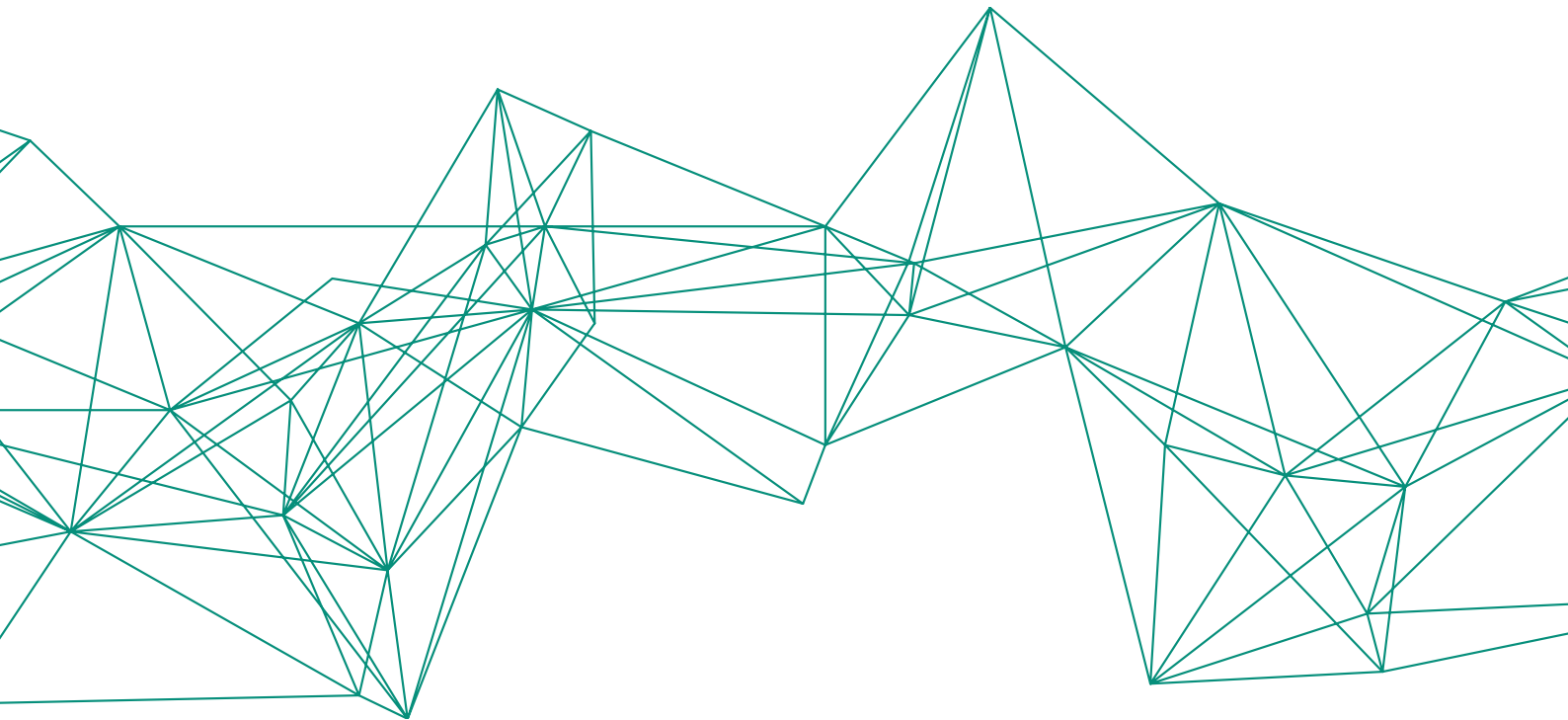
An introduction to mesh networks

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.

So, in simple terms, a wireless mesh network (WMN) is a cooperative system where each device helps spread the connection, making it stronger and more reliable as a whole.

Star network
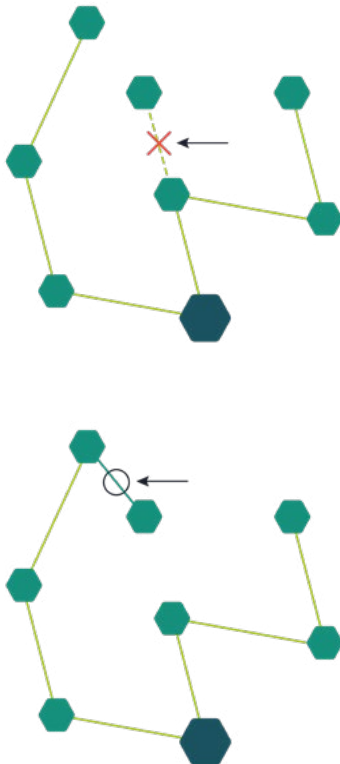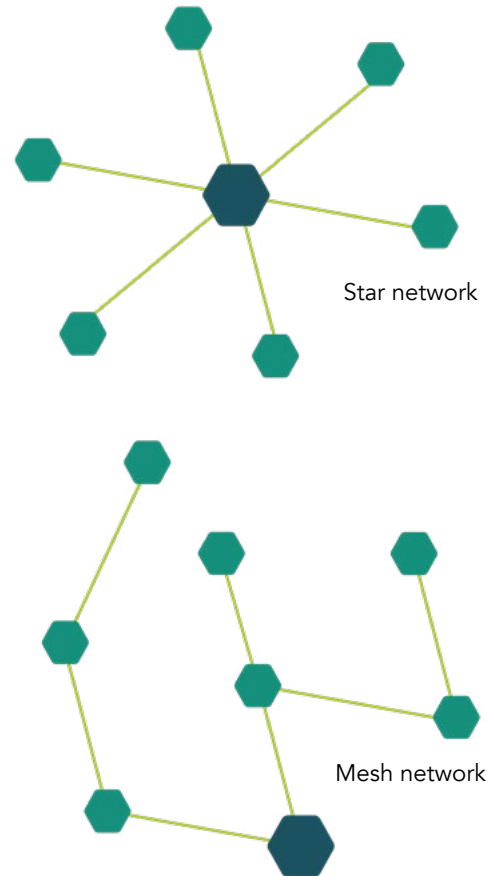
Mesh network

Key features of wireless mesh:

Self-healing

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. Any node can send information to any other node making wireless mesh extremely flexible and resilient across a large area as there is no single point of failure.

Self-configuration

Another useful property of a mesh network is self-configuration. Self-configuration means that the network of devices sets itself up, adjusts itself and maintains itself without needing someone to manually configure each connection.

As a result, the network is incredibly flexible and simple to deploy, especially in places where manual setup would be difficult or time-consuming. This also makes mesh a solution which scales extremely well since any new nodes which are added automatically join the network.

LumenRadio's W-DALI builds its networks for wireless lighting control using mesh technology

HELPFUL DEFINITIONS

WMN – wireless mesh network; a decentralized structure with interconnected devices or nodes which can all communicate with each other.

Node – any device which is part of the mesh network.

Gateway – a node which provides an interface between the mesh network and external networks, such as the Internet. Gateways route traffic between the internal mesh network and outside networks, allowing for broader connectivity.

Mesh Router – a specialized node which primarily manages network traffic. Routers facilitate communication by forwarding data packets between nodes, ensuring that information can travel through the network efficiently.

Mesh Client – an end-user device, such as a laptop, smartphone or tablet, that connects to the mesh network to access services.

Repeater – a node with the primary function of extending the network's range by receiving and retransmitting signals. Repeaters help in areas where direct communication between nodes is not possible due to distance or obstructions.

CHAPTER TWO

Taking Wireless Mesh to the Next Level

How to realize the full potential of mesh

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.
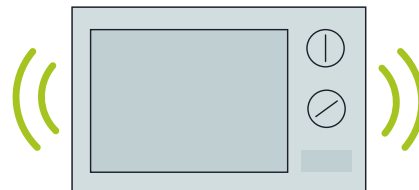
Introducing MiraMesh with Cognitive Coexistence

LumenRadio's own mesh network platform, MiraMesh, removes this Achilles heel thanks to patented Cognitive Coexistence technology – a feature unique to MiraMesh networks.

Cognitive Coexistence ensures the reliability of a network by scanning the 2.4GHz band and avoiding areas being used by other wireless devices.
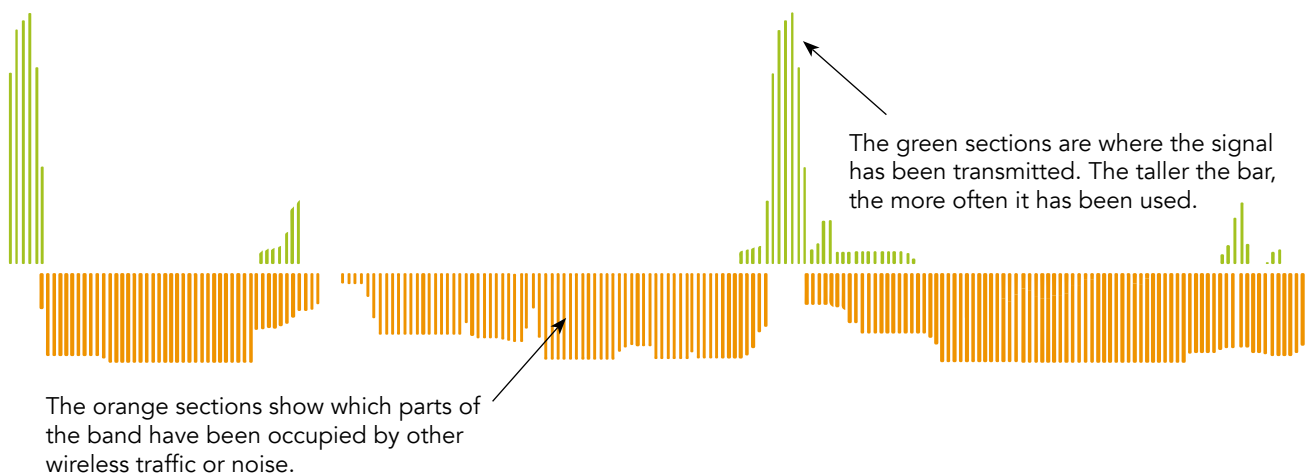
As a system with only a few pre-defined rules, it has the freedom to be completely flexible and react to changing conditions in real-time, hopping to the optimal channel for transmission whenever needed.

In this way, it allows a MiraMesh network to operate in the crowded 2.4GHz space with other wireless technologies without causing interference or being interfered with.

For a deeper dive into the merits of Cognitive Coexistence and what makes it such a gamechanger in the world of wireless, you can download this Insider's Guide.

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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.

The green sections are where the signal has been transmitted. The taller the bar, the more often it has been used.

The orange sections show which parts of the band have been occupied by other wireless traffic or noise.

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

Giving mesh a superior 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.

Couple this with Cognitive Coexistence – which significantly extends the range of a wireless product – and you have a world-beating solution. You can also read more about this in our Insider's Guide to Cognitive Coexistence.
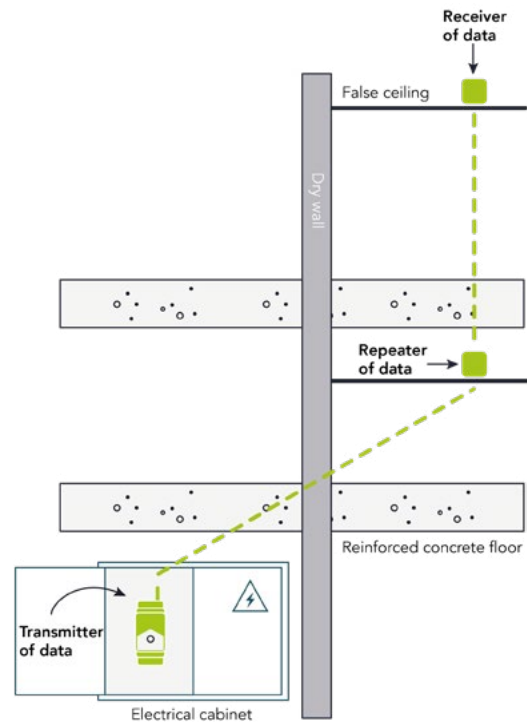
Heritage buildings typically have thick, stone walls so building automation retrofits can only be carried out using a wireless control solution - and mesh is the best option.

Choosing the right tool for the job

LumenRadio specializes in providing winning wireless alternatives to a range of different cable protocols. In the building and industrial automation world, this includes wireless solutions for the BACnet, Modbus and DALI protocols. All of these solutions use meshing technology to create a wireless network.

But in another field – entertainment lighting – where LumenRadio provides CRMX, the industry-leading solution for wireless DMX – a star network is preferred to mesh. If mesh works for the other products, why not here? The answer is latency.

Latency is the time it takes a signal to travel from point A to point B. The lower the latency, the faster the signal has completed its journey. This is important to technical professionals in the entertainment industry because they do not want audiences to experience any form of lagging or out-of-sync lighting effects. They expect a latency of 5 milliseconds or less when controlling lighting for film and concerts[1]. For wirelessly controlling street or office lighting, this type of speed is not mission critical.

What the entertainment lighting industry wants can be described as "deterministic latency" where there is no randomness involved. Here a star network is ideal as it gives lighting technicians controlled latency which they can be guaranteed will not exceed their limit of 5ms.

Mesh cannot make the same assurances, since every time a data packet hops from one node to another, latency is added. Meshing has automated hopping,

Mesh is not suited for all applications - Wireless DMX, which is widely used in the entertainment lighting industry, uses a star network configuration.

so the number of hops made cannot be influenced and the exact time it takes for the signal to be received cannot be known in advance.

Mesh also requires a certain amount of bandwidth to operate. For wireless DMX, all the available bandwidth is required to transmit the lighting control data so using mesh in this case is too costly.

Cable protocols	Application area	LumenRadio's wireless options	Type of network
DMX	Entertainment lighting control	CRMX	Star
DALI	Lighting control	W-DALI	Mesh
BACnet	Building automation and control systems	W-BACnet	
Modbus	Industrial automation and control systems	W-Modbus	

[1]Research from various universities (MIT, Parma and St. Andrews) would suggest that the human eye cannot perceive movement quicker than 13ms. With a latency of 5ms you can be assured that no human being will notice a lag!

Frequency synchronization creates mesh network stability

The beauty of Cognitive Coexistence is how effective it is at making use of the gaps on the narrow 2.4GHz frequency by optimizing adaptive frequency hopping (AFH).

When a standard wireless system uses AFH, it cycles through a static list of frequencies and blocks a section of the 2.4GHz band 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.

Mesh networks are particularly sensitive to this loss of synchronization as it can cause the whole network to fail. If there is a node which hasn't received a signal,

then it cannot repeat that signal. Frequency synchronization is lost but it still takes time for the network to realise this and once it does register, it takes even more time as the entire network resets itself.

Packet loss is a reality which even the best networks have to live with this. This does not have to be fatal for a star network, but for mesh it is catastrophic, which is why most companies do not even attempt to do wireless mesh using AFH.

LumenRadio, however, can give you the advantages of AFH in a mesh network thanks to Cognitive Coexistence.

Mesh networks rely heavily on frequency synchronization. A loss of alignment due to interference can disrupt data flow and cause network-wide failure, as unsynced nodes are no longer listening on the correct frequency.
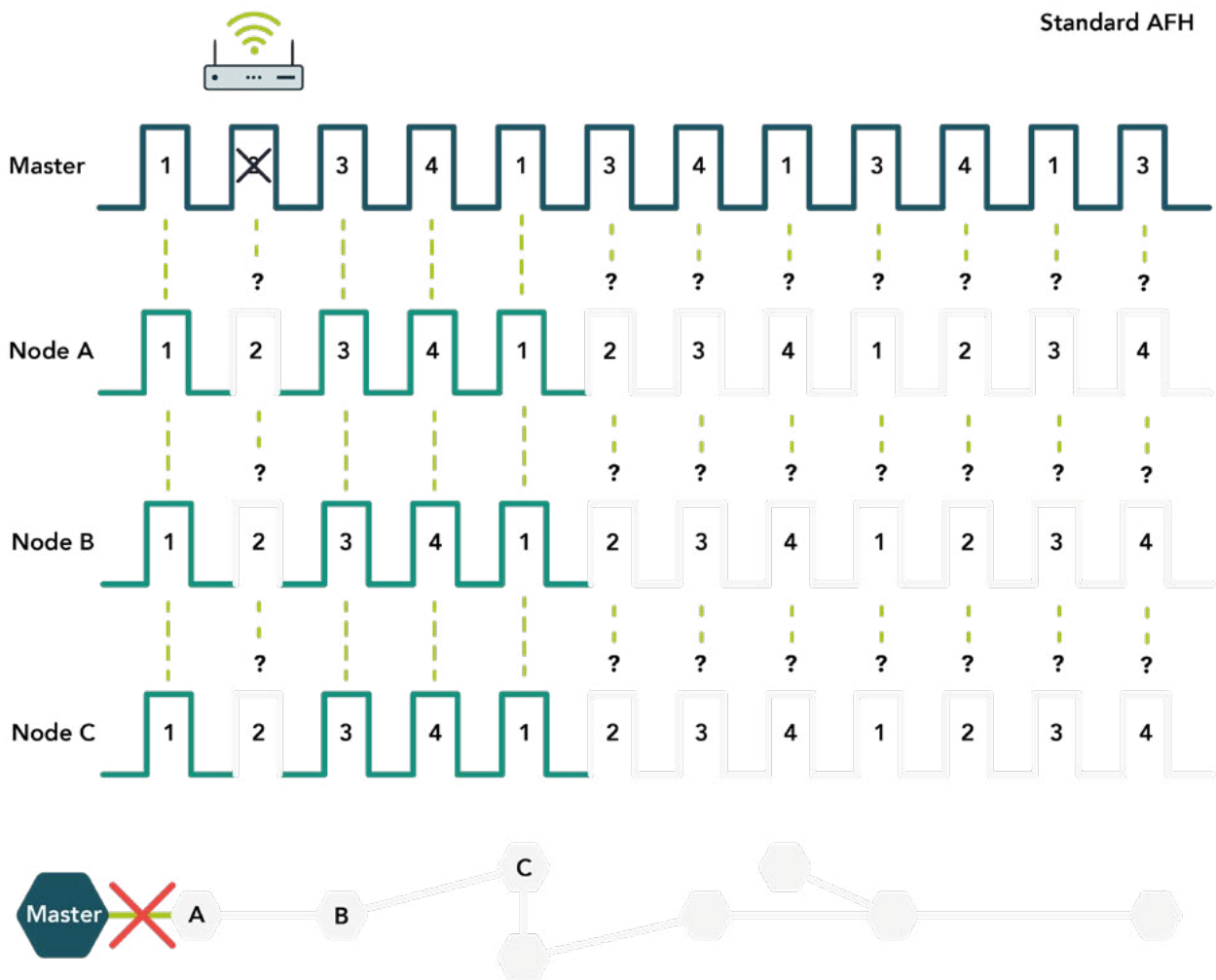
How it works

Cognitive Coexistence improves upon the weaknesses of standard AFH systems by employing "smart blocking" technology. Essentially it replaces the blocked channel with a good channel on the list, so the rest of the sequence is maintained and only a small piece of data is lost. This ensures that the transmitter and receiver remain sufficiently in sync to avoid a system failure.

This is why the marriage of Cognitive Coexistence with LumenRadio's mesh is so important as it ensures a vastly more stable and reliable network.

Cognitive Coexistence minimizes data loss in mesh networks by intelligently adapting to interference and keeping nodes in sync.
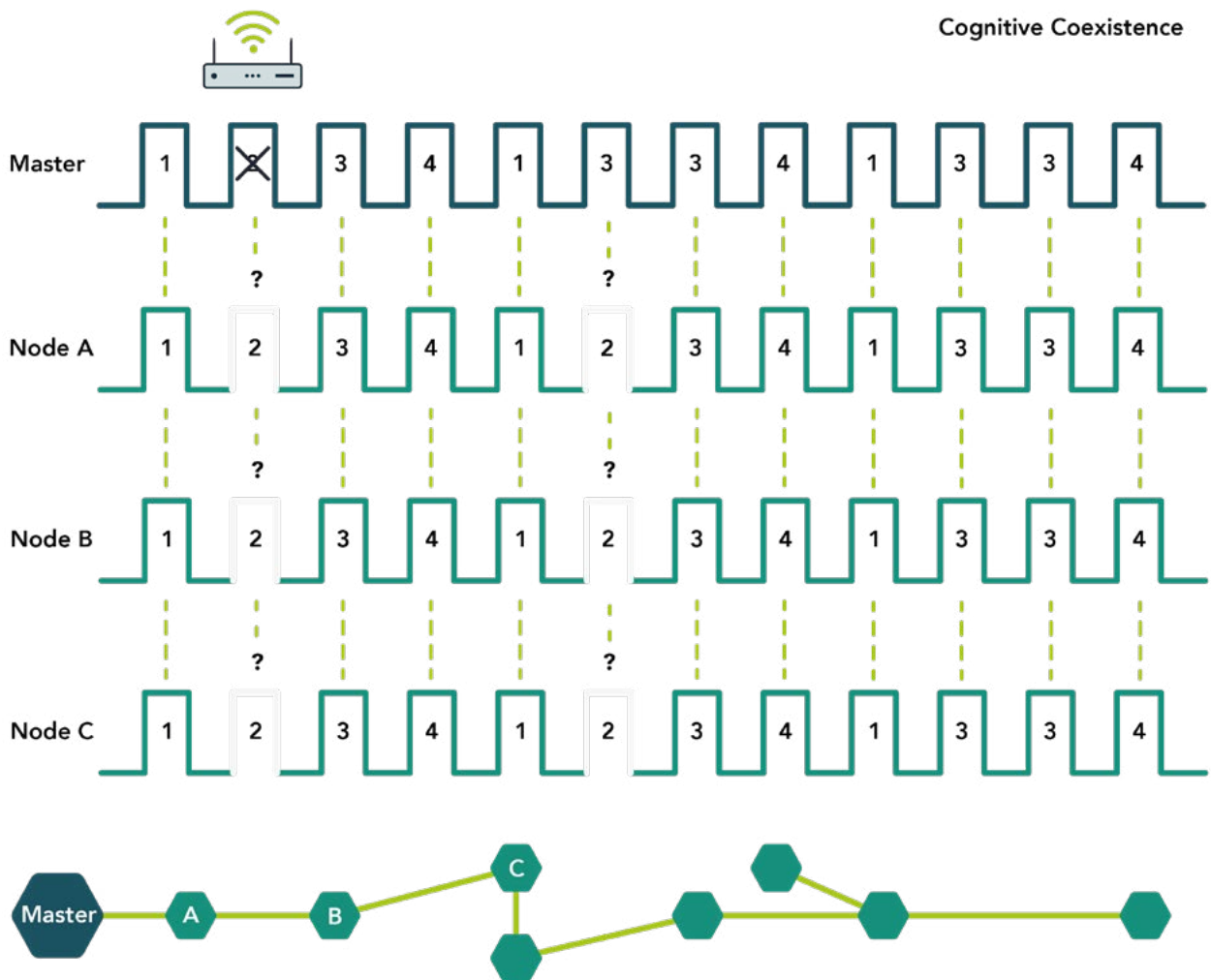
Balancing the Data Flow
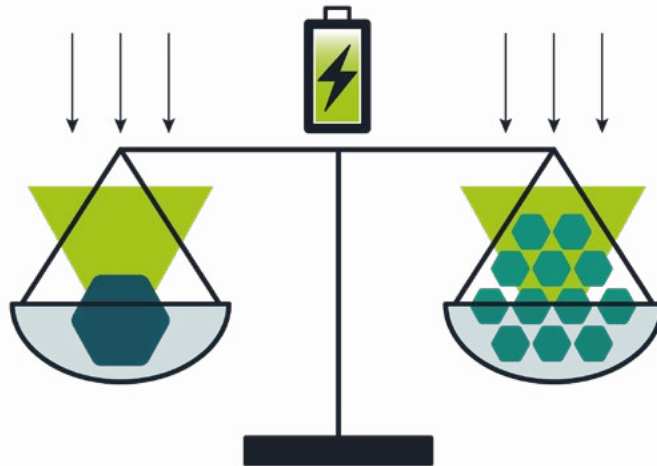
LumenRadio's wireless mesh takes a balanced approach to decision-making

Imagine you want to have a mesh network made up of 200 nodes. Conventional wisdom says that you would require a "super node" – one which is designated as the ultimate decision maker for the whole network and works out the frequencies for all the other nodes. This super node would have to handle a large flow of data and therefore require a larger CPU. This creates an issue not least in terms of energy usage.

LumenRadio's MiraMesh solves this problem by removing the need for a super node altogether. It spreads the data workload over each of the nodes in the network, so that there isn't one single node which requires a much higher level of computing power. Why does this matter? Because it means there is effectively no limit to the number of nodes a MiraMesh network can have.
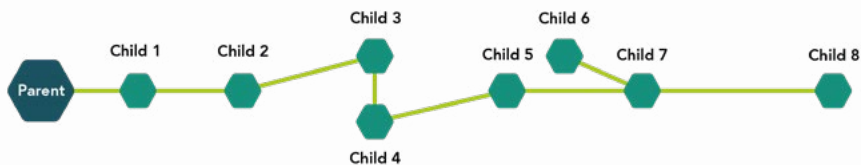
Every child node in the network talks and contributes with data, but the closer a child is determines how important the parent rates that information.

CHAPTER THREE

Low Energy Mesh

The (un)official record holder

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 (un)official record for the 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.

The experts' choice

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 battery-powered meshing connectivity is achievable.

Many large companies – such as SKF, Honeywell and Swegon – have chosen LumenRadio because of this best-in-class energy usage. In lab tests, LumenRadio always performs the strongest. And in real-world conditions, it performs even better.

This is because Cognitive Coexistence technology makes it incredibly likely that a data packet is delivered at the first time of asking. On average, other technologies will take more tries and resend the data more often, which results in higher energy usage.

For low energy mesh, MiraMesh outperforms the competition making it best-in-class for power usage
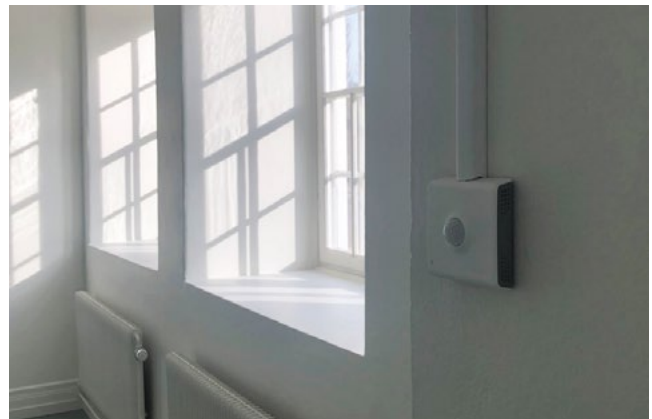
Phew! It's draining to always repeat! I'm glad you heard me the first time.

My alarm is set, I won't miss your signal.

Wake me up when you need me! I'm gonna take a nap.

HOW LOW ENERGY MESH KEEPS POWER CONSUMPTION AT AN ABSOLUTE MINIMUM

Devices in a low energy mesh network are optimized to use minimal power, extending battery life so that they can operate for many years on a single charge. Here are some of the features they use to conserve power:

Sleep modes: Devices often have sleep modes where they consume extremely little power when not actively transmitting or receiving data.

Duty cycling: Devices can be configured to wake up periodically to check for data transmission needs and then return to a low power state, reducing overall energy usage.

Optimized communication: Efficient routing algorithms and data packet management help minimize energy usage during communication.

CHAPTER FOUR

Time Synchronization
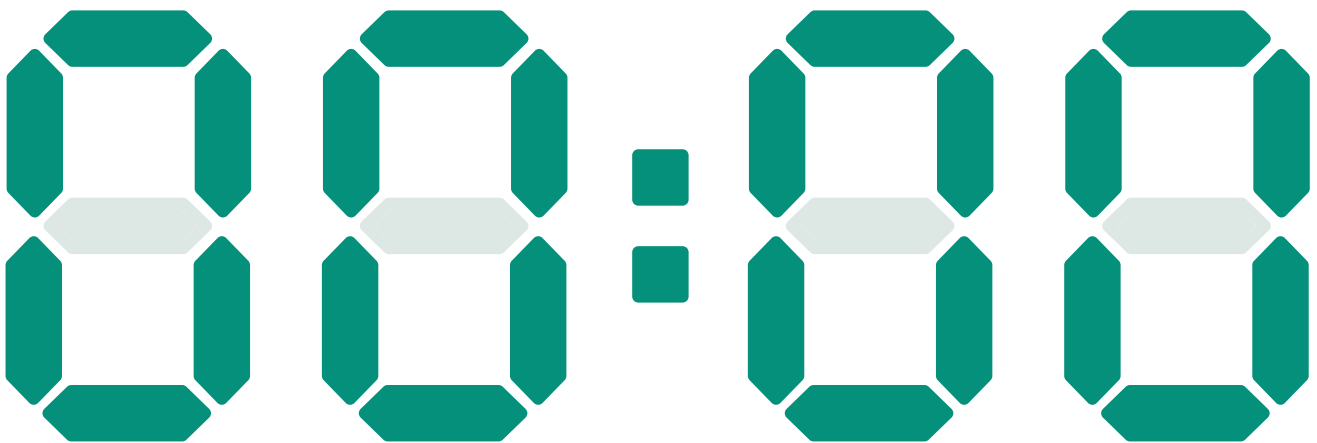
Keeping in sync with microsecond accuracy

If a node in a wireless mesh network is powered by electricity, it can transmit and receive information all the time – there are no issues with energy consumption. A battery-powered node, however, cannot be constantly "on" and must use features like sleep mode to ensure it isn't wasting battery life (see Chapter Three: Low Energy Mesh).

In many real-world cases though, it is necessary for mesh to combine battery and electricity power sources in the same network. This is referred to as "mixed configuration". One typical example could be a battery-powered control switch on a wall which controls a node on a lighting fixture which is connected to the mains.

To be able to run mesh on a mixed configuration network like this, everyone has to work from exactly the same clock – and this is where LumenRadio's MiraMesh excels.

The benefits of a precise internal clock

Accurate time synchronization is a key feature of MiraMesh. It allows nodes which are saving energy by sleeping, to wake up when it's time to receive a signal. The greater the accuracy, the more energy is saved, as the node does not need to be active longer than is absolutely necessary.

Ideally every node would wake up at exactly the same time, namely at the point when the signal is transmitted. But if this cannot happen simultaneously, then the "dead time" between the signal being sent and the signal being received, should be as minimal as possible.

In a 200-node network, for example, MiraMesh is tuned to make sure the internal clock in node 1 and the internal clock in node 200 are never out of sync more than 50 microseconds! The system regularly recalibrates to maintain this incredible level of accuracy and reduces dead time massively so that wireless mesh can be kept running for as long as a decade without having to change the batteries.
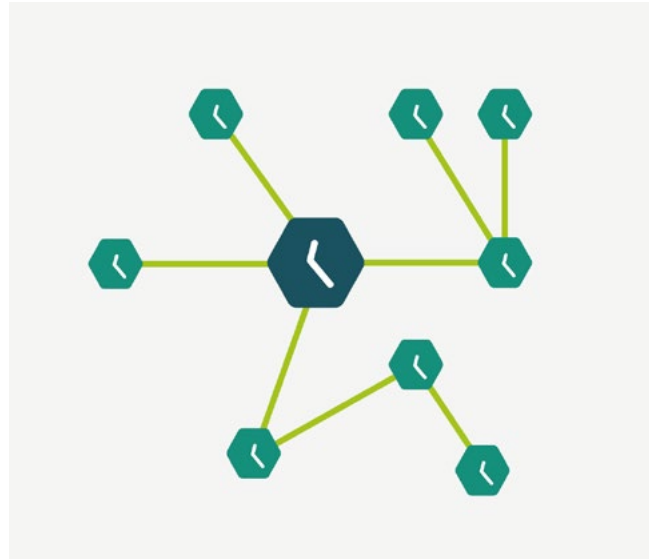
What can you use high precision timing for?

Here are a couple of real-world examples where super-accurate time synchronization is a real plus.

i) Have you heard of the "popcorn effect"? It refers to the phenomenon where multiple lights in a wireless network do not turn on or off simultaneously, but instead activate or deactivate in a staggered, inconsistent manner. This creates a visual effect where the lights appear to pop on one after another, similar to the way popcorn kernels pop at different times in a popcorn maker.

With MiraMesh the popcorn effect is avoided entirely as the internal clock in each chip ensures synchronization between transmitter and receiver so accurate that all the lights will be perceived to turn on in unison.

ii) Having wireless mesh with an accuracy to within 50 microseconds is also a great advantage when it comes to measuring and collecting data.

Swedish company, SKF, is the world's largest manufacturer of ball bearings and is at the absolute cutting edge of technology in that field. It can measure the minute vibrations in its bearings and accurately predict when those bearings need to be replaced. As a result customers never have to experience any downtime in their production line because of faulty bearings. To correctly make these lifespan predictions, however, SKF needs to know that measurements from two vibration sensors on either side of an axel, for example, were taken at exactly the same period of time.

Standard mesh networks are not only unstable but also lack accurate time synchronization, which is why SKF uses LumenRadio's wireless mesh for the job.

Summary

Done right, you can achieve great things with mesh

Wireless mesh networks have revolutionized the way we achieve reliable, flexible and cost-effective connectivity over large areas, making them integral to IoT ecosystems and the development of smart cities.

They create a decentralized system where each node relays data to others, forming a self-healing, self-configuring network. But they are vulnerable to interference and collapse.

Enter MiraMesh, LumenRadio's own mesh network platform, which removes this Achilles heel thanks to its unique Cognitive Coexistence technology.

Cognitive Coexistence dynamically scans the 2.4GHz band to avoid interference from other devices, allowing it to operate in extremely crowded environments. This approach provides stable, synchronized communication with minimal packet loss, outperforming other wireless technologies in range and reliability.

Together with extremely low energy usage and accurate network-wide synchronization, this has taken wireless mesh to a whole new level.

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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