WP-PD-123 - Wirepas Mesh Overview

Product Description

Version: v1.0A

Wirepas Mesh is a de-centralized radio communications protocol for devices. The Wirepas Mesh protocol software can be used in any device, with any radio chipset, and on any radio frequency band. This document introduces the benefits, features, and the technology behind Wirepas Mesh product.

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1. Introduction to Wirepas Mesh

Wirepas Mesh (WM) is a de-centralized wireless communication protocol for devices (Figure 1). With the unique de-centralized operation, the devices contain all the intelligence. The devices themselves make all decisions locally and co-operatively. This enables the most reliable, optimized, scalable and simple to use connectivity for devices. The embedded WM stack software (protocol firmware) can run on any radio chipset and is integrated to customer devices to enable wireless networking. The combination of de-centralized connectivity with rich feature-set and hardware independence gives unique value for large scale IoT applications.

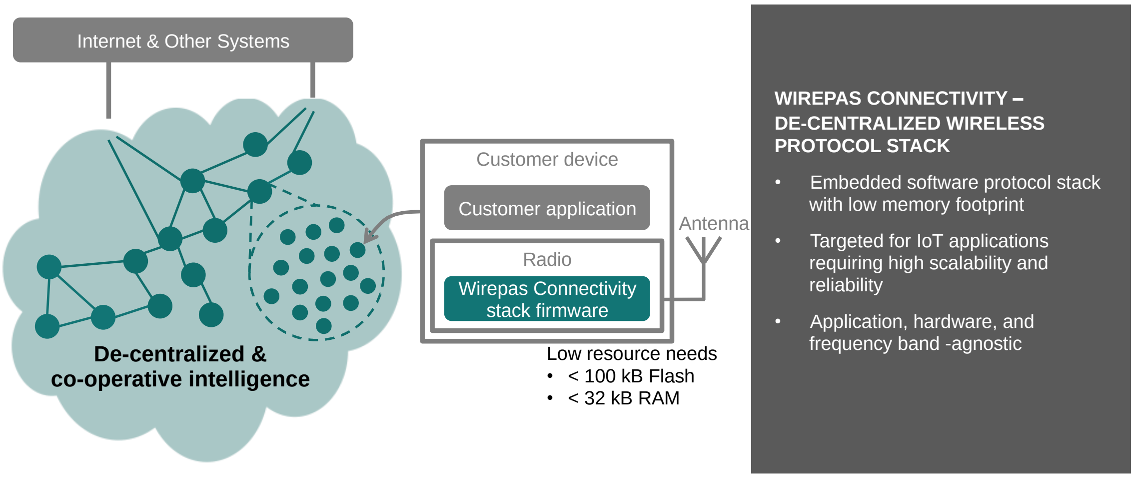


Figure 1. WM is the most reliable, optimized, and simple to use connectivity firmware for devices. All the protocol functionality is de-centralized to the devices. The devices implement the network functionality co-operatively using local decisions. No external intervention or central control is needed.

The unique characteristics of Wirepas Mesh ensures it is fit for the real world and addresses the breadth of IoT connectivity challenges. Unprecedented levels of scale, density and low power consumption have been achieved by Wirepas and customers in existing deployments. For example:

- **Over 700,000 smart meters connected in a single mesh network, believed to be the largest wide area mesh network deployed on the planet;**
- **More than 1,000 radios per cubic metre proven without collisions;**
- **A battery operated IPv6 router that consumes only 20 µA on modern BLE radios.**

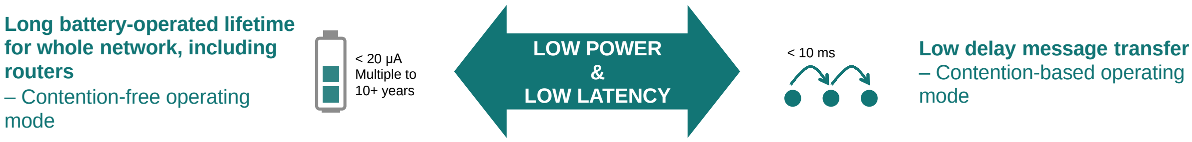
1.1 Main Benefits of Wirepas Mesh

WM provides many benefits for enabling the implementation of large scale IoT applications. The main benefits of WM are:

Unlimited scale, coverage, and density: WM provides unlimited scale in number of devices and coverage as all devices are able to route data and decisions are made locally. The networks can cover large geographical areas and provide connectivity in hard to reach places such as deep indoors and basements. Ultra-high device densities as well as sparse installations are enabled by WM.

High reliability and availability: There are multitude of self-healing and interference avoidance methods built into WM. These enable high reliability and availability. When data is sent it also goes through to the destination. The devices are connected and available 24/7. All this is independent of the environment dynamics and interferences.

Low power and low latency: With the highly energy-efficient operation, all devices (including devices routing data) in the network can be battery-operated with multi-year lifetime. Low latency multi-hop message transfer is supported for applications requiring delays in the order of tens to hundreds of ms.



Lowest total cost of ownership: WM minimizes both capital costs (CAPEX) and operational costs (OPEX). With WM, no extra infrastructure is needed as the devices themselves form the network, the fully automatic operation enables easy and quick installation, and the firmware runs on low cost radio hardware. During the system lifetime, the data plan costs are minimized as backhaul connectivity is needed only for small fraction of devices, and the self-healing operation maintains the network continuously, removing the need for external interventions and field maintenance.

Openness and flexibility: WM provides easy-to-use open API for applications to use the network services, and the network can be integrated to any system and used in any application. IPv6 is supported for scenarios that require native IPv6 addressing to every single device. All the protocol intelligence is implemented in the WM firmware and de-coupled from the physical layer. Thus, the firmware can run on any radio hardware and frequency band.

Future proof: The WM protocol stack is developed all the time to meet the evolving demands of IoT applications. Thus, the protocol adapts to the application, not vice versa. Efficient Over The Air Programming (OTAP) support enables remote updates for already installed devices. Bot the protocol firmware and application can be remotely updated. This way, the lifetime of the installed hardware can be maximized.

1.2 Core Operation Principles of Wirepas Mesh

The disruptive operation of Wirepas Mesh builds on six core operation principles, highlighted in Figure 2:

- **De-centralized network architecture:** All the intelligence is de-centralized to the devices in the network, which make decisions locally, such as selection of best neighbors, optimal TX powers, and most reliable frequency channels. This removes the need for central management and end-to-end network signaling, and guarantees that the protocol functionality is independent of network size or the location of a device in the network.
- **All devices able to route:** Since all devices are able to route, every device is also a possible connection point to the network providing high coverage independent of the environment. Also, there is no need to plan the network and device roles as all devices are homogeneous from the connectivity point of view.
- **Multi-gateway support:** Multi-gateway operation provides means to expand system capacity easily. The routing balances load between gateways. Also, multiple gateways remove single-point of failure at the gateway-level as the routing automatically chooses best gateways.

- **Efficient collision-free spectrum usage:** With locally synchronized and scheduled channel access, the radio spectrum is divided between the devices in time and frequency domain. The used frequency band is used efficiently enabling high device density. The synchronized operation removes communication overhead and scheduling removes intra-network collisions.
- **Multi-channel operation:** The whole frequency band is always used for communication. This increases the network capacity as different devices can communicate at the same time using different channels. Also, interferences can be avoided by using only the good quality channels.
- **Hardware and frequency band independence:** Hardware independency enables the usage of different radio chipsets. De-coupling SW and HW enables both to evolve independently and different combinations can be used for the best performance. Also, usage of different frequency bands is possible either e.g. per application requirements (such as power vs. device-to-device range tradeoff) or per region.

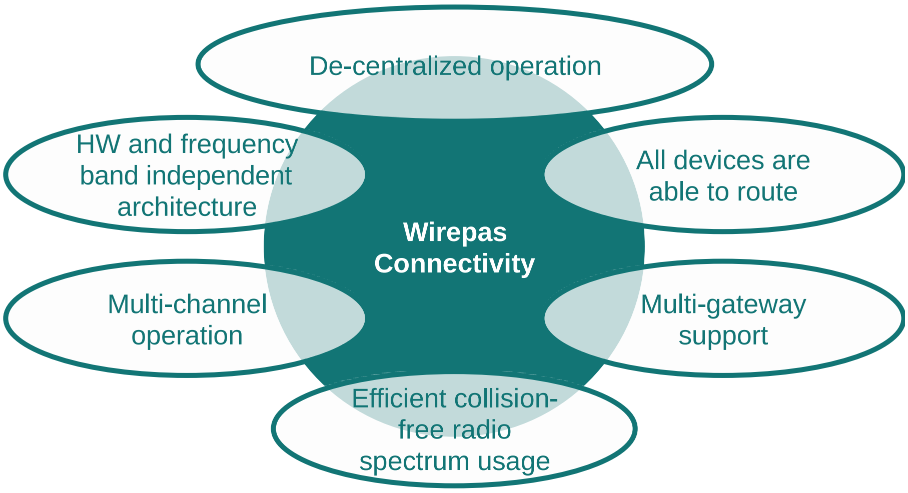


Figure 2. WM builds on six main operation principles: 1) De-centralized operation, 2) all devices are able to route, 3) multi-gateway support, 4) efficient collision-free radio spectrum usage, 5) multi-channel operation, and 6) HW and frequency band independent architecture.

1.3 Single Flexible Software Asset, Multiple Applications, Application-Specific Optimization

WM provides a multitude of features in the same software asset. This enables usage in different applications with application-specific optimization. Examples of the applications are illustrated in Figure 3. Majority of IoT applications share the same requirements of cost-effectiveness, large scale, high reliability, and high availability. However, there are also many key requirements that vary from application to application. For example:

- Wireless sensors and beacons require long battery lifetime,
- Smart meters require long device-to-device range, and
- Lighting requires low latencies.

With WM, all these are enabled.

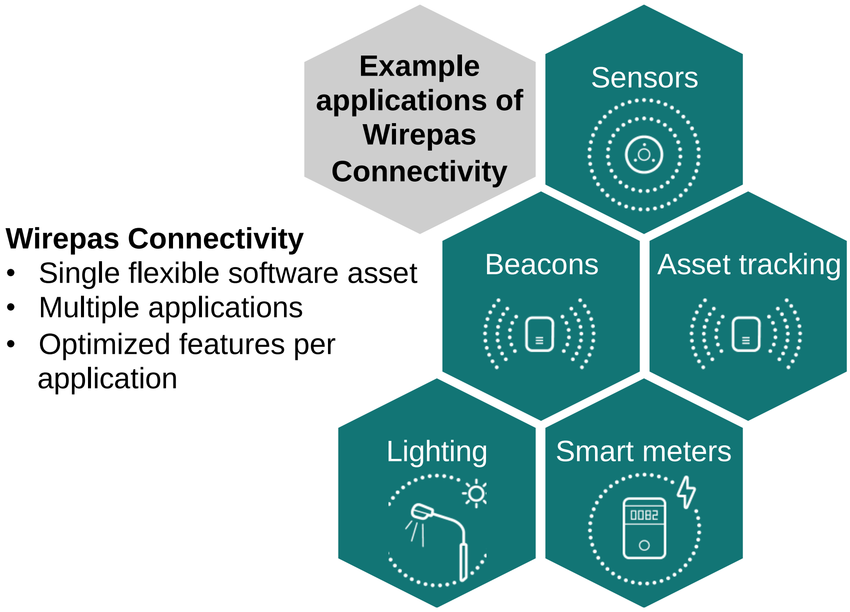


Figure 3. Wirepas Mesh supports multitude of applications with the same software asset. The application-specific features and optimizations are all in-built to the same product.

2. Wirepas Mesh Benefits Explained

The main features behind WM benefits,

- Unlimited scale coverage, and density,
- High reliability and high availability,
- Low power and low latency,
- Lowest total cost of ownership, and
- Openness and flexibility,

are introduced in this section.

2.1 Unlimited Scale, Coverage, and Density

WM supports any installation topology and large scale. This means that the network

- Can include large amount of devices,
- Can cover large geographical areas,
- Can provide connectivity in hard to reach places, such as basements and deep indoor areas,
- Can include large number of devices inside same radio range (dense networks), and
- Can support long device-to-device range (sparse networks).

Figure 4 summarizes the main WM features behind unlimited scale, coverage, and density.

Unlimited scale is enabled by the de-centralized operation. All the protocol intelligence is distributed to the devices that form the network. The devices among themselves make all decisions locally and co-operatively. No external intervention is needed. Due to this, the implemented protocols and algorithms operate the same way independent of network size or a device's location in the network. Also, no end-to-end signaling or central management is needed. This removes signaling overhead and provides good reactivity to local environment changes and dynamics.

High device density is enabled by locally synchronized and scheduled TDMA and FDMA channel access, minimized transmission time-on-air, and automatic role selection. The radio spectrum is used efficiently in time and frequency domain and communicating devices locally agree on exact times and frequencies to send and receive data. There is no overhearing, idle listening, or intra-network collisions. Multi-hop communication enables the usage of high radio data rates, and minimizing time-on-air, whilst still achieving good network coverage. This way, the time used to transmit specific amount of data and channel occupancy is shorter. The automatic role selection chooses run-time which devices need to be routers and which can act as end devices in the network.

High coverage is enabled by the fact that every device can route data and communicate over multiple hops. Each device is also a potential connection point to the network. This provides good coverage even in hard to reach places, without any additional infrastructure. If a device can hear even one other device from the network, it can acquire a connection. Multi-hop communication makes it possible to extend the network coverage by just adding new devices.

Device-to-device range can be adjusted with the used physical layer. The selection of different physical layers is enabled by the physical layer independent architecture and operation of WM. Different frequency bands and radio data rate vs. range options can be used depending on application needs. E.g. 2.4 GHz can be used for dense indoor installations and sub-GHz if longer device-to-device range is needed for inter-building communication.

Network capacity can be easily increased by adding gateways. When data transmission frequency and/or device amount is increased, a gateway can become a bottleneck. Multi-gateway operation removes this potential bottleneck, as each gateway adds capacity to the network and load balancing forwards the data to the best gateway. Same functionality is also employed between routers, balancing the load throughout the network.

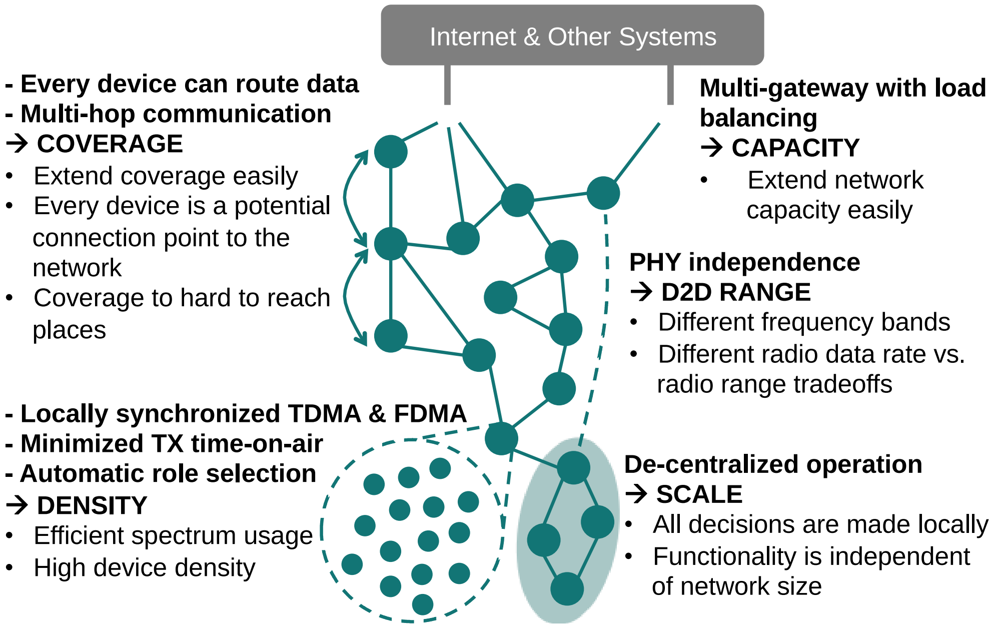


Figure 4. Main WM features behind unlimited scale, coverage, and density.

2.2 High Reliability and High Availability

WM supports high reliability and availability. This means that when a message is sent it is also received at the destination device and that the devices are connected 24/7, independent of the environment. The wireless environment and link qualities can change e.g. due to weather conditions, people amount or obstacles such as closing/opening of doors. Also, there can be other wireless systems in the area causing interference. With large scale networks the environment and interferences can differ a lot depending on the local conditions. Thus, the network should

- Adapt to conditions locally,
- Enable no single point of failure operation at any part of the system,
- Provide high tolerance against environment dynamics, and
- Provide high tolerance against wireless interferences.

Figure 5 and Figure 6 summarize the main WM features behind high reliability and availability.

Quick adaptation to the local environment is enabled by the de-centralized operation as all devices make local decisions and rely on local information to make these decisions. There is **no single point of failure** at any part of the network. At the node-level there is no single point of failure as every device can route data, and thus, there are inherently many different routes. The multi-gateway functionality removes single point of failure at the gateway-level. If a gateway is lost or there are problems with its backhaul connection, data is automatically routed to another working gateway.

Self-healing and –optimizing routing provides resilience against dynamic environments. The routing automatically finds new optimal routes as the network environment changes and/or if existing routes are lost. **Adaptive TX power control** always use minimum reliable TX power for optimizing reliability and minimizing interference to other systems in the area.

Interferences from other wireless systems are avoided by using **multi-channel interference avoidance** (local channel blacklisting) and **short TX time-on-air**. Channel blacklisting senses the interference in the used channels, and, if interference exists, a channel is locally blacklisted and avoided. This way, reliable, non-interfered frequency channels are used. Short TX time-on-air (enabled by the multi-hop operation) minimizes the probability of packet collisions with other systems even if same frequency channels are used.

All data exchanges are **acknowledged at the link layer and re-transmitted** if necessary. Thus, if despite of the interference avoidance methods a packet is lost, the packet loss will be noticed and the packet re-transmitted.

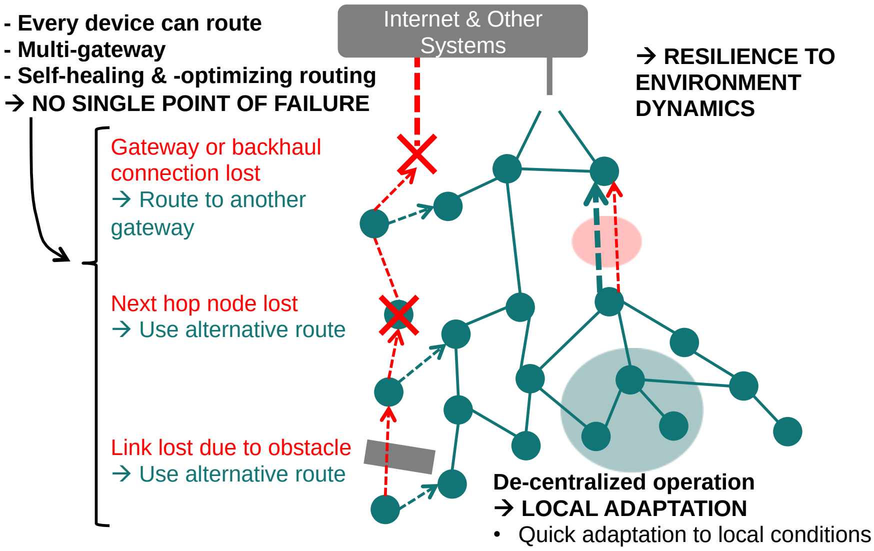


Figure 5. Main WM features behind high reliability and availability, high resilience to environment dynamics.

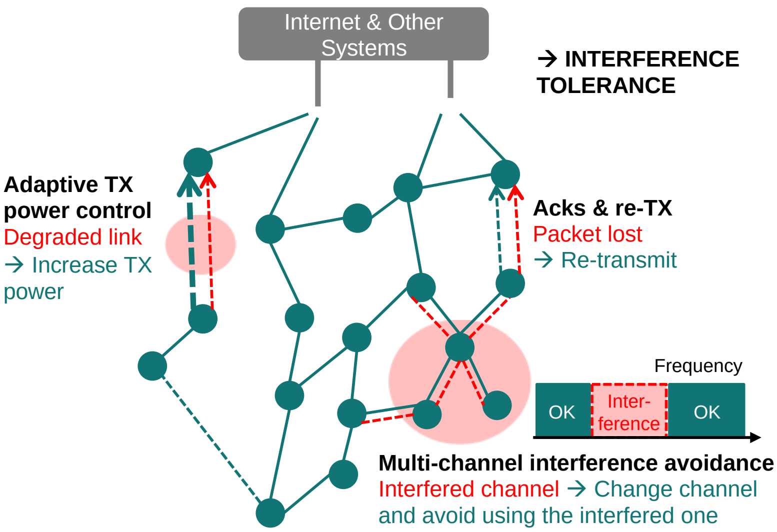


Figure 6. Main WM features behind high reliability and availability, high interference tolerance.

2.3 Low Power & High Energy-Efficiency

The low power and high energy-efficiency are enabled by contention-free time-slotted multi-channel access operation. All devices, including devices that route data, can achieve long battery lifetime. The main features enabling the high energy-efficiency are

- Locally synchronized & scheduled channel access,
- Short time-on-air, and
- Energy-optimized routing.

With **locally synchronized & scheduled channel access** (Figure 7), the devices are active only when required. Rest of the time is spent in low-power sleep mode. With the scheduling, the communicating devices always know the exact times when to send and receive data. This removes all unnecessary overhead, such as overhearing, idle listening, and intra-network collisions. Local synchronization provides high accuracy, minimizing the required amount of radio activity. **Short time-on-air** optimizes the energy-efficiency further, as the radio needs to be on only short time periods.

At the network level, the **energy-optimized routing** optimizes whole network lifetime. Load balancing distributes data evenly between devices and devices with depleted batteries are avoided from data forwarding.

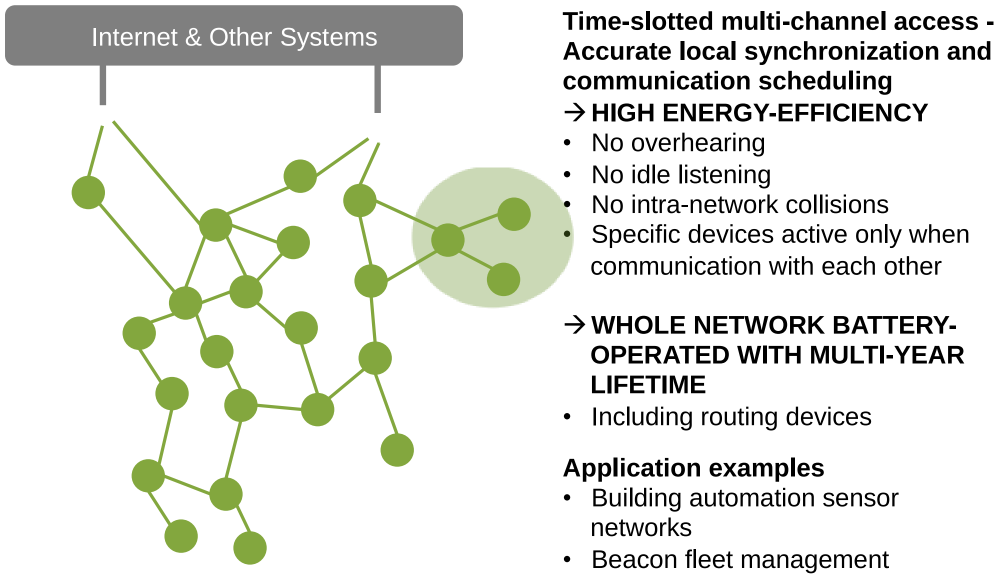


Figure 7. High energy-efficiency is given by accurate local synchronization and scheduling of data exchanges. This removes overhead, and enables devices to sleep as much as possible.

2.4 Low Latency

The low latency multi-hop message transfer is enabled by contention-based CSMA-CA multi-channel access operation. In the low latency operation (Figure 8), the routers are active all the time, spending all their idle time in RX mode. Thus, data can be transmitted immediately. Low energy devices with duty cycling can also join the network and operate with low power. Note that, as the low energy devices can also do routing, the network can be extended with “branches” of battery-operated devices.

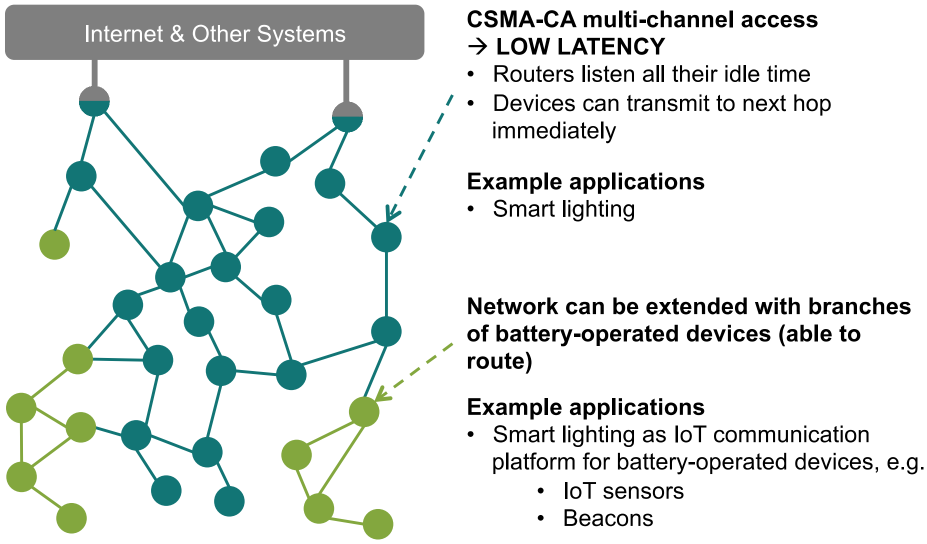


Figure 8. Low latency operation is achieved using contention-based CSMA-CA channel access. This enables devices to transmit and receive data immediately.

2.5 Lowest Total Cost of Ownership

WM minimizes the lifetime costs of the wireless system i.e. both the setup costs (CAPEX) and running costs (OPEX) as illustrated in Figure 9. The CAPEX is minimized by

- Minimizing the connectivity BoM,
- Removing the need for extra communication infrastructure,
- Minimizing the radio planning effort, and
- Making the installation easy and quick.

The OPEX is minimized by

- Removing the need for remote and in-field maintenance work,
- Minimizing data plan cost by minimizing the amount of devices with backhaul connection, and
- Providing efficient OTAP capability for remote firmware upgrades.

Figure 9 summarizes the main WM features behind lowest total cost of ownership.

The **low connectivity BoM** results from the hardware independent architecture of WM. WM runs on low cost off-the-shelf radio hardware and the hardware can be sourced independently of Wirepas. Also, WM does not impose any extra requirements on the gateway side, but runs on the same hardware on all of the devices. Naturally, the gateways require some backhaul connectivity, which is customer-specific and can be freely chosen by the customer.

WM can be integrated to the devices implementing the actual application functionality, such as meters or sensors. Thus, the devices that implement the application functionality also form the communication network. As WM forms the wireless network independently and every device can route data, **there is no need for additional communication infrastructure**.

As WM provides fully automatic operation, from network joining to run-time self-healing and –optimizing functionality, **only light or non-existent radio planning is needed and installations are easy and quick**. Only thing that is needed is that a device can hear at least one other device in the network. WM handles the rest and keeps the network optimized and working.

The automatic operation with multiple interference mitigation methods also **minimizes the need for maintenance work**. The network handles the maintenance and repairs itself as the environment changes. Furthermore, the efficient multi-hop OTAP functionality enables **easy firmware upgrades** to already deployed system maximizing installed hardware lifetime.

WM supports small gateway-to-node ratio. This means that a single gateway can serve a large amount of node devices. Due to the de-centralized operation and local decision making, adding nodes or hops does not increase the load in the gateway. The nodes make the decisions locally and do not need central coordination. This **minimizes the amount of devices with backhaul connection** (i.e. gateways).

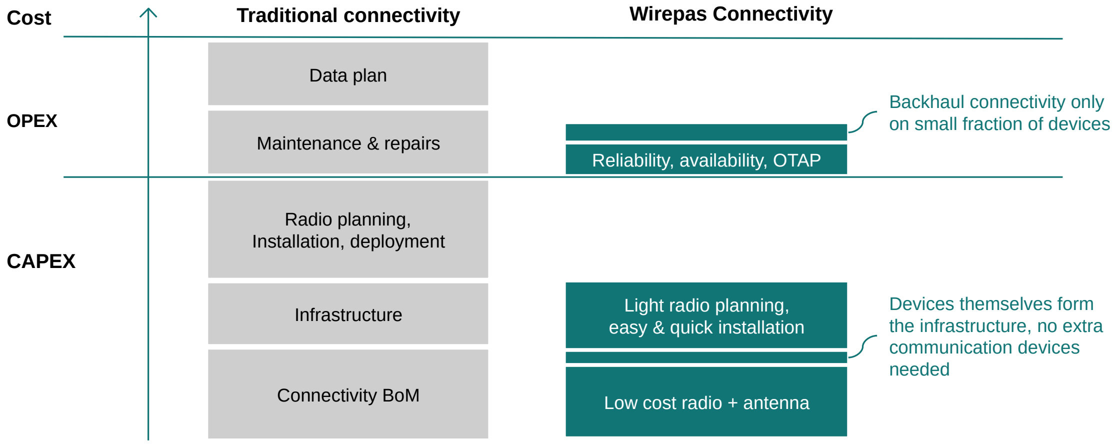


Figure 9 Main WM features behind lowest total cost of ownership.

2.6 Openness and Flexibility

As depicted in Figure 10, WM provides high flexibility and can be used in multitude of IoT system implementations. WM is highly agnostic on the components above and below the communication stack and

- Can be used in different applications,
- Can be integrated to any back end / front end system,
- Can run on any radio hardware, and
- Can use any frequency band.

The key features include

- Open easy-to-use API,
- Payload-agnostic data transfer, and
- Hardware and frequency band independent architecture.

WM provides **easy-to-use API** for any application to use. All the protocol complexity is hidden and the application can concentrate on implementing only the application logic. WM takes care that the connectivity is there when the application needs it. The **data transfer is payload-agnostic** i.e. application can send and receive any kind of data and use any application protocol on top of the WM stack.

WM stack firmware implements a **hardware and frequency band independent architecture**. All the intelligence is implement in the stack itself and nothing special is required from the hardware. Thus, multitude of different radio chipsets can be used. The architecture also enables the usage of different frequency bands (e.g. 2.4 GHz and different sub-GHz bands) providing possibility for radio data rate vs. range tradeoffs depending on application needs. This open architecture makes it possible to combine optimized connectivity stack and best fit for the purpose radio chipsets.

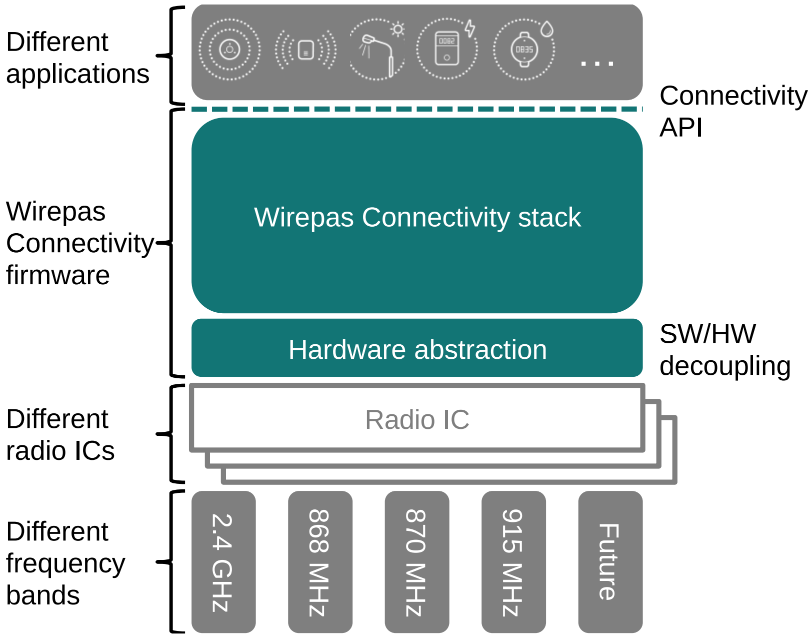


Figure 10. WM stack is application, system, hardware, and frequency band -agnostic. The architecture of WM hides the complexities of the stack behind a easy-to-use API. Hardware and frequency band are abstracted using a hardware abstraction layer.

3. Conclusions

Wirepas Mesh (WM) is the most easy to use, scalable and reliable embedded wireless protocol stack for devices. It can be used in any application, radio hardware, and frequency band. The main benefits of WM are:

- Unlimited scale, coverage, and density,
- High reliability and availability,
- Low power and low latency,
- Lowest total cost of ownership,
- Open and flexible, and
- Future proof.

The main operation principles and differentiators of WM include:

- De-centralized operation,
- All devices are able to route and homogeneous,
- Multi-gateway support,
- Efficient collision-free spectrum usage with deterministic performance,
- Multi-channel operation, and
- HW and frequency band independent architecture.

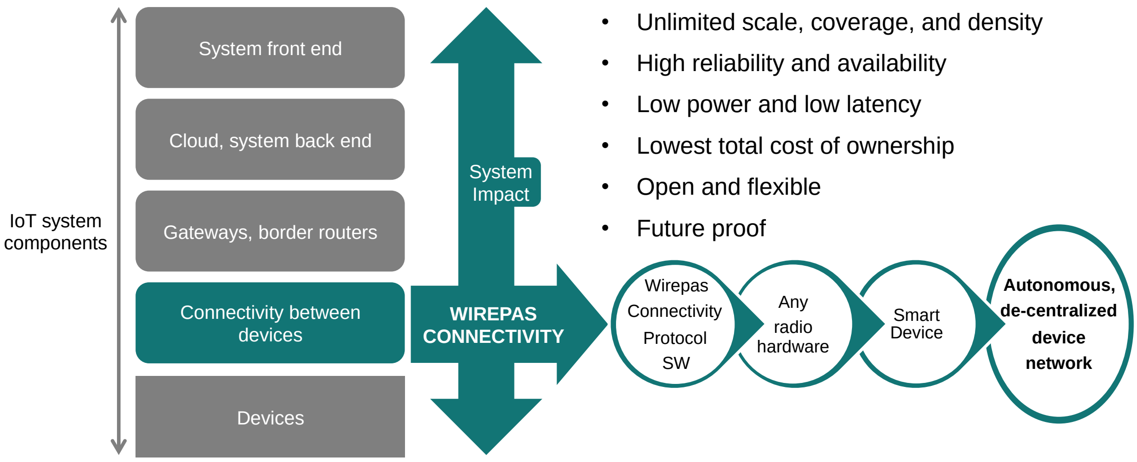


Figure 11. Wirepas Mesh is the most easy to use, scalable and reliable embedded wireless protocol stack for devices.