Powerful LPWAN Solutions for IoT

How low power wide area networks will accelerate smart city and connected business initiatives

A Technical Paper prepared for SCTE•ISBE by

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Introduction

1. Abstract

The rapid growth of IoT has dramatically expanded the number of wireless devices in the home and around us. This expansion has been remarkable considering large dependence upon short range, local area networks, and longer range, antiquated cellular networks. One of the key changes enabling the explosion of IoT solutions is the deployment of LPWAN (low power wide area network) with accessibility measured in kilometers rather than meters. Greater ranges open the flood gates to more comprehensive hybrid solutions that are driving smart cities, business, automotive, and industrial connected initiatives.

What are the use cases and value that will be enabled with LPWAN? What are the advantages over similar 5G cellular solutions being developed? Which platforms provide the most promise? How will operators position themselves as key players in this new ecosystem? Get ready to see real examples of LPWAN use cases and how operators will drive the next wave of evolution in IoT. This paper will share some approaches and examples of how LPWAN will drive value. Readers will get an overview of the technology, its applications, and some of the leading wireless solutions in this space.

Audience:

The audience for this paper is anyone planning or designing an IoT solution to serve home, business, municipality, and/or industrial purposes. This includes product executives, solution architects, and operations professionals who are interested in understanding the strategic opportunities and impacts – in addition to specific use cases and value propositions – involved with leveraging LPWAN solutions.

2. Preview

Wireless technologies have played an important role in technology advancements for decades. In fact, we are amid perhaps the greatest technology transformations ever. Many experts have tagged this transformation Industry 4.0 – as in the fourth massive shift in technology since the advent of commercial implementation of mechanization and steam/water power. What makes this shift greater than all others is the speed, reach, and predictive intelligence of new wireless technologies and accompanying applications.

Connectivity, home automation, smart buildings, energy conservation, security, health monitoring, business applications, transportation, agricultural, and industrial applications are all driving factors for wireless communications. The number of wireless protocols and technologies have grown to meet various needs across industries. These multiple wireless technologies have many different requirements and benefits in terms of bandwidth, cost, privacy, installation, and operation. The development of Internet-connected technologies particularly requires implementing solutions that harness value, savings, and improve quality of service while remaining safe from increasing security threats.

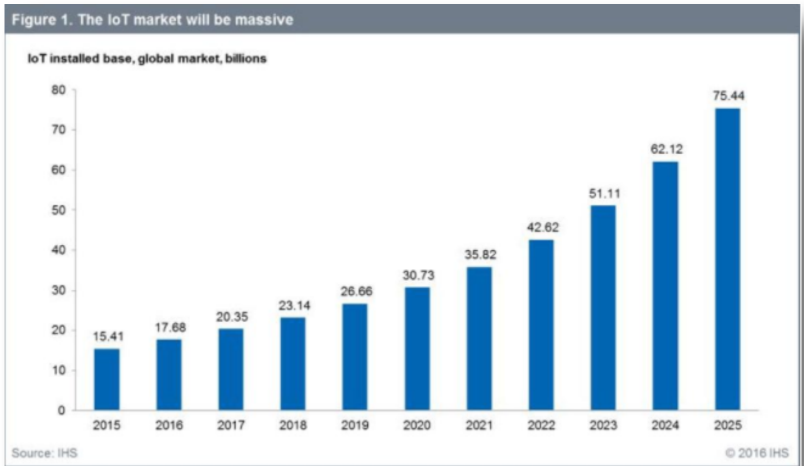

Figure 1- IoT Market Forecast from IHS

In past decades, wireless technologies have focused heavily on short-range Wi-Fi, long-range cellular, and satellite for global reach. In recent years, the acceleration of connected devices and sensors in every industry and aspect of our lives has created great demand for short- and mid-range reach. Millions (soon to be billions) of connected devices communicate simple status infrequently requiring very low bandwidths and small batteries that last for years. Current cellular protocols require significant bandwidth, large batteries, and a higher cost compared to newer LPWAN protocols specifically designed for large scale, efficient communications.

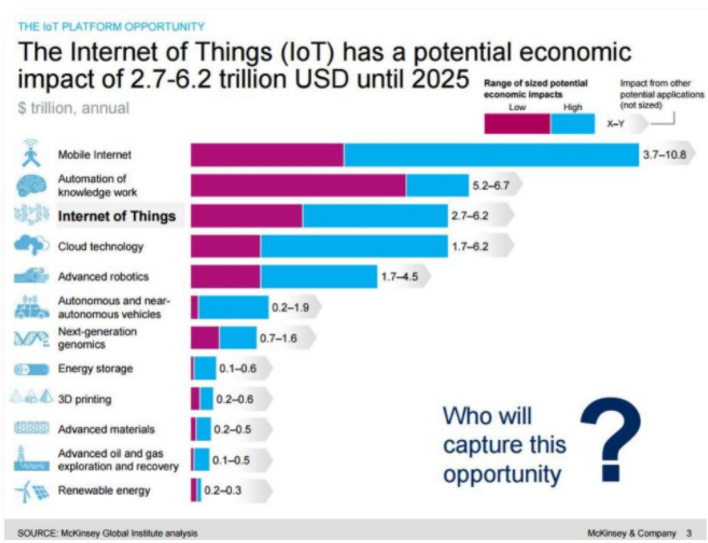

Figure 2- IoT Economic Impact Forecast from McKinsey

Several standard-based LPWAN networking protocols allow fast growth and implementation of self-healing mesh networks, which are more reliable network arrangements. Some of these networking protocols, including LoRaWAN, SigFox, Senet, The Things Network, and RPMA are based on protocols operating in the unlicensed 915Mhz range. They enable cost-effective communication between devices with low bandwidth, low power, and low installation costs.

This paper describes several commercial flavors of LPWAN solutions that have been developed to meet recent monumental changes in the industry. We will illustrate frameworks based on existing solutions for practical, readily usable and hardware-independent low power solutions. We will demonstrate compelling evidence for the real power offered by LPWAN solutions.

This paper highlights the importance of low-power networks and cites some of the important use cases that can be fulfilled. The focus is on long-range scenarios for smart cities, transportation, agriculture, and industrial. It also includes several localized short-range home and business scenarios for comparison.

Additionally, this paper includes test results and examples for professionals to consider when attempting to deploy the most effective LPWAN wireless platforms.

Wireless Technologies

1. Historic Overview

Let's begin with a short history of wireless technologies for context. What do you think was the first invention of wireless voice communication? Many would guess the telegraph, telephone, or more recently Wi-Fi. The key to the answer is "wireless voice" and very few would know that the photophone, invented in 1880, was the first *successful* wireless voice communication. On the Franklin School building in Washington, D.C. there is a plaque highlighting the achievement by Alexander Graham Bell and his associate Charles Sumner Tainter. The historic marker explained the photophone invention transmitted voice via a beam of light and was considered by Graham as his greatest achievement. The photophone paved the way for fiber optics which achieved wide-spread implementation 100 years later in the 1980s.

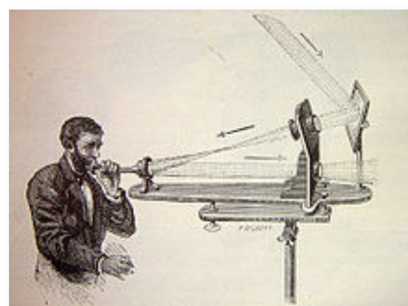

Figure 3- Historic Wireless Invention

2. Modern-day Wireless

Fast forward to modern-day wireless technologies. Wi-Fi has been the most prevalent standard for local area connectivity. Cellular has been most prevalent for wide area communications. Satellite has been most prevalent for long-distance global communications. Each of these wireless technologies began to serve very specific uses with unique requirements. With the rapid proliferation of connected devices, cloud-based services, and global mobile device usage, these wireless technologies are beginning to serve in a complimentary hybrid wireless network.

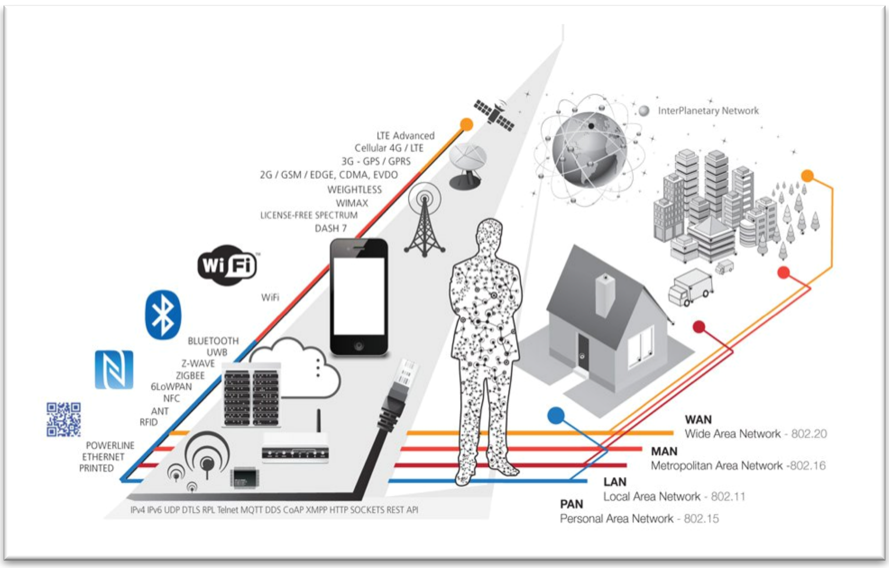

Figure 4- IoT Wireless Technologies Spectrum by Postscapes.com

3. Short-Range Wireless

For the purpose of this paper, we will characterize short-range wireless as less than 300 meters range, usually in a single premise or within shouting range. The Wi-Fi protocol is the most popular short-range consumer wireless solution due, in large part, to the standard being adopted many years ago by the laptop and portable device industry. Connectivity became extremely important for traveling professionals, students, and growing numbers of startup companies. Rabid desire for access to email, internet sites, and video content has driven the growth of indoor and outdoor public Wi-Fi deployment to meet consumer and business demand for access.

Bluetooth technology usage exploded in commercial usage in the early 2000's with wireless headsets, portable speakers, audio equipment, and, more recently, wearables and sensors. Advertisers are also employing Bluetooth beacons for proximity-based ads. Most of these devices run on small batteries with wearables especially enabled with rechargeable batteries. Bluetooth has evolved through several generations of specifications, adding more advanced capabilities for bi-directional communications, greater security, and battery usage.

ZigBee and Z-wave protocols provide the basis for many home security and home automation systems due to their greater focus on securing device access and network traffic. Large cable and telco operator home security platforms have seen much success and high QOS with these solutions.

Wi-Fi, Bluetooth, ZigBee, and Z-Wave protocols are all based on IEEE 802.x specifications operating in the 2.4Ghz and 5Ghz ranges. Their standardization has enabled wide spread industry adoption and commercial success for short-range wireless communication.

In industrial, retail, and other industries we have seen healthy adoption of other short-range technologies like RFID (radio frequency identification) and NFC (near field communication) technologies. RFID applications include asset tagging, electronic toll collection, and building access credentials. Multiple low and UHF frequencies are used by various vendors. Standards have also helped the adoption of RFID through a mix of several bodies including ISO, EPC, IEC, Dash7, and ASTM. NFC is often used for asset tracking and payment transactions. Standards have been developed by ISO and GSMA continues to develop standards for mobile device support of NFC.

Short-range wireless solutions are capable of managing large numbers of sensors and volumes of transactions as long as sensors and devices are in close proximity with their gateway or source of network connectivity. Range becomes an issue as use cases include highly mobile, remote locations, or broad areas that need to be covered. Typically, the longer the range, the more power is required to transmit and receive a signal. Sensors with significant physical obstructions (concrete walls, buildings, hills) or sensors at the extremities of the network range will use significantly more power to maintain adequate signal strength. That may be okay for powered devices; however, it becomes a major problem as batteries drain much faster, becoming an operational nightmare for companies needing to deploy thousands of sensors. As more sensors are being deployed for smart city, agricultural, and industrial applications, we have a growing need to go beyond short-range use cases.

4. Long-Range Wireless

We will characterize long-range wireless as greater than 300 meters, typically serving a several-kilometer range. Mobile phones are probably the most recognized commercial device utilizing long-range wireless. Common cellular protocols have evolved over generations from 1G Analog, 2G GSM & IS-95, 3G UMTS & IS-856, 4G LTE & WiMAX, and soon to be 5G protocols. Do you remember your first mobile phone? Mine was a bag phone that was used in the car for frequent long highway trips in the early 90s. Even though reception was spotty, we still managed to benefit from analog voice coverage along much of our drive. Currently, users benefit from good coverage in most areas with high-quality digital data, large video bandwidth, and voice support; although it's just shy of the high QOS expectations and performance of land lines.

Telcos and industry trade bodies GSMA, 3GPP, and more have been working hard to advance the specifications for 5G solutions, conducting significant trials throughout 2017. Telcos have been working on variants of low-latency and low-power alternatives to support the "connected" world. Low-latency applications like assisted or self-guided vehicles manage constant communication, requiring significant bandwidth and power. 5G technology is a good fit for these use cases, at a reasonable cost.

Conversely, low-data-rate applications like connected meters for water, power, sewage, and lighting use infrequent bursts of small data packets to report status. The compact nature of these applications has spurred rapid development of "low-power" technologies that enable sensors to run on small batteries for years. With aggressive plans for low-data-rate device deployments, the industry is focusing on solutions with a better cost equation. The following examples of LPWAN are intended to be representative of the technology sub-groups, rather than an exhaustive list. The industry is moving so fast that any roundup of solutions will change dramatically in a relatively short amount of time.

LPWAN (Low Power Wide Area Network) technologies have been developed to manage large-scale deployments with low-bandwidth requirements and operate at a very low cost compared to modern high bandwidth alternatives. There are several competing flavors of LPWAN deployed around the world, including those based on the proprietary LoRa radio CSS (Chirp Spread Spectrum), UNB (Ultra Narrow Band), RPMA (Random Phase Multiple Access), Narrow Band IoT, LTE-MTC, and more.

The LoRa Alliance, with their 300+ members, has made a large impact with world-wide deployment of their LoRaWAN protocol over the past couple of years. This group of solutions includes open-source solutions from The Things Network in Europe and Carnegie Mellon's OpenChirp management layer. Commercial platform solutions are provided by Senet, Everynet, ThingPark by Actility, and most recently Comcast machineQ. These solutions operate in the unlicensed 868MHz range in Europe and the 915MHz range in North America. The great number of members and solutions has strengthened and matured LoRaWAN tremendously in just a few years-time. This space is crowded with platforms and success for each of them will be influenced by serving large industries and building strong partner ecosystems.

Ultra Narrow Band solutions were first developed by Telensa to utilize small bandwidth packets measured in hundreds of Hz (instead of KHz or MHz) operating in unlicensed sub gigahertz range for greater penetration of walls and ground. SigFox is a leading UNB-based commercial solution using the ISM radio band. The solution excels at long ranges and ground penetration; however, the maximum payload/message size is roughly one fifth that of LoRa's. The company is based in France that has had success in Europe and North America. There are additional variants promoted by the Weightless SIG and adopters.

Cellular-based variants of LPWAN include LTE-MTC, an evolution of LTE for machine type communications and NB-IoT by 3GPP. These solutions leverage existing "in-band" spectrum or "standalone" unused frequency. One benefits of NB-IoT solutions is no gateway cost as all devices connect to base station towers, which has some economies of scale in large deployments. Also, NB-IoT often has better signal performance in urban or dense environments, in addition greater bandwidth capacity.

Another LPWAN solution by Ingenu is RPMA (random phase multiple access) that was designed for broad coverage beyond 300 square miles and over 600 kbp/s uplink. This solution operates in the 2.4GHz range which can be impacted by overall traffic and has lower capability to penetrate walls and floors.

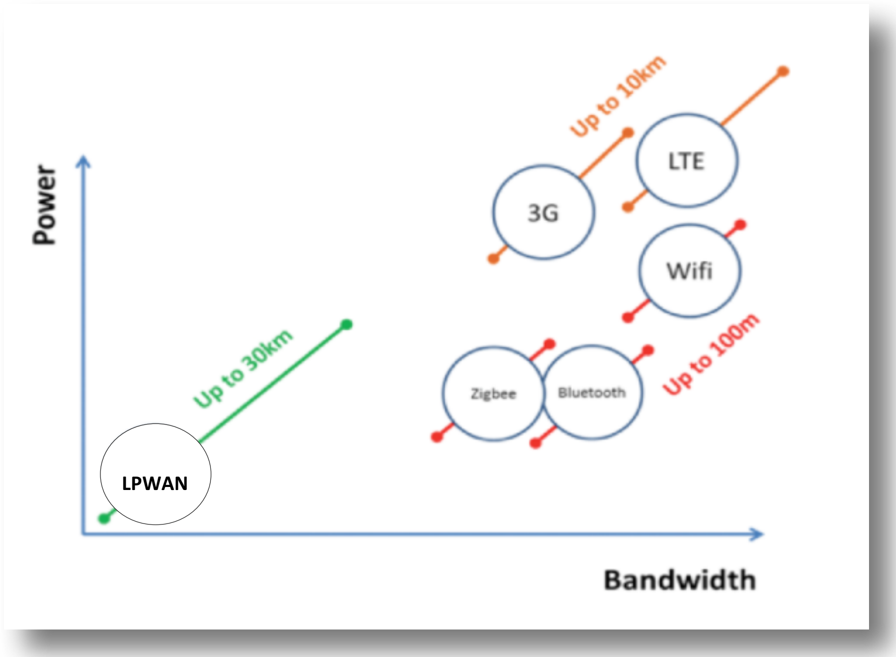

Figure 5- Wireless Power vs. Bandwidth Niche

The following is a comparison of common wireless technologies.

LPWAN	Short-Range	Cellular 4G LTE
Range of 6km-10km	Range of 100m-300m	Range of 10km-20km
Unlicensed Spectrum 915Mhz	Licensed Spectrum 2.4Ghz	Licensed Spectrum
Long Battery Life (8-10yrs)	Short Battery Life (1-2yrs)	Short Battery Life (hrs or wks)
High Latency	Low-Medium Latency	Low Latency
Low Data Rates (10s of Kbps)	Medium Data Rates (100s of Kbps)	High Data Rates (Gbps)
Low Cost Sensors	Low Cost Sensors	High Cost Sensors
Medium Cost Gateways	Medium Cost Gateways	High Cost Base Station
100s of Devices per Gateway	100s of Devices per Gateway	1000s of Devices per Base Station
High Penetration of Walls/Floors	Medium Penetration of Walls/Floors	Medium Penetration of Walls/Floors
Better in Rural and Indoor	Better Indoor	Better in Urban and Indoor

Table 1- Wireless Feature Comparison

LoRaWAN Range Testing

1. Objectives and Scope

The overall objective of the LoRaWAN range testing was to demonstrate the long distance and strong signal capabilities of the technology compared to other wireless technologies.

The scope of testing includes:

1. Stationary Semtech Pico Cell gateways
2. Roving Microchip sensors
3. Suburban and rural environments
4. Ground floor, subway level, and above 150 meters high

2. Test Devices and Environment

For initial testing, a new prototype Semtech pico cell LoRa gateway on a Raspberry Pi running RDK-B software along with a GPS sensor was assembled, all connected to the Semtech test environment. Thanks to Semtech, the founder of LoRaWAN and the LoRa Alliance, for graciously supporting these testing efforts.

The first round of testing the prototype was intended to shake down the environment and prove the concept of using a USB form-factor pico cell on the RDK-B platform. After making several changes to the packet forwarder and RDK environment, a robust test environment with standardized test equipment was imminent.

Figure 6- LoRaWAN Test Device Prototype

In the next round of testing, the environment was modified to enable a more standardized and repeatable setup that works in the lab, home, or field. In this implementation, a 7” touchscreen was added along with a slim battery power source to enable portability and ease of controlling the Linux environment without having to remote into a headless device. Not only does this setup enable testing of the sensors’ mobility, but also mobile gateway scenarios.

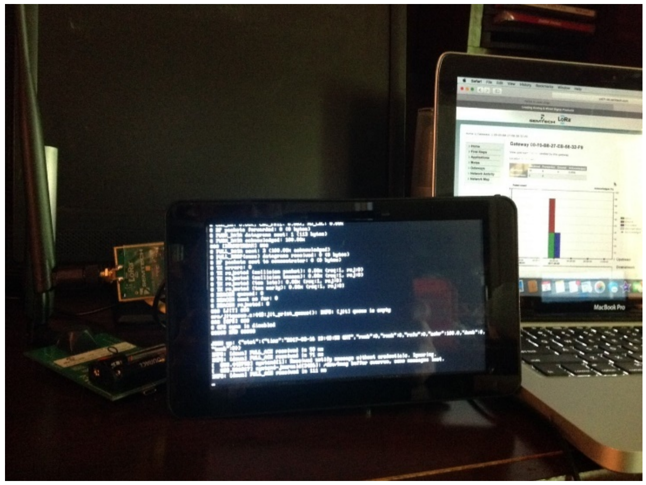

Figure 7- LoRaWAN Mobile Gateway Device

The current test environment has evolved to include cable operator all-in-one gateway devices hosting an integrated LoRa radio operating on multiple leading network servers. As a result, it became possible to conduct tests on stationary commercial-grade gateways, in addition to mobile gateways to cover dynamic scenarios.

Figure 8- LoRaWAN Commercial-grade Test Devices

3. Test Scenarios

For the purpose of this paper, the primary focus was a stationary gateway, taking measurements from sensors at different distances (ranges) under multiple conditions. The range testing was conducted using several common scenarios and use cases; however, the data is presented from a primary basic scenario to illustrate the power of LPWAN. The intent is to also illustrate performance in examples that were as close to real-life as possible.

1. Range of multiple distances from a single gateway in a suburban environment.
2. Handoff from one gateway to another in a suburban environment.
3. Range of multiple distances from multiple gateways in an urban environment.
    a. Ground level
    b. 150 Meters above ground (future)
    c. Subway level (future)
4. Range of multiple antennas with different dbi levels.

4. LoRaWAN Test Results

The following test results were conducted by Igor Sabaldash of pureIntegration.

Baseline Test: with a 0 dbi antenna on both the Mote and Gateway while roaming, beginning at 1m distance from the gateway reference implementation.

Time	Mote	Seq	Freq (MHz)	Mod	BW (Hz)	SF	Coding Rate	ADR	Gateway	Chan	RSSI (dBm)	SNR (dB)
7/9/2017 19:17	00-00-00-00-15-22-46-89	52	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-71	7.5
7/9/2017 19:17	00-00-00-00-15-22-46-89	51	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-79	-6.2
7/9/2017 19:16	00-00-00-00-15-22-46-89	50	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-84	-0.2
7/9/2017 19:16	00-00-00-00-15-22-46-89	49	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-83	1.8
7/9/2017 19:16	00-00-00-00-15-22-46-89	48	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-84	N/A
7/9/2017 19:16	00-00-00-00-15-22-46-89	47	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-84	-5
7/9/2017 19:16	00-00-00-00-15-22-46-89	45	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-89	-6.2
7/9/2017 19:16	00-00-00-00-15-22-46-89	44	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-87	-3.8
7/9/2017 19:15	00-00-00-00-15-22-46-89	43	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-88	-8
7/9/2017 19:14	00-00-00-00-15-22-46-89	36	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-84	-12.5
7/9/2017 19:12	00-00-00-00-15-22-46-89	20	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-88	-11.8
7/9/2017 19:12	00-00-00-00-15-22-46-89	14	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-84	-7
7/9/2017 19:11	00-00-00-00-15-22-46-89	13	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-87	-4.5
7/9/2017 19:11	00-00-00-00-15-22-46-89	12	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-87	-3
7/9/2017 19:11	00-00-00-00-15-22-46-89	11	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-83	-3.8
7/9/2017 19:11	00-00-00-00-15-22-46-89	9	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-83	-2.8
7/9/2017 19:11	00-00-00-00-15-22-46-89	8	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-83	-7.2
7/9/2017 19:11	00-00-00-00-15-22-46-89	7	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-81	5.5
7/9/2017 19:10	00-00-00-00-15-22-46-89	6	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-73	3.5
7/9/2017 19:10	00-00-00-00-15-22-46-89	5	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-76	3.5
7/9/2017 19:10	00-00-00-00-15-22-46-89	4	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-67	9
7/9/2017 19:10	00-00-00-00-15-22-46-89	3	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-66	10
7/9/2017 19:10	00-00-00-00-15-22-46-89	2	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-75	5.8
7/9/2017 19:10	00-00-00-00-15-22-46-89	1	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-66	9.2

Table 2- Baseline Test Data

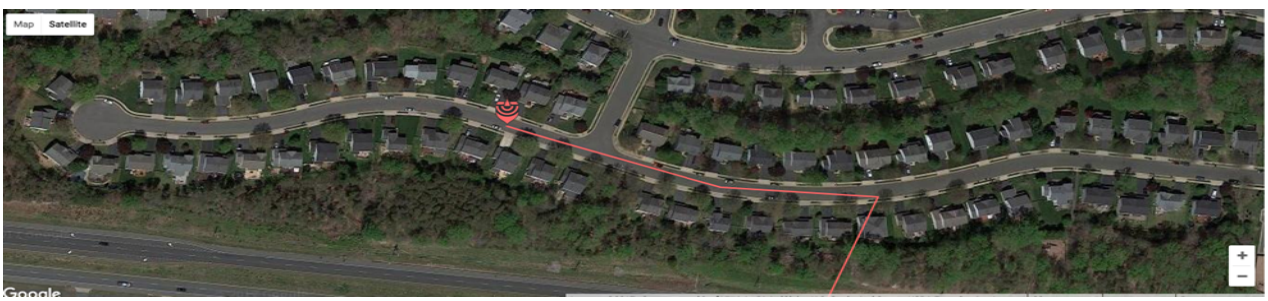

Figure 9- Baseline Test GPS Map

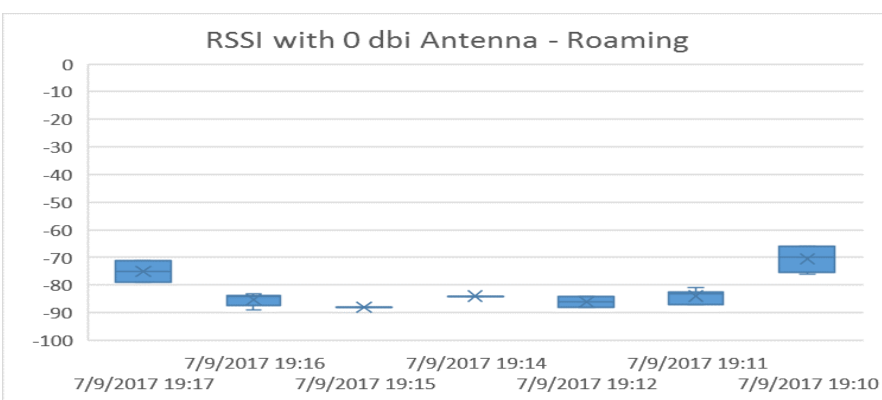

Figure 10- Baseline Test RSSI Range

Test # 2: With 2 dBi antenna on a mote, and 0 dbi antenna on the gateway.

Time	Mote	Seq	Freq (MHz)	Mod	BW (Hz)	SF	Coding Rate	ADR	Gateway	Chan	RSSI (dBm)	SNR (dB)
7/9/2017 19:33	00-00-00-00-15-22-46-89	57	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-72	9
7/9/2017 19:33	00-00-00-00-15-22-46-89	56	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-55	11.5
7/9/2017 19:33	00-00-00-00-15-22-46-89	55	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-53	9
7/9/2017 19:33	00-00-00-00-15-22-46-89	54	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-66	10.5
7/9/2017 19:33	00-00-00-00-15-22-46-89	53	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-59	10.5
7/9/2017 19:33	00-00-00-00-15-22-46-89	52	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-71	8.5
7/9/2017 19:32	00-00-00-00-15-22-46-89	51	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-63	11
7/9/2017 19:32	00-00-00-00-15-22-46-89	50	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-73	7.8
7/9/2017 19:32	00-00-00-00-15-22-46-89	49	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-82	4.8
7/9/2017 19:32	00-00-00-00-15-22-46-89	47	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-84	-5.8
7/9/2017 19:32	00-00-00-00-15-22-46-89	46	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-84	0.2
7/9/2017 19:32	00-00-00-00-15-22-46-89	45	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-78	3.5
7/9/2017 19:31	00-00-00-00-15-22-46-89	44	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-80	1.5
7/9/2017 19:31	00-00-00-00-15-22-46-89	41	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-84	-3.5
7/9/2017 19:31	00-00-00-00-15-22-46-89	40	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-82	-3.8
7/9/2017 19:31	00-00-00-00-15-22-46-89	38	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-84	0.2
7/9/2017 19:31	00-00-00-00-15-22-46-89	37	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-83	-3.2
7/9/2017 19:30	00-00-00-00-15-22-46-89	36	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-85	-4.2
7/9/2017 19:30	00-00-00-00-15-22-46-89	34	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-84	-7
7/9/2017 19:30	00-00-00-00-15-22-46-89	33	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-84	-11
7/9/2017 19:29	00-00-00-00-15-22-46-89	26	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-85	-9.5
7/9/2017 19:29	00-00-00-00-15-22-46-89	25	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-84	-13
7/9/2017 19:29	00-00-00-00-15-22-46-89	24	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-84	-4.5
7/9/2017 19:29	00-00-00-00-15-22-46-89	23	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-85	-8.2
7/9/2017 19:29	00-00-00-00-15-22-46-89	22	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-85	-7
7/9/2017 19:28	00-00-00-00-15-22-46-89	20	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-84	-2.8
7/9/2017 19:28	00-00-00-00-15-22-46-89	19	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-85	-6.5
7/9/2017 19:28	00-00-00-00-15-22-46-89	18	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-83	-5.2
7/9/2017 19:28	00-00-00-00-15-22-46-89	17	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-82	-4
7/9/2017 19:28	00-00-00-00-15-22-46-89	16	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-83	-2.8
7/9/2017 19:28	00-00-00-00-15-22-46-89	15	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-84	-6.5
7/9/2017 19:27	00-00-00-00-15-22-46-89	14	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-83	4.5
7/9/2017 19:27	00-00-00-00-15-22-46-89	13	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-85	3.5
7/9/2017 19:27	00-00-00-00-15-22-46-89	12	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-83	-4.2
7/9/2017 19:27	00-00-00-00-15-22-46-89	11	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-78	2
7/9/2017 19:27	00-00-00-00-15-22-46-89	10	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-87	1.2
7/9/2017 19:27	00-00-00-00-15-22-46-89	9	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-70	5.5
7/9/2017 19:27	00-00-00-00-15-22-46-89	8	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-75	6.5
7/9/2017 19:26	00-00-00-00-15-22-46-89	7	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-68	1.2
7/9/2017 19:26	00-00-00-00-15-22-46-89	6	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-79	1.2
7/9/2017 19:26	00-00-00-00-15-22-46-89	5	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-58	9.2
7/9/2017 19:26	00-00-00-00-15-22-46-89	4	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-55	8
7/9/2017 19:26	00-00-00-00-15-22-46-89	3	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-53	11.2
7/9/2017 19:26	00-00-00-00-15-22-46-89	2	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-61	4.5
7/9/2017 19:26	00-00-00-00-15-22-46-89	1	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-53	11

Table 3- Test Cycle #2 Test Data

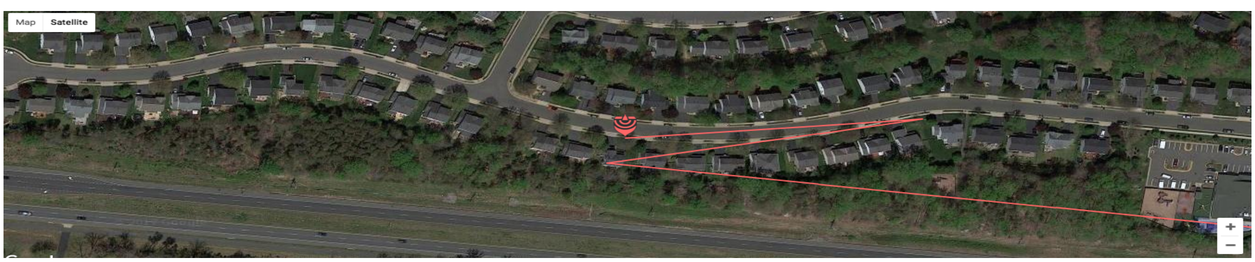

Figure 11- Test Cycle #2 GPS Map

Figure 12- Test Cycle #2 RSSI Range

Test # 3: With 6 dBi antenna on a mote, and 0 dbi antenna on the gateway.

Time	Mote	Seq	Freq (MHz)	Mod	BW (Hz)	SF	Coding Rate	ADR	Gateway	Chan	RSSI (dBm)	SNR (dB)
7/9/2017 19:51	00-00-00-00-15-22-46-89	51	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-71	10.5
7/9/2017 19:51	00-00-00-00-15-22-46-89	50	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-61	11.5
7/9/2017 19:50	00-00-00-00-15-22-46-89	49	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-65	11.2
7/9/2017 19:50	00-00-00-00-15-22-46-89	48	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-75	11.2
7/9/2017 19:50	00-00-00-00-15-22-46-89	47	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-91	9.2
7/9/2017 19:50	00-00-00-00-15-22-46-89	46	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-87	2.5
7/9/2017 19:50	00-00-00-00-15-22-46-89	45	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-86	-3
7/9/2017 19:50	00-00-00-00-15-22-46-89	44	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-90	4.2
7/9/2017 19:50	00-00-00-00-15-22-46-89	43	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-91	-2.5
7/9/2017 19:50	00-00-00-00-15-22-46-89	42	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-90	-2
7/9/2017 19:49	00-00-00-00-15-22-46-89	41	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-82	1.5
7/9/2017 19:49	00-00-00-00-15-22-46-89	40	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-88	5.2
7/9/2017 19:49	00-00-00-00-15-22-46-89	39	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-91	-3.2
7/9/2017 19:49	00-00-00-00-15-22-46-89	38	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-89	-5.5
7/9/2017 19:49	00-00-00-00-15-22-46-89	37	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-93	-7
7/9/2017 19:49	00-00-00-00-15-22-46-89	36	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-90	0.2
7/9/2017 19:49	00-00-00-00-15-22-46-89	35	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-89	-0.5
7/9/2017 19:49	00-00-00-00-15-22-46-89	34	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-93	-6.5
7/9/2017 19:48	00-00-00-00-15-22-46-89	33	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-91	-9.2
7/9/2017 19:46	00-00-00-00-15-22-46-89	18	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-91	-10.8
7/9/2017 19:46	00-00-00-00-15-22-46-89	16	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-91	-5.2
7/9/2017 19:46	00-00-00-00-15-22-46-89	14	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-90	-6
7/9/2017 19:46	00-00-00-00-15-22-46-89	13	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-90	-4.8
7/9/2017 19:46	00-00-00-00-15-22-46-89	12	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-93	-5
7/9/2017 19:45	00-00-00-00-15-22-46-89	11	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-91	-1
7/9/2017 19:45	00-00-00-00-15-22-46-89	10	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-89	3.5
7/9/2017 19:45	00-00-00-00-15-22-46-89	9	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-81	3.8
7/9/2017 19:45	00-00-00-00-15-22-46-89	8	903.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	7	-89	5.8
7/9/2017 19:45	00-00-00-00-15-22-46-89	7	902.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	1	-84	3.2
7/9/2017 19:45	00-00-00-00-15-22-46-89	6	902.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	0	-79	1.2
7/9/2017 19:45	00-00-00-00-15-22-46-89	5	903.1	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	4	-77	10.2
7/9/2017 19:45	00-00-00-00-15-22-46-89	4	903.3	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	5	-76	9.8
7/9/2017 19:44	00-00-00-00-15-22-46-89	3	902.9	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	3	-60	9.5
7/9/2017 19:44	00-00-00-00-15-22-46-89	2	902.7	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	2	-51	8.8
7/9/2017 19:44	00-00-00-00-15-22-46-89	1	903.5	LoRa	125000	SF10	4/5	off	00-00-B8-27-EB-0C-F9-F3	6	-70	9

Table 4- Test Cycle #3 Test Data

Figure 13- Test Cycle #3 GPS Map

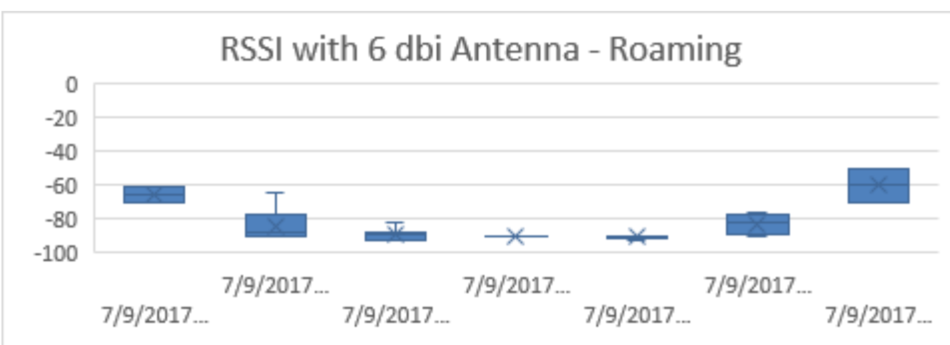

Figure 14- Test Cycle #3 RSSI Range

The following testing was conducted by Semtech's Michael Grudsky and team in Iowa to demonstrate performance in the unobstructed open range. The tests included a gateway positioned on an 80-foot-high pole and a mobile GPS sensor communicating with the gateway. The image below illustrates the coverage obtained in the open range was the size of the Chicago metropolitan area. Test results courtesy of Michael Grudsky from Semtech.

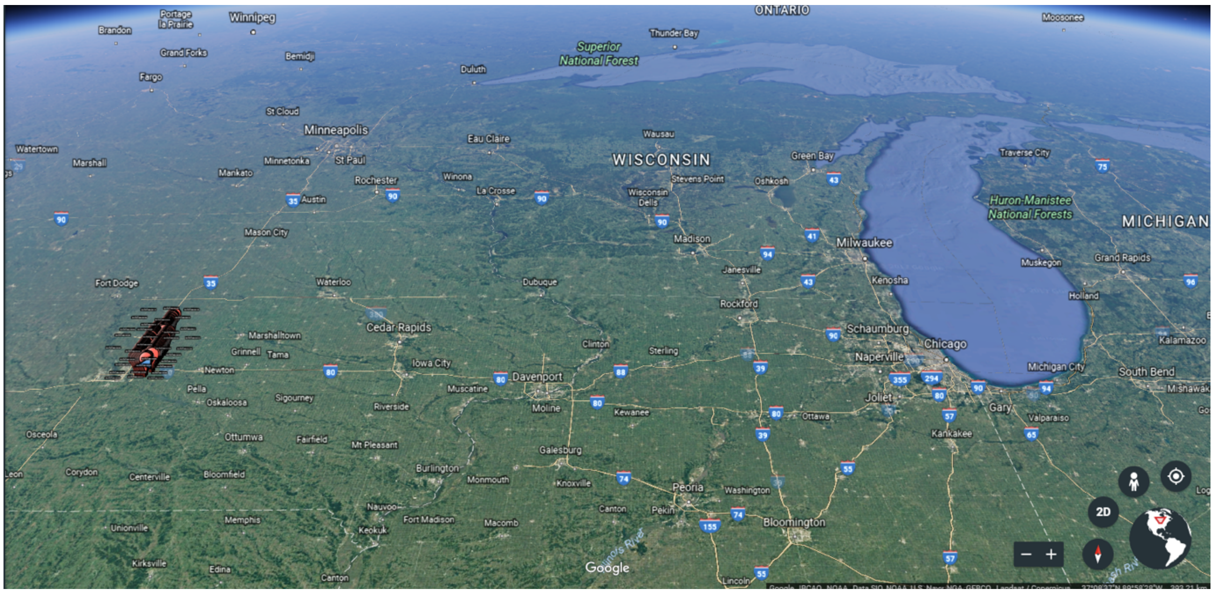

Figure 15- Open Range Testing

A close-up view of the range testing reveals successful LoRaWAN packet transfers up to 50 km from the gateway.

Figure 16- Open Range Testing 2

The signal strength ranged from -68dBm to -125dBm at the extreme north end of the grid.

Conclusion

Overall, the test results illustrate that LPWAN wireless technology is very powerful for use cases requiring low-data-rates. This is supported by industry and engineering research that has been conducted along with actual deployment results around the world. LPWAN was created for a specific purpose; to communicate with and manage large numbers of sensors/devices in the field that report status infrequently, at low data volumes. This wireless technology was not created for low-latency applications that require constant communication with large amounts of data, like vehicle-to-vehicle applications.

Testing and real-life deployments indicate advantages in better penetration of walls and ground than cellular and protocols that use 2.4 Ghz ranges due to lower frequencies. LPWAN has a lower noise floor and link budgets than higher-power solutions due to physics of low power transmission versus noise levels with higher power solutions.

Because LPWAN is focused on low-data-rates, it has been optimized to enable sensors/devices to run on small batteries that may last for over 10 years. Battery lives measured in tens of years helps reduce operating cost related to battery replacement and equipment maintenance.

LPWAN has arrived at a time when radio, chip, and component costs have dropped to a level where BOM incremental cost is under $10 (and continuing to decrease). When quantities of sensors/devices needed for deployment are measured in thousands or millions, the economies of scale quickly make for compelling business cases in many industries.

Add to the equation that unlicensed spectrum enables solution providers to create more cost-effective products, while network operators have an economic advantage over operators of licensed spectrum (especially considering the cost to purchase spectrum in addition to operating cost).

The ecosystem for LPWAN is also very strong. SigFox and Ingenu have an impressive installed base around the world. The Things Network and other open solutions have grown rapidly via grassroots movements over the past two years. Semtech, as the creator or LoRaWAN and the LoRa Alliance, has gone from 15 members two years ago to over 300 members (which include IBM, Cisco, Orange, Comcast, and many other giants across multiple industries). The standards are in place and the industry adoption is arguably one to beat.

It is a compelling business model that makes use of many strategic advantages. LPWAN includes advantages in regulatory (unlicensed), cost (startup and operations), technology (range and penetration), customers (right use cases), and competition (strong ecosystem). While not perfect, and recognizing some of the advantages of other competing technologies, LPWAN has established a solid niche across many industries and will likely continue to be successful for years to come.

Abbreviations

AP	access point
bps	bits per second
Kbps	kilobits per second
Gbps	gigabits per second
FEC	forward error correction
GSM	global system for mobile communications
GSMA	GSM Association
HFC	hybrid fiber-coax
HD	high definition
Hz	hertz
GHz	Gigahertz
ISBE	International Society of Broadband Experts
SCTE	Society of Cable Telecommunications Engineers
LPWAN	Low power wide area network
LoRa	Long range
IEEE	Institute of Electrical and Electronic Engineers
QOS	quality of service
RPMA	random phase multiple access

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