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AN038: Performance of RIIM™ in Street Lighting Networks: Simulations Results

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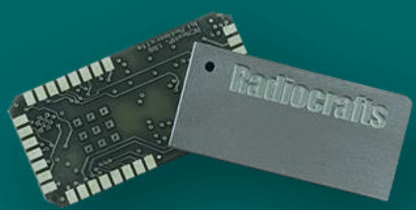

Performance of RIIM™ in Street Lighting Networks: Simulations Results

By Omar Khalil & Frode Eskelund

Introduction

This application note demonstrates how Radiocrafts' Industrial IP Mesh (RIIM™) is perfectly suited for street lighting applications. At the beginning of this application note, a short introduction about street lighting and an in-depth examination of one of the possible application scenarios is presented. Then, after a quick re-cap about RIIM™ , simulation results are presented which clarify how RIIM™ behaves in the use-case under examination and how such a network is expected to perform.

Importance of using Smart Street Lighting Solutions

According to the UN, streets lighting accounts for around 19% of global electricity usage. On a city level, street lighting is responsible for around 40% of a city's electricity expenditure. Such high energy utilization is not just expensive, it is also very environmentally unfriendly, especially with growing concerns over climate change due to CO2 emissions.

Smart street lighting systems offer a variety of benefits and flexibility features to operators. For example, not all streets require to be fully illuminated at night, as they might have very little traffic. By using LED lamps, customized lighting intensity levels are possible. LED lamps also increase nighttime visibility, which reduces car accidents and light spillage into residential apartments. In addition to these benefits, novel street lighting solutions also offer the feature of having a centralized control and management system for the network,

Challenges of using Smart Street Lighting Solutions

Until not so long ago, implementing large-scale smart street lighting networks was not a feasible idea as the technologies involved were not mature enough to encourage investors to invest in this field. Such aspects include radio technologies, management-center technologies, and the lighting technology itself.

Currently, many advancements have been made in regard to radio technologies which offer low cost hardware and more option in license-free frequency bands.

Moreover, as database systems and local servers become more abundant and secure, it became relatively easier and cheaper to manage large-scale network remotely through an online server such as a cloud service for example. These kinds of technologies not only act as a database, they also offer a wide variety of data-visualization tools, which makes such solutions more attractive.

Lastly, technological advancements also encompass the lighting technology, where huge leaps have been made over the last few decades. The most widely used light bulbs in the past were the HID (high intensity discharge) mercury vapor and the sodium halide bulbs. The switch to LED bulbs offers a 52% reduction in energy usage over HID and a 26% reduction over sodium halide bulbs. In addition to providing some new features such as reduced glare and better color rendering. Although LED lamps have a higher initial cost, the above-mentioned features added to the fact that LED lamps have much longer lifetimes makes them a very feasible solution for large scale street lighting systems.

Possible Connectivity Options

When considering wireless connectivity options to enable street lighting systems, a customer can be faced with the challenge of choosing the right radio protocol for his network. According to the study "Design, Deployment and Evolution of Heterogeneous Smart Public Lighting Systems" published, at the MDPI journal for applied sciences, by University of Bologna's Gianni Pasolini et.al, two main categories of LPWANs (Low Power Wide Area Networks) exist, cellular and non-cellular proprietary networks.

Cellular LPWANs

The most commonly used cellular LPWANs are NB-IoT (Narrowband IoT) and LTE CAT-M1 (LTE Category M1). Both these technologies are based upon the already existing LTE cellular technology. According to the above-mentioned study, using cellular technologies to enable street lighting networks does in fact offer some advantages, as the long communication range and the utilization of the already abundant LTE networks. However, there are serious disadvantages to these networks in the scope of street lighting.

Firstly, LTE networks are not used for free, a subscription fee must be paid to the network operator to give the customer the right to use their network infrastructure. Same as we all do with our cellular phones, but since street lighting networks usually encompass thousands of devices, this will reduce the attractiveness of this investment for potential investors. Second, one of the main drawbacks of mobile networks in general is that they cannot achieve 100% availability. This can be problematic as it means that in a street lighting network, there will always be some light poles without connection, which is very inconvenient. Finally, the expected lifetime of street lighting networks is between 10-15 years. In terms of telecommunication technology, this is a very long time and drastic advancements can be achieved in these years which might entail that network operators might rollout their existing technologies and replace them with the latest technology. Such disadvantages might make cellular technologies not the best enabler for street lighting networks.

Star Radio Topology

As for non-cellular LPWANs, two main network topologies exist, star networks and mesh networks. Star networks most commonly used in street lighting applications are LoRa and Sigfox networks. Both technologies are similar in architecture, in the fact that they offer very low data rates, and that they are optimized for uplink traffic. This means that they are well suited for sending sensor data up to a gateway but have limitations in the downlink which makes them a poor fit for street lighting. Both technologies have a major drawback in common, which is communications range. Although the range is good, it is limited to the fact that all light poles must have direct access to the gateway. And RF is tricky in that one light pole position might be in a radio coverage blind spot or close to a cellular based station giving less range due to noise. Moreover, star networks are not dynamic in a sense that if, for example, a new building is built in between the gateway and one of the nodes, the only solution for that would be to change the position of either the gateway or the node, which might be expensive, problematic or even impossible. Due to the limitations in star LPWAN, they are not a common choice for street light control systems as of today.

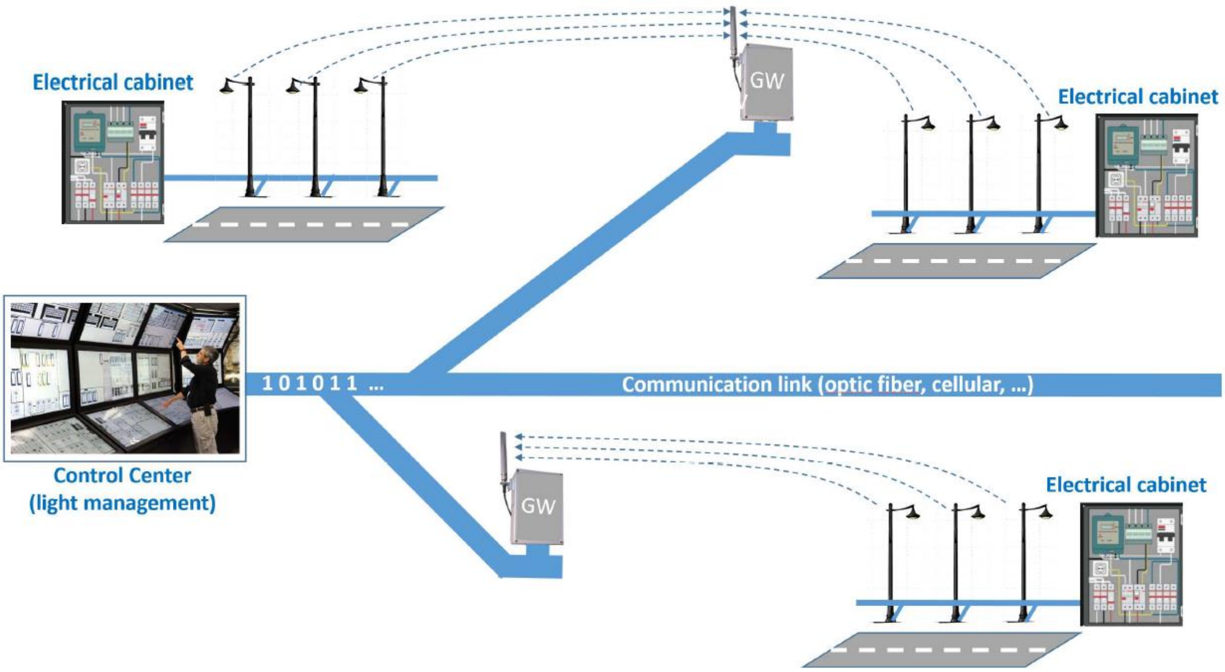

Figure 1. Picture from the above-mentioned study. License: https://creativecommons.org/licenses/by/4.0/ with no changes made. It shows a possible layout of star networks in street lighting applications.

Mesh Topology

On the other hand, mesh networks offer a good solution to tackle the above-mentioned challenges. Mesh networks offer a dynamic and versatile network architecture which serve to mitigate many of the shortcoming of star and cellular architectures, in regard to street lighting applications. The main two enablers for short range mesh networks are the standards IEEE 802.11 and IEEE 802.15.4.

Mesh topologies are easy to implement in street lighting scenarios as, usually, there is Los (Line of Sight) or a at least limited range between each lamp pole and the next. Figure 2 depicts an example layout of a mesh network used in a street lighting application. A key feature of the mesh is that each node can communicate to at least 2 or 3 light poles in one direction. This is important in order to create redundancy in the network and avoid single points of failure in the network. A radio module (router) is equipped on every light pole, to allow communications with neighboring poles. At a central location, a root node is set up, whose role is forming the mesh network, maintain it, and route data to and from light poles and the management system.

Data is routed through the mesh structure, up and down the network, by hopping from one router to the other. As lamps are deployed in streets, the resulting topology is composed by linear segments and some branches, which form a tree-like structure, with its root at the root node. More information about the resulting topology will be shown in the “Simulation Results” section below.

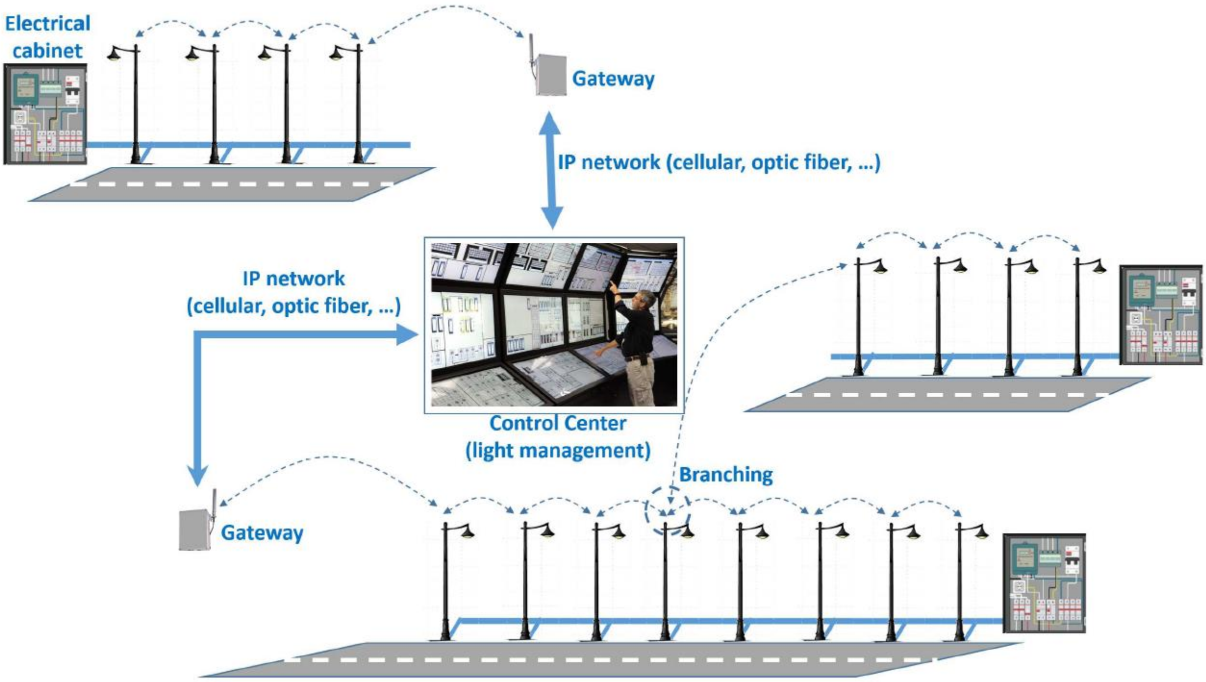

Figure 2. Picture from the above-mentioned study. License: https://creativecommons.org/licenses/by/4.0/ with no changes made. It shows a possible layout of mesh networks in street lighting applications.

Radiocrafts' Industrial IP Mesh – RIIM™

RIIM™ is an IP mesh network developed specifically for industrial IoT (IIoT) access networks. RIIM™ is designed for networks which require, industrial grade reliability, long range, low power, and where simple-network setup is an advantage. This makes RIIM™ ideal for a variety of applications, such as, smart cities and buildings, energy management systems, light and climate control, and much more.

RIIM™ is a self-forming and self-healing network. Which means the network automatically sets-up and can also configure a new route when current route has a poor connection.

End-to-end IP connectivity gives RIIM™ a number of advantages, such as, scalability, IPv6 addressing, end-to-end security and ease of use as no protocol converter is needed in the communication path. RIIM™ is programmed with a novel solution to allow designers to interface the sensor/actuator, called ICI (Intelligent C-Programmable interface). ICI applications are written in high-level C language, using a powerful API available in the SDK. The API eliminates the need for developers to understand all the underlying architecture and resources in the module. An ICI application configures, the radio network, the module's hardware, and defines read and write sensor functionalities. The main driver behind ICI is Radiocrafts' commitment to making connectivity easy for developers.

The building block in a RIIM™ network is the RC1882-IPM module. This module is versatile and can be used for 3 different roles: as a border router, a mesh router node, and as a leaf-node.

Some of the main features of RIIM™ include:

- Operates in the 868 MHz or 915 MHz frequency band.
- Link layer security
- Multicast
- Supports both CoAP and UDP protocols
- Supports up to a thousand nodes organised in a mesh network-topology.
- Line of Sight (LoS) range of up to 1 km in normal low power module and 5 km in the high-power module
- 2-way symmetrical communication with OTA (Over the air) updates.
- Very short network delays for near real time applications.
- Cloud application compatible via IP packets to each mesh router.

In addition, Radiocrafts s implementing Time Synchronized/Slotted Channels (TSCH) which will be available in by mid-2020. TSCH is specified in the IEEE 802.15.4-2015 standard. In TSCH, the nodes form a globally synchronized network. The network broadcasts beacons which contain timing information to let other nodes synchronize and join. Child nodes continuously correct their relative clock drift to their parent through timing information in acknowledgement packets. The airtime is divided into a continuously repeated set of slots and a node is only allowed to communicate during its assigned slot(s). Within a slot there is time to transmit and receive an acknowledgement from the destination. Communication happen on different channels for each repetition of the same slot, and therefore if a packet is lost due to RF interference, its retransmission is more likely to succeed in the next slot repetition since it will be sent on a different channel. TSCH is suited for low power networks in demanding environments, since the nodes can sleep most of the time and only wake up during their assigned slots, and RF interference is mitigated through channel hopping.

Benefits of TSCH include:

- Higher resilience to RF interference
- Higher network reliability
- Enabling battery-operated Mesh Routers
- Enabling frequency hopping, which is a requirement for FCC certification to enter the US market

Use case

Streetlighting networks designs can vary a lot, depending on the network design and application requirements. Various parameters can be tweaked to produce different network behaviors. Such parameters include, number of nodes, network's physical and logical architectures, desired latency, frequency of broadcast messages, and much more. In more detail, a user can choose to limit the communication range in which a certain node can hear other nodes

In this application note, we will examine a specific use-case which fulfills various application scenarios requested by some of Radiocrafts' customers.

The use case under examination entails:

- 100 nodes (1 Border Router and 100 Mesh Routers)
- 4 km street (straight line)
- 40m in average between each light pole
- Broadcast messages every 4 hours

- Assumed maximum range between a node can communicate at is 210 m
  (With a good antenna design and LoS between light poles this is expected to be longer than this)
- Sensor reading from each light pole every 2 hours

Simulation Results

Based on the use case described, some key performance indicators (KPIs) need to be found. E.g. What is the latency for a broadcast message to light up all lamps to 100%. The behavior of the network is not 100 % deterministic as there will be packet loss due to packet collision and noise. While RF experience and theoretical models sometimes offer a good insight to clarify certain network KPIs, some might remain a little vague and hard to predict as they depend on many variables. For such questions, Radiocrafts has started using a simulation software which predicts, to a very high degree of accuracy and detail, the performance of RIIM™ .

Network Formation Time

The above-mentioned parameters were fed to our simulation software to give us a solid idea about how this network would act in real-life requirements. The results show a number of interesting outcomes. Firstly, a network with 100 nodes, with all the network formation and rerouting packets being sent, took only 6 minutes to be formed, of course, automatically, without any configuration or setting needed from the user.

Network Logical Topology

Figure 3 below shows the logical topology the network has formed itself into. It can be observed that the furthest and most remote node in this network was found to be 20 hops away from the Border Router. Figure 3 also shows that in some cases, the best route for a node was to connect to on the string in a straight line manner, and in other situations it was best for a node to form a little mesh at some points with only of the nodes of that little mesh laying on the main string.

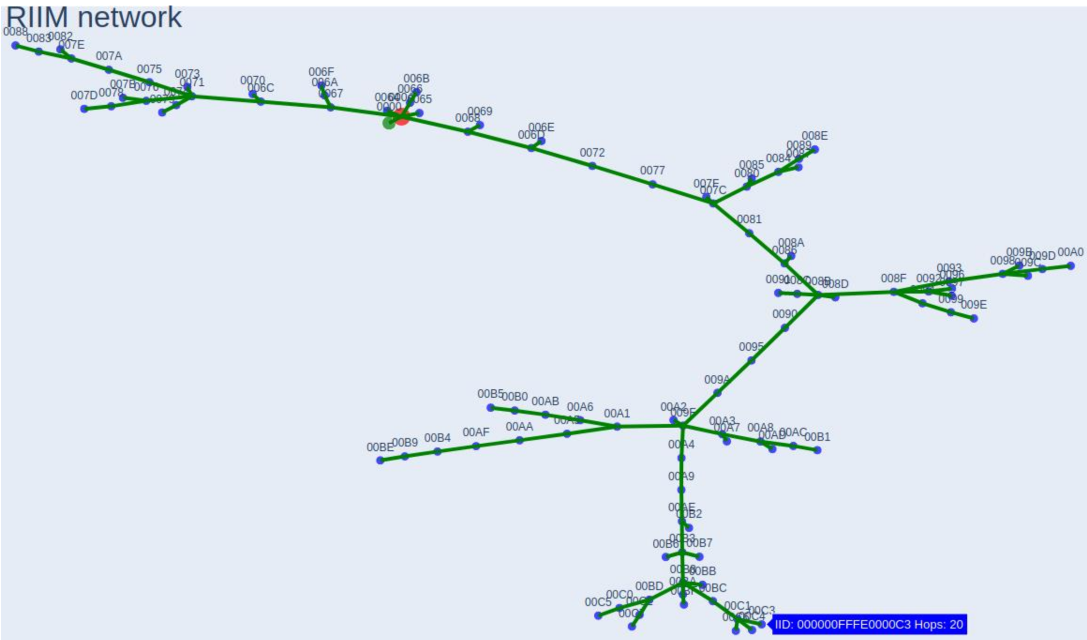

Figure 3. Picture from Radiocrafts' simulation software. It shows the logical network topology and the interconnections between the nodes.

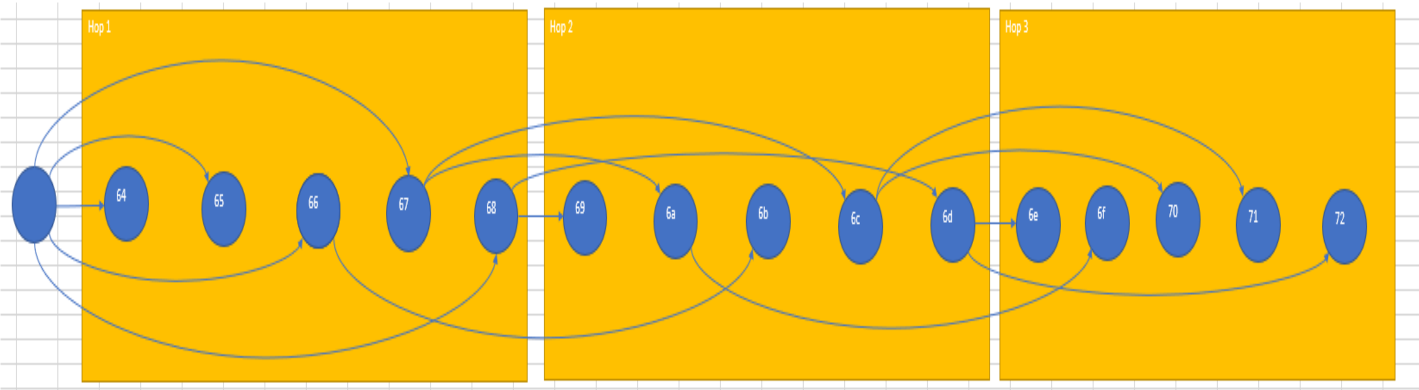

Figure 4. This figure shows the physical network topology. It shows the sequence of hops for some example nodes.

Packets Frequency

During the time of the simulation, a total of 514749 packets were sent on air in 86382 seconds. Which is equivalent to 24 hours. This equals about 6 packets/second being sent in the network. Out of these 514749 packets, 251000 are MAC ACKs (Acknowledgments).

On a single node level, a randomly picked node, in this case it was node number 75 which is 3000m away from the Border Router, was found to have sent 1731 packets (not counting ACKs) in the same amount of time. This equals 0.02 packets / second = 50 seconds between packets
Border router sends 5859 (counting ACKs) in the same times period. This is 0.07 packets per second = 15 seconds between packets.

Multicast Latency

Multicast is a feature in the newly released RIIM™ SDK which enables the Border Router to broadcast messages, and the child nodes repeat this message to ensure that even the most remote node still gets it. Multicast messages are of utmost importance in street lighting applications as they are the means by which the core management system will send "turn lights on/off messages".

In this simulation scenario which was, as mentioned earlier, run over a period of 24 hours, 5 multicast messages were sent from the Border Router to the nodes. With the following results:

Multicast latency (msg: "MCast 100"): 32496
Multicast latency (msg: "MCast 101"): 31186
Multicast latency (msg: "MCast 102"): 28742
Multicast latency (msg: "MCast 103"): 33996
Multicast latency (msg: "MCast 104"): 30789

The average time observed for the 5 multicast messages was 31.4 seconds.

Unicast Latency

Unicast messaging refers to messages sent from a child node to the Border Router. Such messages can be very important as it might be a lamp trying to inform the core management system of a certain failure it has. Therefore, unicast latency is a crucial parameter to consider in street lighting networks.

In this simulation scenario, unicast messages were sent every 2 hours, and the latency it took the messages t be sent from the child node to the Border Router was observed. This was observed for all the 100 nodes. Figure 4 below shows the minimum time, maximum time, and average time taken for unicast messages to be sent from each node. Differences in latency, of course, are due to different proximities between nodes and the Border Router.

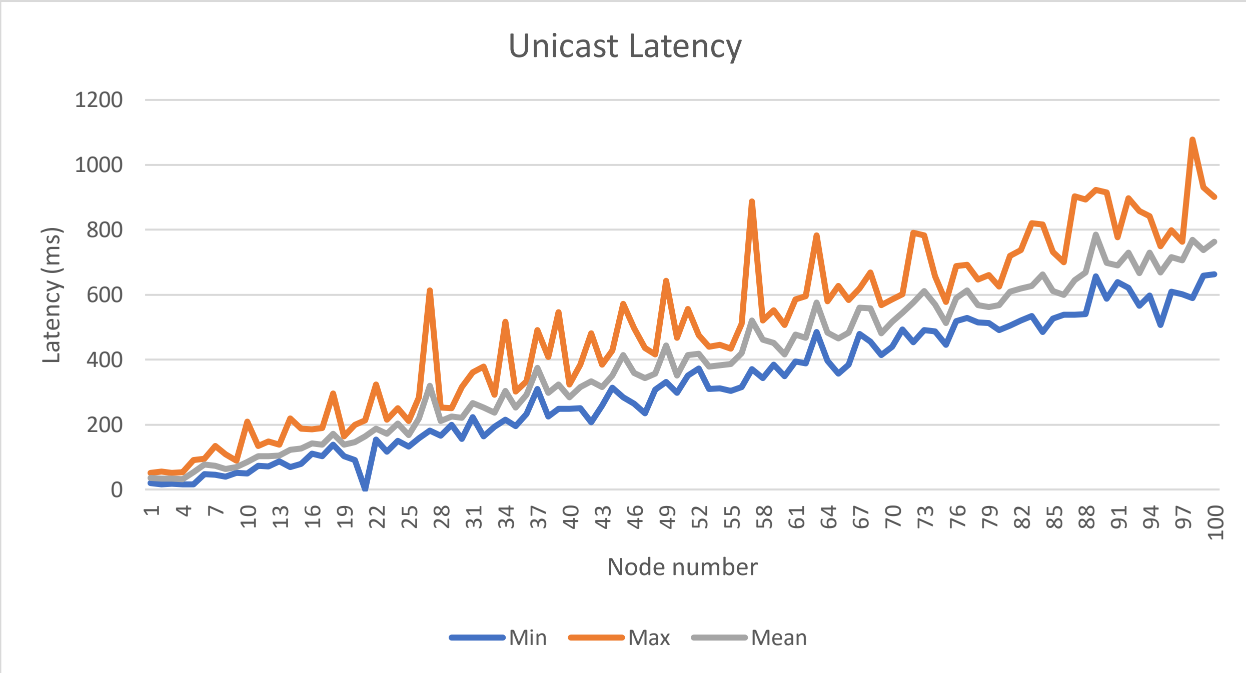

Figure 5. Different statistical values of latencies in unicast messages.

It is worth mentioning that in such a network, the maximum average latency recorded for a message to reach the Border Router, from a distant child node, was around 570ms.

Summary

Intelligent street lighting networks are important corner stones in new smart cities. They offer a wide variety of benefits for everyone. For investors, smart street lighting networks are cheaper in terms of lamps used and power consumption, which encourages investors in this field. For management systems, they offer automatic control in addition to customized dimming plans. For the environment, since they use less energy, they are more environmentally friendly. Lastly, for people passing in the streets, LED lights offer better visibility which means more safety on roads.

A number of RF solutions exist, to enable street lighting applications. Cellular solutions such as NB-IoT or LTE-CAT-M1 are the LTE variants created to support IoT applications. However, they suffer from the typical drawbacks of cellular networks, such as, requiring subscription fees, practical impossibility to reach 100% availability, in addition to being a technology with a -relatively- very fast pace of technological advancements, which might lead to huge changes in the network every time a new technology is available.

Star topology networks also suffer some limitations, most importantly, being very inflexible networks, which might not very well fit street lighting networks. For example, new buildings are expected to be built all the time on any street. This might cause a signal blockage for some light poles. If the network used is a star topology network, then the gateway has to be moved every time you lose LoS, which is very impractical.

On the other hand, mesh networks mitigate all the above-mentioned drawbacks, putting them in first place as the best enabler for smart street lighting solutions. RIIM™ is Radiocrafts' new IP mesh solution. It offers a variety of options which makes it a very attractive solution in enabling smart street lighting applications. RIIM™'s LoS range is a few hundred meters, which makes it certain that not only the next light pole will be withing range. RIIM™ also offers the right Transport Layer protocols, such as UDP, which enable important network features such as Multicast. In addition to supporting cloud connection and high reliability using the CoAP protocol.

To correctly predict how RIIM™ would perform in an example street lighting network, RIIM™ was tested through a simulation software under a set of pre-defined network specifications. The simulation results presented above indicate RIIM™'s short network formation time, high reliability as no packets were lost in the simulation period which lasted for 24 hours, in addition to the quick response time even to the most remote node in the network with 20 hops between it and the Border Router.

Document Revision History

Document Revision	Changes
1.0	First release

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