Radiocrafts
Embedded Wireless Solutions

WP021

Choosing the best IoT connectivity solution for a given use case

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Introduction

IoT (Internet of Things) has moved from a buzzword to a broad business segment with a complex ecosystem of solutions. An important part of the IoT solution is wireless technology. The advantages of wireless technologies over wired has been accepted for decades with benefits such as scalability and lower total cost of ownership.

A myriad of different wireless technologies has emerged and there is a vast number of standards and proprietary solutions available to choose from today. Due to the variety of use cases within IoT, there is no one solution that fits all. It is obvious that for a heart rate training sensor, a streetlight, or a container tracking device, the requirements for wireless connectivity are different.

This White Paper aims at drawing the map over the IoT connectivity terrain and to position the Radiocrafts Industrial IP Mesh (RIIM) among the other technologies, e.g. LoRaWAN, Wi-SUN and Wirepas. The purpose is not to find one best solution, but to identify the trade-offs and priorities that the user must do when considering wireless connectivity.

In the end it's all about finding the best solution for each use case with regards to maximizing business profit. This can be mapped to business goals like minimizing time to market and lower total cost of ownership. But mapping this further to technical features such as current consumption, range, firmware upgrade over air, reliability etc. is a much more challenging task. Due to this, many decisions on wireless connectivity are based on gut feeling rather than business arguments.

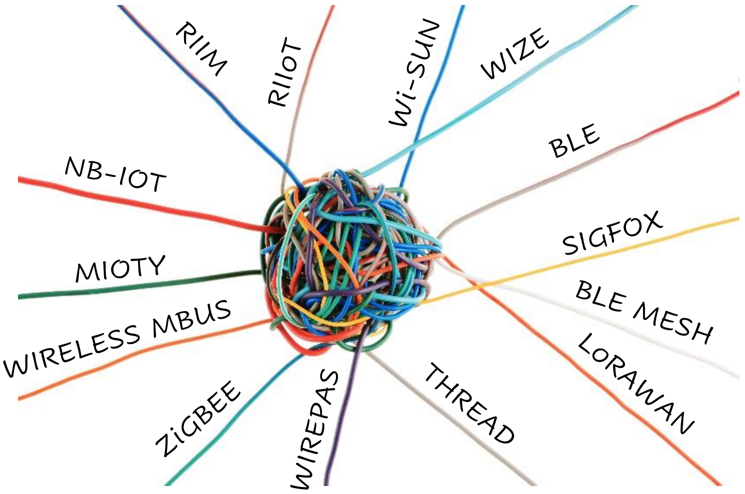


Figure 1. Myriad of wireless solutions

Key differentiator

Before discussing specific use cases it is important to simplify by grouping the different technologies by their main characteristics. The available solutions are conceptually very different from each other that it makes it impossible to compare the technologies directly on the same metrics.

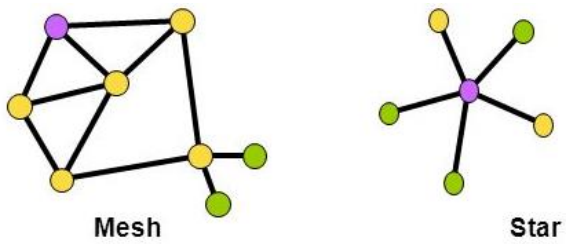
Below in Table 1 the most relevant technologies are listed with some of their main characteristics.
In the next chapters these main characteristics will be discussed in more detail.

Technology	Network Topology	Operating Frequency	Business model
RIIM	Mesh	868 / 915 MHz	Private networks
RIIOT	Star	868 / 915 MHz	Private networks
LoRaWAN	Star	868 / 915 MHz	Network as a service or private network
Mioty	Star	868 / 915 MHz	Private networks (as of now)
Wize	Star	169 MHz	Network as a service or private network
Wireless MBus	Star	433 / 868 MHz	Private networks
Sigfox	Star	868 / 915 MHz	Network as a service
NB-IOT	Star	Different cellular bands.	Network as a service
ZigBee	Mesh	2.4 GHz	Private networks
BLE mesh	Mesh	2.4 GHz	Private networks
Wirepas	Mesh	2.4 GHz	Network as a service
Wi-SUN	Mesh	868 / 915 MHz	Network as a service

Table 1 - Overview of wireless technologies

Network topology

The first point to notice is that there exists mesh and star network topologies. In star topology the concept is one gateway, and all nodes communicate directly to a gateway. While in mesh, nodes can forward messages on behalf of others and a radio packet can thus hop from one node via the others to reach its destination.



Comparing a mesh solution with a star solution is difficult as they are different concepts and cannot be compared one-to-one. A mesh router node does not exist in a star network and a promotor of a mesh solution will talk about the extra range achieved, and how multiple paths give extra reliability, while the promotor of the star network will claim that the mesh router adds latency. Both statements are correct, but there is no way to say that one is better than the other.

A star network is easier to understand due to simplicity. However, every node must have a direct radio link to the gateway. Due to this fact, a star network that wants to cover a large area must trade off something to get the increased range. Normally this is done by reducing data throughput (lower data rate) and thereby increase current consumption. Technologies that have made this tradeoff are normally referred to as LPWAN (Low Power Wide Area Network), and technologies that fall in that category are LoRaWAN, Mioty, Wize, Sigfox and NB-IoT.

The low data rate and high current consumption have some additional drawbacks, specifically in the unlicensed band. A given data packet has a long time-on-air and also a potential acknowledgement from the gateway will occupy the radio channel for a long time. And during this time when the gateway transmits it is not capable of simultaneously receiving packets. Due to the limitation being deaf-during-transmission, many nodes connected to one gateway combined with acknowledgment on each packet does not work well. As a result, most of these LPWANs disable acknowledgement messages by default.

With no acknowledgement the sensor does not know if data has been received or not by the gateway. This gives poor Quality of Service (QoS) and could be business critical. There is no way to do re-transmission of critical data if there is no feedback that the data has been received or not. Each use case must evaluate its own requirement for QoS.

Other star networks are more focused on longer battery lifetime and high capacity. These star networks do not accomplish the same range as LPWAN, however they are much more kind to battery lifetime and they also offer higher data throughput. Example of such medium range start networks are Wireless M-Bus at 433 or 868 MHz and RIIoT (IEEE 802.15.g).

2.4 GHz vs. sub 1 GHz.

From Table 1 it is also a clear difference between 2.4 GHz solutions and sub 1 GHz solutions. These are different license-free bands used around the world. Sub 1 GHz is a term to include wireless solutions running on different local regulated bands, typically at 433 MHz, 865-870 MHz and 902-928 MHz.

In consumer-oriented applications such as home automation and personal fitness, 2.4 GHz has proven a huge success, while in Neighbor Area Networks (NAN), such as smart metering, have historically used mainly sub 1 GHz.

The low of physics tells us that the path loss increases with increasing frequency. The formula for free space path loss is $Path\ loss = DtDr\left(\frac{\lambda}{4\pi d}\right)^2$ and this show that double the frequency equals half the range. The indoor range situation is a bit more complex. The lower the frequency the better it penetrates walls, drywall/concrete etc, while the higher frequency is better reflected. Therefore 2.4 GHz can be good for moving along a corridor, while sub 1 GHz can penetrate through walls and into closed rooms and between floors. But the path loss when moving in open areas within buildings is still lower for lower frequencies and combined with better penetration of wall the sub 1 GHz solution will give much better coverage in buildings.

The 2.4 GHz-band is a wider band, and it offers higher data throughput in terms of data rate. The data rate of 2.4 GHz transceivers is typically 128 kb/s - 1 Mb/s over the air. The higher data rate and higher RF frequency both contribute to shorter range. A rule of thumb is that increasing data rate by a factor of 4, halves the range, and reducing the data rate by a factor of 4 double the open area range.

In addition, there is also the effect of interference by other wireless solutions in the same environment. Due to the success of 2.4 GHz in the consumer space there are always plenty of Wi-Fi, Bluetooth and other 2.4 GHz wireless solutions nearby and they contribute to a very busy frequency band. This will again cause packet loss and retransmission of data. This is a key point to consider and plan for in indoor wireless solutions.

Using 2.4 GHz mesh includes advantages such as one common worldwide solution, and it allow smaller antennas. For consumer and home automation applications this is clearly the preferred solution. But other applications requiring longer range (NAN and LPWAN) like metering are focused mainly on sub-1 GHz.

Figure 2. shows how the operating frequency and network topology splits the different wireless technologies in main groups.

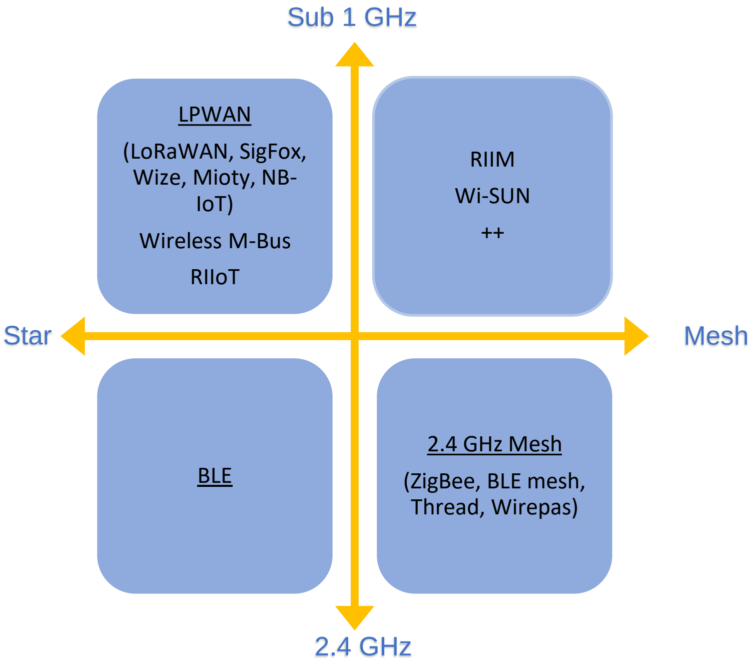


Figure 2 Main differences in wireless connectivity

Public or private networks

An important element of IoT connectivity is if this is managed by a connectivity service provider (Public network by cellular operator / SigFox / some LoRaWAN operator), or it is managed by the system owner (private network). Publicly available networks can make it easier to deploy the system, but there is of course a fee for this service that must be calculated in the total cost of ownership. A private network may provide more security and longevity of the network. However, these considerations are more strategic, economical and risk based and not very technical and are not covered in further details here.

Range and coverage

One parameter that continues to come up in the evaluation of wireless connectivity is the communication range and coverage. And often the marketing team of the different providers outbid each other on having the highest number of meters.

LPWANs achieve long range through low data rate and thereby high receiver sensitivity, while mesh networks get its range through multi-hop. Due to this conceptual difference range is not something that can be compared directly. But each use case must be investigated separately.

It is not possible to discuss range without discussing network physical layout. Where are nodes located, what are the distances between nodes, can the gateway (antenna) be raised to a position giving line of sight to all nodes?

Mesh has an advantage when there is a certain density of nodes, e.g. sensors in a building, street lighting, etc. If your solution has very few nodes (<5) there are not much benefit of the mesh.

The density required for a mesh to be efficient will of course depend on the environment where the nodes are operating.

[1]Type of network	Open field [meter]	Office building [meter][2]
"2.4 GHz Mesh (e.g. ZigBee)	150	10
Sub 1 GHz Mesh	500	25
Sub 1 GHz Mesh high power (500 mW)	2500	50
LPWAN	10000	85

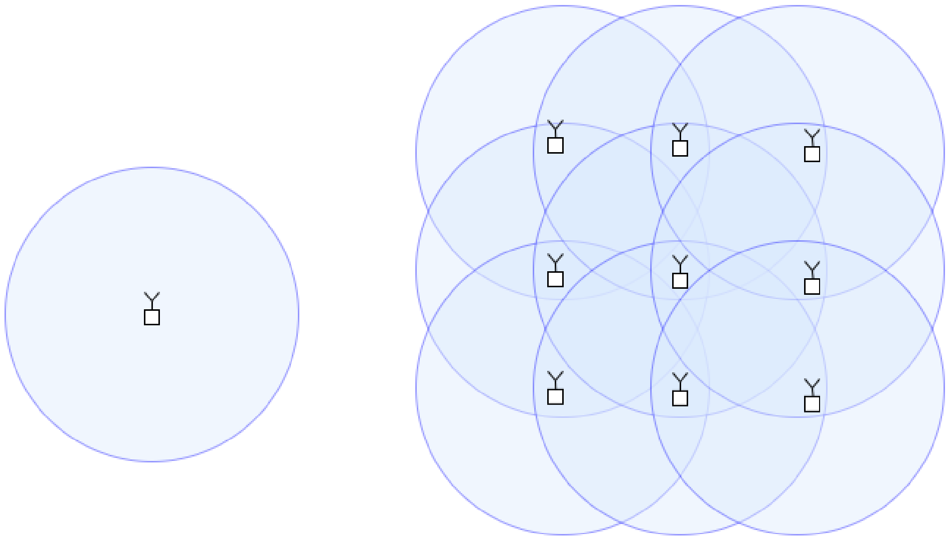


Figure 3. Coverage of one gateway (left) and coverage of a mesh with 9 mesh routers (right)

Mesh also brings a different aspect of range into the equation. In a LPWAN with one gateway, and intended to cover a 2 km radius, there will be some areas which end up in radio blind spot. This means that environment is such that the path loss to a particular area (due to obstacles) is too high and no connection is possible, while other

[1] This is not a max range to receive a packet, but an estimate on a range with robust link with margin and low packet loss.

[2] Range is based in open field the path loss increases by 6 dB for doubling of range, while indoor path loss increases by 15 dB per doubling of range. But also, the fact that 2.4 GHz has more loss penetrating walls is added.

areas further away have a good connection. With mesh, one node typically has several other nodes nearby that can operate as forwarder. If an object interferes with communication in one direction, it is possible to communication with a node in a different direction. A good example of radio shadow is the coverage map for LoRa in Figure 4.

A mesh solution cannot normally cover the same area in one hop, but through collaboration between nodes, fewer red areas would been seen. Thus, a mesh can ensure less shadows than a single LPWAN gateway.

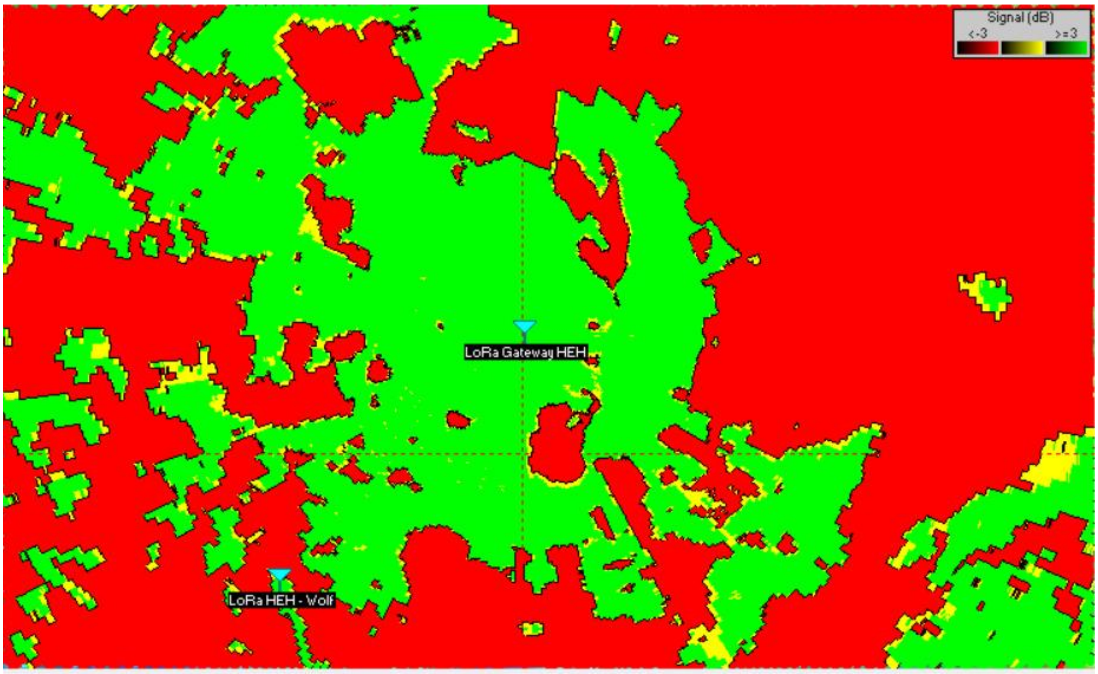


Figure 4. Coverage from a LoRa Gateway (*Source and copyright: https://www.thethingsnetwork.org/forum/t/can-i-improve-my-lora-coverage-simulation-using-radio-mobile/32008)*

QoS vs battery consumptions

As mentioned, one of the limiting elements in an LPWAN is the downlink. Low downlink capability limits the option for acknowledging all packets and the control traffic must be reduced. The limited downlink is caused by two factors:

1) When the Gateway is transmitting it cannot receive, and therefor other simultaneous incoming packets will be lost.
2) In Europe, the gateway must comply to RED directive which limits how much the gateway may transmit (transmission duty-cycle).

Due to these factors acknowledgement of each packet is highly discouraged and sometimes disabled in gateway. This means that a sensor does not know if its reading has been received or not. For business-critical data this can be a problem as the insight is not that good and any action taken might be non-optimal.

Mesh solution with higher data rates does in general include acknowledgement and retransmission on each hop. Thus, the QoS in terms of packet delivery rate is normally much higher. However, there is also a drawback here. If a module has the option to repeat a message an unpredictable number of times, then the current consumption and hence battery lifetime will be harder to calculate. This also means that a sensor A, 50 meters from neighbor node might have longer battery lifetime than a sensor B, located 200 meters from its neighbor and hence use more retransmissions.

LPWANs try to cope with this lack in QoS in different ways. Sigfox gives an option for users to repeat the same message 3 times, always. LoRa has a weak Forward Error Correction (FEC) that helps somewhat. Mioty has the most advanced feature which employ a strong FEC together with splitting the telegram in many small pieces spread in time and over different channels. This gives Mioty the advantage in reliability, but all the LPWANs try to improve reliability by sending more data and thus sacrificing battery lifetime.

Downlink control data

As previously mentioned, LPWAN solutions are made first and foremost to gather sensor data (uplink). In a use case which includes critical and frequent downlink data, LPWANs are often limited. One reason is that downlink messages often must follow just after an uplink message to make sure the node is listening. This is described as polling. Polling is a challenge since more energy is needed and all nodes cannot poll every 10 seconds as it would lead to congestion and packet loss. So, polling in LPWANs is typically done every 15 minutes to every one hour. This leads to a long latency for control data in an LPWAN.

In RIIM, which is a time synchronized mesh, nodes have dedicated time slots for talking together. This means that the latency per hop is the range of seconds (typically 1-3 seconds) and thus a total latency can be calculated based on number of hops.

For a mesh without time synchronization, downlink data must be polled as with an LPWAN, but since the data rate is much higher the network handles such polling better.

Battery lifetime

The data rate has a strong impact on battery lifetime. As shown in Table 2., actual battery usage is a factor of protocol, overhead, maintenance traffic and much more. But here we use a more simplified model by looking at TX current consumption of known chips/modules and the energy it takes to send 30 bytes on RF each 1 minute. The table shows that a 1000 mAh battery must be replaced every 1-2 months with LPWANs, but for protocols with higher data rate the battery lasts for years.

LPWANs can also last for 10 years but this requires much less frequent transmissions. Typical every hour or more seldom is used in LPWAN's, and this must be compared to the requirements in each use case.

Technology	Bit rate [kb/s]	Time to send 30 bytes on RF [ms]	TX current [mA]	Energy per packet Inmilliamp* millisecond [mAmS]	Battery lifetime 1000 mAh battery and transmission each 1 minute [days]
RIIM	50	4,8	26	125	20032
RIIoT (50 kb/s)	50	4,8	26	125	20032
LoRaWAN	0.3	805	47	37852	66
Sigfox (EU)	0.1	2400	59	141600	18
Mioty	2.38	101	26	2600	962
Wize / 169 MHz Wireless M-Bus	2.4	100	400	40000	62
868 MHz Wireless M-Bus	100	2.4	26	62	40064
BLE	1000	0.2	16	3,8	651042
BLE long range	125	1.9	16	31	81380

Table 2. Data rate vs. energy per to send 30 RF-bytes

RIIM vs. LoRaWAN

Solution providers considering the different technologies normally simplify the evaluation of wireless connectivity and ask for a comparison between RIIM (mesh) and LoRaWAN. Without understanding the specific use case, this is impossible to do as they are fundamentally different solutions. Both technologies can work excellent, and the use case will dictate which solution is the best. Setting up a comparison table makes no sense for these technologies, but the different use cases can be discussed for the two radio technologies.

LoRaWAN is a LPWAN technology focusing on long range. The comparison done in this chapter can typically also apply to other LPWANs (such as Sigfox, Mioty, Wize etc.). As a general statement, all features that give a benefit also provide some drawback, and the term “there are no such thing as free lunch” has never been more fitting.

LoRaWAN has its primary benefit in the range covered by one gateway, which can be greater than for RIIM. But this also can give the users challenges. Each packet takes longer time to send and this is negative for battery lifetime and for scalability. As a rule of thumb, a packet that reaches double the range (6 dB more) is typically sent with 4x less data rate and it takes 4 times the time on air to send it. This gives 4 times more current consumption and ¼ of the battery lifetime.

Also, LoRaWAN has limited downlink traffic capability, and this has a negative impact on QoS and the large latency for control data will also be a challenge. RIIM as a mesh with higher RF data rates has acknowledgement and retransmission on each link, and in addition an option of end-to-end acknowledgement and retransmissions. This leads to better reliability and the QoS will then be higher.

RIIM gets it range or coverage from the cooperation of nodes in the mesh. So, a cornerstone for RIIM is to have sufficient number of devices in an area to make a suitable mesh. This is referred to as node density, as discussed above.

RIIM	LoRaWAN
QoS (increased reliability)	Longest range
Downlink latency is short Downlink traffic does not have huge negative impact on uplink packets	Biggest ecosystem
Mesh + mesh router gives coverage. (less blind spots) + mesh routers enable end-nodes with longest battery lifetime	Star + mesh routers are avoided which can give lower system cost

Table 3. Strengths for each technology

RIIM (868 / 915 MHz Mesh) vs. Wirepas (2.4 GHz Mesh)

RIIM and Wirepas are both mesh networks, however there are some key differentiators. The two most notable is the operating frequency and business model.

Wirepas is predominantly on 2.4 GHz, with its advantage and drawbacks covered above (most notably shorter range and more subject to interference, however available band world-wide). Due to this Wirepas is suitable for denser networks and higher data throughput. But in terms of network coverage the sub 1 GHz approach of RIIM gives a clear advantage. Both in outdoor environment with large distance between nodes and indoor with much Wi-Fi / Bluetooth interference, the range between nodes is expected to be four times larger with RIIM than with a 2.4 GHz mesh. A good understanding of the operating environment, including placement of nodes, is important to choose the most appropriate wireless solution.

Wirepas offers a license model for its mesh SW as a preferred business model while RIIM from Radiocrafts is offered as a complete RF-module with embedded FW (no license or subscription fee).

Both Wirepas and RIIM offers battery operated routers. This is not available in the standard mesh solution such as Thread, Zigbee, BLE-mesh or Wi-SUN.

RIIM vs. other sub 1 GHz mesh - Uniqueness of RIIM

As outlined in this White Paper, there are some advantages sub 1 GHz mesh has compared to other technologies. Due to this there are many other sub 1 GHz mesh technologies available. Some are listed below (alphabetical order):

- Digimesh
- IQ mesh
- Neomesh
- RFtide
- Thingsquare
- TinyMesh (offered by Radiocrafts together with its partner TinyMesh)
- Wi-SUN Alliance offer the Wi-SUN standard

Within the wireless subcategory of sub 1 GHz mesh there are still some features that are unique for RIIM.

- RIIM offers a time synchronous network with the option of battery-operated mesh routers.
- RIIM offers adaptive frequency agility which allows higher duty-cycle in Europe.
- RIIM offers high power modules with up to 500mW output power, giving unprecedented range in a mesh.
- RIIM is based on open standards and not tied to any backend solution.
- RIIM is IP based (6LoWPAN).

When using IP based networks all security mechanisms can be utilized end-to-end. That means protocols like DTLS/TLS can be used between end nodes and endpoint in the cloud service. In this case the gateway does not know the encryption keys used, and any hacking of the gateway will not threaten the confidentially of data exchanged end-to-end.

Summary

This White Paper has illustrated how different use cases require different wireless solutions. Mesh solutions give the advantages of low latency downlink traffic, high quality of service and long battery lifetime on end nodes. Sub 1 GHz give better range than 2.4 GHz.

But to evaluate which technology to use, every system owner must ask a series of critical questions about the use case:

- How does the network look like, placement of nodes, distances etc.?
- Do the use case require somebody else to manage connectivity as a service, or does the user want to own and manage his own private network.
- Are some nodes battery operated? What is acceptable battery size, and required battery lifetime?
- How does the data traffic pattern look like? How many nodes send data? To where? How often? Does the gateway send downlink data to the nodes?
- What is the quality-of-service requirement? How much data can the use case accept to lose?
- What is the latency requirement?
- In which country/region will the equipment be operating?

Based on the answers each use case gives, it should be possible to get some guidance into which direction the wireless system design must go.

This White Paper tries to cover some of these considerations. To get more help, please contact us by using the contact form on www.radiocrafts.com.

This white paper is intentionally not covering other aspects of choosing the best solution such as quality, longlivity, support, tools, cost etc.

Document Revision History

Document Revision	Changes
1.0	First release

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