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Low-Cost Long Range IoT Communication Systems for Smart Farming Applications in Developing Countries

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Abstract

To provide communication network connectivity to the internet for Internet of Things (IoT) applications, reliable communication systems are needed. This paper presents a performance-based analysis of a Low Power Wireless Area Network (LPWAN) named LoRa. A client server model is used to conduct the measurement tests. Performance metrics that were investigated included, coverage, effect of payload size and selection of parameters settings. It was found out that a higher spreading factor and coding rates lead to better coverage using LoRa.

Keywords: IoT; LoRa; Smart Agriculture.

1. Introduction

The Agricultural sector, covering both crop and livestock production, plays a major role in a Motswana's (Citizen of Botswana) life and for many others in developing countries. A higher number of rural households in Botswana depend on agriculture as their principal means of livelihood. Most of these farmers are small scale farmers. This sector contributes about 3% to the total GDP[1]. Today farmers work hard to grow crops to earn their livelihood yet still the country is not self-sufficient due to poor yields leading to losses to the farmer and government. To try and mitigate the issue, the agriculture industry is leveraging the use of technology particularly Internet of Things (IoT) [2].

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IoT allows sensors to take readings and the microcontroller through the communication network can send this data to the intended recipients either to a mobile phone, or a website [3]. Some of the wireless connectivity requirements for IoT deployment include long battery life, low device cost, low deployment cost, extended coverage, and scalability (support for a huge number of devices). Common solutions such as short-range wireless networks e.g. Bluetooth, Wi-Fi as well as cellular networks e.g. GSM have constraints in their use in IoT applications. These solutions are usually high cost, have high energy consumption or have short range coverage. In this work we use and test LPWANs to provide the connectivity to the internet. LPWANSs have high energy efficiency, low power consumption and high coverage capabilities for low throughput, limited QoS and security requirement applications [4, 5]. Some of the major LPWAN technologies available in the market today include LoRa, Sigfox and DASH-07. Each technology uses different techniques to meet IoT wireless system requirements. In addition, a licensed cellular technology track introduced by the telecom industry offers an alternative connectivity for IoT applications. These technologies include 3GPP(third generation partnership project (3GPP) technologies like GSM(extended coverage GSM (EC-GSM), WCDMA, LTE, Narrowband IoT (NB-IoT) and fifth generation (5G), which promises 100-times the speed of 4G LTE [6]. Potential applications for LPWAN technology span across vast and diverse industries such as mining, healthcare, agriculture, transportation, utilities and many more. Some of these are mentioned in figure 1. In this work we test LORA for suitability for SMART farming applications.

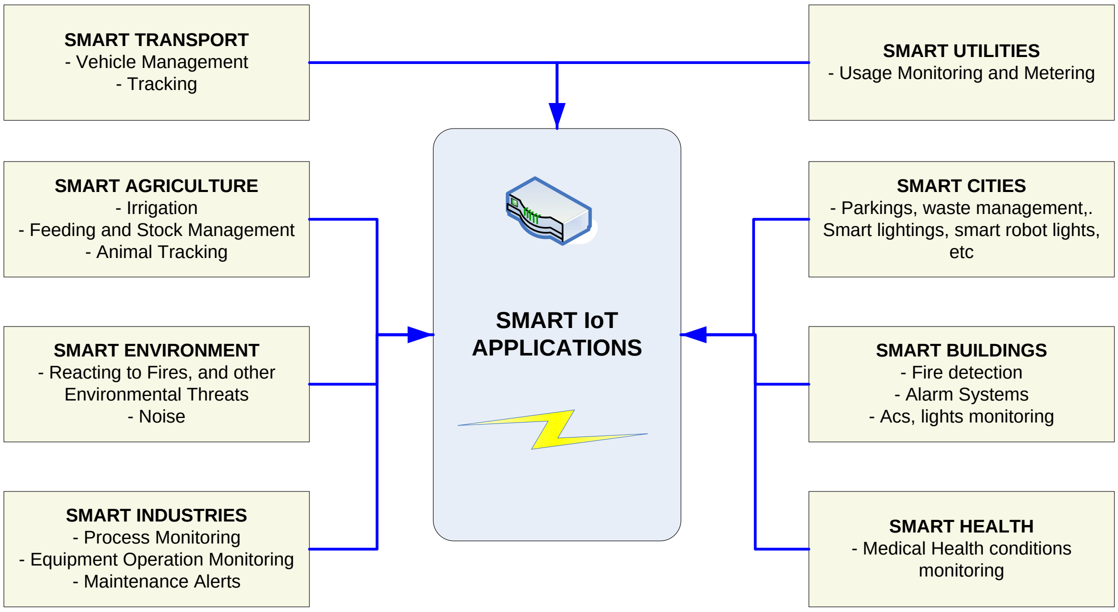

Figure 1: LPWANs Smart applications

An incorporation of IoT into agriculture is called "smart farming" or "precision agriculture" [7]. Smart farming can be implemented looking at various levels and types of farming,

- Type of farming i.e. livestock or production
- Aim of applied technology i.e. monitoring, actuation, control, and automation
- Projected outcomes i.e. aiming at better yields, pest and disease control, quality standards, safe

transportation, improved storage, nutrient levels, health status, sustainable process [8].

This has been advantageous to farmers because:

- Real-time data and production insight: Farmers can track varying factors that influence production yield and quality (in real time) such as soil moisture, sunlight intensity etc. in real time, which allows them to make decisions concerning crop treatment efficiently.
- Higher yields: Systematic and improved farming activities such as watering crops, accurate planting, adequate pesticide application and direct harvesting will result in increased yields.
- Water conservation: Monitoring humidity and weather patterns using trackers and sensors allows for watering only when necessary.
- Increased production quality: Analysis of crop treatments allows for results to be evaluated in relation to applied treatments, thus allowing farmers to adjust their crop management activities for future improvement.
- Precise farm and field assessment: Precisely tracking production rates per farm over a period allows for reliable production forecasts to be made for a given field.
- Enriched livestock farming: Livestock health, internal anomalies and reproductive events can be monitored and observed and attended to earlier using sensors and machinery. Moreover, livestock movements can be monitored using geo-fencing location tracking systems.
- Lowered operation costs: Automated planting, watering, fertilization, harvesting and overall treatment processes reduces resource uptake/ waste and eliminates chances of human error.

With these benefits of smart farming, a potential application is in Botswana’s agriculture sector. One of the characteristics of smart farming is internet connectivity. The Internet connectivity in Botswana is mostly concentrated in towns and cities (except through mobile networks), yet most agricultural activities take place in rural areas where internet connectivity is limited. Thus, this limitation dampens the implementation of smart farming in areas such as remote sensing and smart irrigation. This requires a capillary network comprising of an LPWAN technology and traditional solutions e.g. Wi-Fi to be designed to facilitate collection of data from sensor network located in remote areas and be transmitted to an IoT cloud server located in cities where most farmers live. The aim of the work in this paper is to provide data on the performance of LoRa in Botswana. The performance metrics used includes coverage of LoRa, effect of payload size and effect of parameter selection on the network performance. This is to be achieved by showing signal quality, Received Strength Indicator (RSSI), Signal to Noise Ratio (SNR), and Packet Delivery Ration (PDR) environments in different terrains. In this also an IoT network based on LoRa is depicted to show use case of the technology for remote monitoring in smart farming. The rest of this paper is organized as follows. Section 2 provides an overview of the LoRa technology, it also goes to show a comprehensive comparison of LoRa and other major LPWAN technologies available. Section 3 presents the literature review and considers previous research done on measurement of LoRa performance in various environmental conditions. Section 4 presents the research methodology employed and the experiments including the setup and specification of the hardware and software used. Section 5 illustrates the findings obtained with graphs detailing the RSSI, SNR and PDR. This chapter also includes an analysis of the results and how they can affect use cases of LoRa. Section 6 summarizes the findings for the performance measurement and presents future work and limitations in the research.

2. Lora overview

LoRa is a wireless communication system used to create a communication link between network nodes located far from each other. LoRa operates in the physical layer of the OSI network model as a hardware interface. It uses a modulation technique called CSS where a chirp signal continuously varies in frequency [9, [0] which allows for long range low power transmission, higher bandwidth, and robustness against interferences like Doppler effect which are essential in IoT. Data transmission occurs in the ISM spectrum i.e. 433, 868 and 915 MHz and the data rate can reach up to 50 Kbps. To optimize LoRa for a given application 3 critical parameters must be taken into consideration, spreading factor (SF), bandwidth (BW) and coding rate (CR) [11]. A higher spreading factor increases the Signal to Noise Ratio (SNR), sensitivity, range, and airtime of the packet. But also, at higher SF there is an increase in energy consumption and susceptance to interference resulting in packet loss. Spreading factor can be selected from 6 to 12 [11–14]. Bandwidth refers to the width of frequencies in the transmission band [14]. The most applied BW settings are 125 KHz, 250 KHz and 500 KHz [14]. A larger bandwidth leads to lower receiver sensitivity while a lower bandwidth gives a higher receiver sensitivity. Coding rate is a rate used by LoRa devices to defend from signal interference. CR equals $\frac{4}{4+n}$ with n ∈ {1, 2, 3, 4}. Therefore, it can be set as 4/5, 4/6,4/7 or 4/8. Higher coding rate factor e.g. 4/8 offers more protection than 4/5 but this increases airtime [12–14]. With these parameters known, the useful bit rate (R_b) can be calculated using the equation given below:

$$Rb = SF \times \frac{BW}{2^{SF}} \times CR \qquad (1)$$

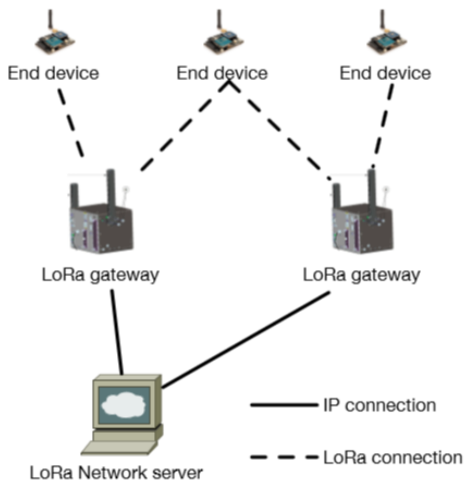

Figure 2: LoRaWAN Network Architecture

For instance, a setting with BW = 125 kHz, SF = 7, CR = 4/5 gives a bit rate of R_b = 5.5 kbps. Another parameter to be considered is transmission power. It is restricted by hardware, but the range is often between 2dBm to 20dBm. Higher transmission power leads to higher power consumption but also to longer distance coverage [12, 14]. LoRa networks use a MAC layer protocol called LoRaWAN. LoRaWAN manages communication between LPWAN gateways and end node devices and defines the network architecture. The network architecture defined by LoRaWAN is a star topology which includes 3 different components: LoRa end devices (i.e. sensors), gateways (i.e. base stations) and the network server as shown in figure 2.

2.1 Comparison of LoRa and major LPWAN

Apart from the LoRa, there are other LPWAN technological solutions available in the marketplace, these include Sigfox, NB-IoT, LTE-M and DASH7. Sigfox is a LPWAN that employs ultra-band modulation which requires little energy for IoT applications. Narrowband-Internet of Things (NB-IoT) is a low power wide area (LPWA) technology standard based on LTE functions for WSN. It improves consumption of power by end devices, system capacity and spectrum efficiency[5, 11]. LTE-M is a type of LPWAN standard published by a 3rd Generation partnership project(3GPP) suitable for IoT applications [5]. The DASH7 Alliance Protocol (D7A) is an Open Radio-Frequency Identification (RFID) Standard for bi-directional in the sub-Ghz medium range wireless communication tailored for WSN [11]. Table 1 provides a summary of the differences between some of the most popular LPWAN technological solutions.

Table 1: Differences between some of the most popular LPWANs

Feature	LoRaWAN	Narrow-Band	LTE Cat-M	NB-LTE
Modulation	SS Chirp	UNB/GFSK/BPSK	OFDMA	OFDMA
Rx Bandwidth	500 -125 KHz	100 Hz	20 – 1.4 MHz	200 KHz
Data rate	290bps-50Kbps	100bps 12/8 bytes Max	200kbps-1Mbps	~20Kbps
Max. Output Power	20dbm	20dbm	23/30dbm	20dbm
Battery Lifetime – 2000mAh	105 months	90 months	18 months	
Interference immunity	Very High	Low	Medium	Medium High

3. Literature Review

LoRa technology is one of the most popularly used LPWAN technology a lot of studies have been made available in the academic community focusing different aspects of the technology. The following is a brief explanation of the works that are more relevant to our work. Augustin [12] provides an overview of LoRa and the performance analysis of its physical and data link layer by conducting field tests and simulations. To conduct the tests, a testbed was built using the KRDM-KL25Z development board with SX1276 MBED shield as the end device and a cisco 910 router as the gateway and ThingsPark as the network server. Experiments to find out LoRa's receiver sensitivity and network coverage were performed. The gateway was placed indoors and the end device outdoor. Total packets sent was 10,000 with the parameters, bandwidth set to 125 kHz and a code rate of 4/5 for the RSSI test. For the network coverage with the gateway indoors, measurements with spreading factors of 7,9 and 12, default transmission power 14dB were chosen. 100 packets were sent from 5 different locations ranging from as low as 650m to as high as 3400m. the PDR at each location was determined. They show that higher spreading factors have better coverage. Also, LoRa has a high receiver sensitivity and thus offers good resistance to interference. LoRa can offer satisfactory network coverage up to 3 km in a suburban area with dense residential dwellings. The spreading factor has significant impact on the network coverage, as does the data rate. Reference [15] performs a similar study to [12] where city wide LoRa deployment is used to perform real-world measurements to present key performance metrics of LoRa zooming in on, the throughput, coverage, and scalability. The network consisted of 3 commercial grade gateways and 4 end nodes. To characterize the coverage the nodes were set to the highest spreading factor i.e. SF=10 and BW=125kHz. At each location 200 packets were sent back to back and the PDR calculated. Tests were conducted for outdoor and indoor measurements. In this paper the smallest distance between a gateway and a node was 2km and highest 7.5km. A PDR of 95.3% was achieved for 7.5km for outdoor measurements. Reference [16] performed various tests on LoRa to show the performance of the network in correlation to different environmental attributes such as distance, height, and surrounding area by measuring the signal strength, signal to noise ratio and any resulting packet loss. A LoRa deployment of a gateway and end node were used in this study. The following settings were chosen for both end node and gateway: bandwidth - 125kHz, Spreading Factor, variable = 7 to 12, Coding Rate, fixed = 4/5 and Transmitting Power - 14dBm. The tests were performed in different physical environmental conditions, OLS, Dense forest and Urban city. The authors point out that when there are obstructions in the way, as the signal drops rapidly up to 300m after which the signal decay rate gets lowered. Reference [13] also performs range tests. The tests were focused on retransmissions and packet loss. Arduino module with built-in radio-communication module is used in the tests. The setup that offered the longest and slowest data rate was used in these tests i.e. SF 12, BW 125 kHz and CR 4/8. In one of the tests, measurements for retransmissions and lost packages at different distances with the same payload size were conducted. With sender in another building, 5000 packets were sent. Many retransmissions were observed at the distance with 43.84% retransmissions and only 3.53% of lost packages. The authors speculated that this was due to obstacles between the sender and receiver. Another measurement test conducted was effect of payload size. The authors pointed out that reducing the package size increases the reliability of communication. The results showed that the number of retransmissions decreases to 25.46% (with 0.99% lost packages) for package size of 30 bytes and to 1.52% (with 0.08% lost packages) for package size of 12 bytes Wang [17] explored the application of LoRa on agricultural environmental information system. They collected data on temperature and humidity. They created a sensor node from the SX1278 LoRa module for transmission and the DHT11 to collect temperature and humidity. The information could be viewed by users on a host computer. In addition to viewing the data, control commands could be sent to the sensor nodes though a command interface that was developed by C# in Visual Studio. The information collection system was realized as the sensor nodes could receive commands and send sensor data. Also, network coverage tests were performed in open area and a maximum distance of 5km between the sensor nodes and central nodes were realized. Their tests also showed no packet loss within a 1km and the maximum packet loss rate was less than 5% in 5km. Thus, they concluded that LoRa has long distance communication and strong anti-interference ability therefore validifying the results of [12].

Table 1: Summary of previous work

Study	Equipment	Parameter setting SF, CR, BW	Number of packets	Conclusions
[12]	KRDM-KL25Z development board with SX1276 MBED shield as the end device and a cisco 910 router as the gateway and ThingsPark as the network server.	BW = 125Khz Cr = 4/5 SF = 7,9,12	100	Higher spreading factors have better coverage. LoRa has a high receiver sensitivity and thus offers good resistance to interference
[15]	3 commercial grade gateways and 4 end nodes (Arduino UNO/RFM95W, Arduino M0/RFM95W,Mbed FRMD/SX1276MB1LAS, ArduinoM0 Pro/RFM95W.)	BW = 125Khz Cr = 4/8 SF = 10	200	Effective long-range communication (≥ 10 Km) can be achieved using LoRaWAN even in urban environments.
[16]	STMicroelectronics NUCLEO-L073RZ MCU Board with a SX1272 LoRa Shield Wimod LoRa Lite Gateway	BW = 125 Cr = 4/5 SF = 7 to 12	2 byte payload every 10 second	packet loss exceeding the threshold of -120dBm causes the packet to become corrupted i.e. unreadable or lost completely Deploying a gateway on a radio tower to prevent obstructions would cause network coverage to exceed 15km
[13]	Adafruit Feather 32u4 microcontroller	BW=125Khz Cr=4/8 SF=12	Average of 5462 packets of 72 bytes	LoRa is promising technology in the field of long-range and high-reliable communication.
[17]	Sensor node - microprocessor STM8L151G SX1278 chip DHT11 sensor Central node – STM32F103ZET6 hybrid microprocessor sx1278 transceiver	BW=125Khz Cr=4/6 SF=8	N/A	LoRa modem has the characteristics of long communication distance and strong anti-interference ability

In this work we conduct similar tests in Botswana in 2 different terrain settings.

4. Methodology

Performance measurements were conducted in 2 different environments, one a partial open and a dense urban environment. The key performance metrics used was coverage, effect of payload size and effect of different parameter selection. A GPS logger was used to create placemarks for all locations which was then exported to google earth to create maps. To collect the result a software called Teraterm was used. It records information from the serial interface and saves it as a .csv file. The server and client nodes used the Dragino's LoRa shield coupled to an Arduino Uno. The Dragino LoRa Shield is a long range SX1276/SX1278 transceiver that allows data to be sent at low data-rates. It provides ultra-long range spread spectrum communication, high interference immunity and minimizes current consumption [14]. The transmitter/ client node was placed on top of a vehicle to create a mobile transmitter and vary the locations as shown in figure 3. The area chosen for the measurement tests was the area between University of Botswana (UB) entrance by UB stadium and the bus stop after the UB circle as illustrated by figure 4. It measures to about 1 km between the two points. Two node devices were setup with one as the client and another as the server. The server was connected to a laptop to record the RSSI, SNR and packet loss.

Figure 3: Client node mounted on car

The transmission power of the end-device was set to 14 dBm, which is the default value. The parameter selection used were, spreading factors of 7, Cr of 4/5 and bandwidth of 125kHz. These were chosen from studying the work of [12, 13]. About 100 packets were transmitted to the server at each test point with a sequence number. To test for the effects of payload size, the tests were conducted with payload sizes of 20 and 100 bytes. The test starts from 300metres and incremented at intervals of 100metres. This is continued until data cannot be viewed anymore on the receiver side which was at point G on the map.

Figure 4: Map of test points

To conduct performance measurements tests, a client-server model was created to perform measurement tests of the LoRa network. These tests focused on the physical layer. A server node was placed at the top of Block 250 in UB (one of the engineering building) and a client node was placed on top of car that moved from site to site as shown in figure 4. A total of 6 sites were used as measurements points i.e. site A-F as seen in figure 5 and their distance are shown in table 2. At each measurement point the RSSI, SNR, PDR were recorded. Timestamps for the time of transmission and time of reception were collected to calculate delays. The transmission power of the end-device was set to 14 dBm, which is the default value. The parameter selection of Spreading factors of 7 and 12 were chosen for the tests with Cr of 4/5 and 4/8 respectively. These were chosen from studying the work of [12, 13]. About 50 packets are transmitted to the network server in each test with a sequence number. To test for the effects of payload size, the tests were conducted with payload sizes of 20 and 100 bytes, using the LoRa spreading factor 12 (SF12), and a bandwidth of 125KHz. A delay was calculated for both payload sizes.

Figure 5: Map showing the different sites from A-F

Table 2: Sites with their corresponding distances from base

Site	Distance(m)
A	80
B	480
C	570
D	870
E	970
F	570

5. Results

For the first measurement tests, a variation of distances where the line of sight between the client and server had little obstructions. The purpose of this measurements was to determine limitations of use case in conditions of little obstructions and observe the range LoRa can be able to achieve. A parameter setting of SF = 7 or 128, Cr = 4/5 and BW =125kHz were configured in the nodes. Looking at figure 6, the general trend of the RSSI values with relation to increase in distance, agrees with works done by [16], as the client node is moved further from the server node, an decrease in RSSI is experienced with erratic changes in SNR values ranging from 9 to -9dB. The results demonstrate that even at distances above 900m, the signal is still strong only degrading at a tiny rate and operating above the stated receiver sensitivity [14]. These distances can be exceeded as observed in the study by [15]where with distances of 7.5km between the client node and server node, a PDR of 95.3% was achieved with increased server node height placement. After 1km, the first packet loss is observed for the network with a PDR of 34%. From there the number continues to grow. This might be due to an increase distortion of line of sight due to many obstructions. It is worth noting that only SF of 128 was used in the test. A higher spreading factor could have offered more range coverage as proven by [12,16].

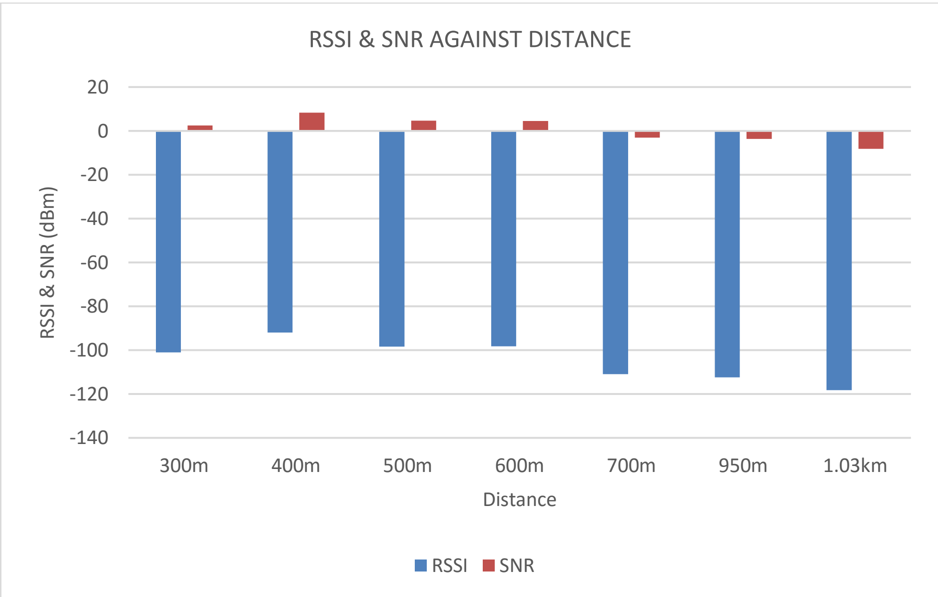

Figure 6: Plot showing RSSI at different distances

The second set of measurements were conducted in an urban environment with dense buildings. The aim of this experiment was to test the network coverage and performance of LoRa with varying SF and Cr. Also, the impact of increased payload sizes was tested. Figures 7 and 8 displays the packet delivery ratio of the two spreading factors chosen with varying payload sizes and distances. The general rule of thumb is higher spreading factors have better coverage as is evident at site D and C. The PDR for SF=4096 was 100% at site C and zero for SF=128. At site D, only for packets sent using SF= 4096 were received while no packet was received when using a spreading factor of 128. The results are consistent with the study conducted by [12], where the spreading factors of 128,512 and 4096 were used to test network coverage. At 2800m, for SF=4096 more than 80% of packet sent were received while 0 packets were received for spreading factor 128. To use a higher spreading factor is to forfeit bit rate as proven by equation 1 while at the same time to choose lower spreading factor to increase bit rate is to forfeit better coverage. Moreover, the coding rate used with SF=4096 speculatively could have offered protection against signal interference thus improving coverage. An effect of payload size on performance of LoRa was clearly observed also at site D. When 100-byte packets were sent at both SF=128 and 4096, 0 packets were received yet 20-byte packets were received. A PDR of almost 40% was achieved. This shows that reducing packet size increases PDR. This phenomenon was also observed by [13], where 12 bytes of packets experienced packet loss of 0.08% and 72 bytes of 3.53%. . Nevertheless, the downside of small packets is the limited amount of data that can be sent. A payload size that does not affect network and still carry enough data must be determined. Figures 9 and 10 show the effect of payload size on RSSI with a spreading factor equal to 4096. For payload of size 20bytes, the RSSI values recorded do not follow the trend that RSSI decreases with increasing distance. Site E is further than site D yet as shown in figure 9, site E experienced higher RSSI than site D. This was caused by a dense obstructed line of site between the base station and client node at site D. The SNR at site D is negative depicting that the noise power is higher than the signal power this also can be attributed to the dense obstructions. From the results, payload size does not significantly affect RSSI the values recorded were approximately equal.

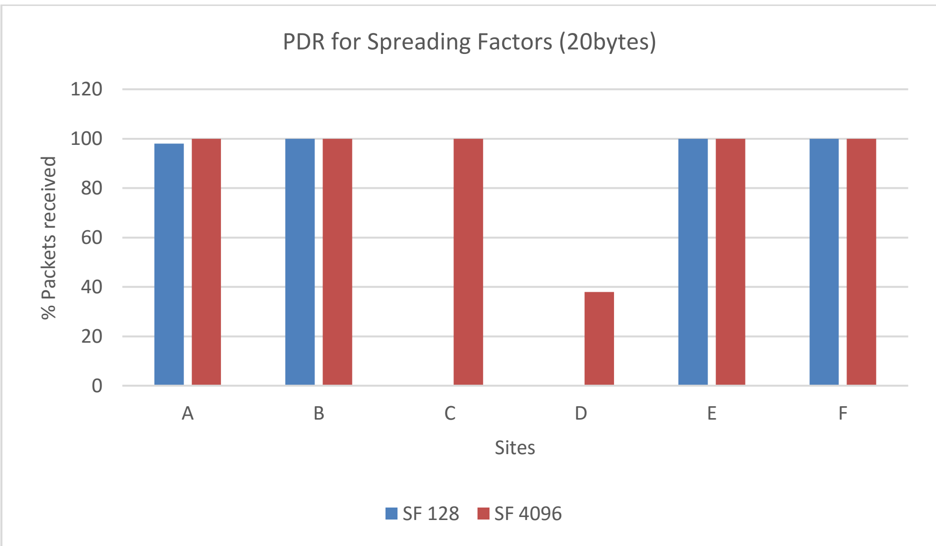

Figure 7: PDR for SF=128 and SF=4096 with payload size of 20bytes

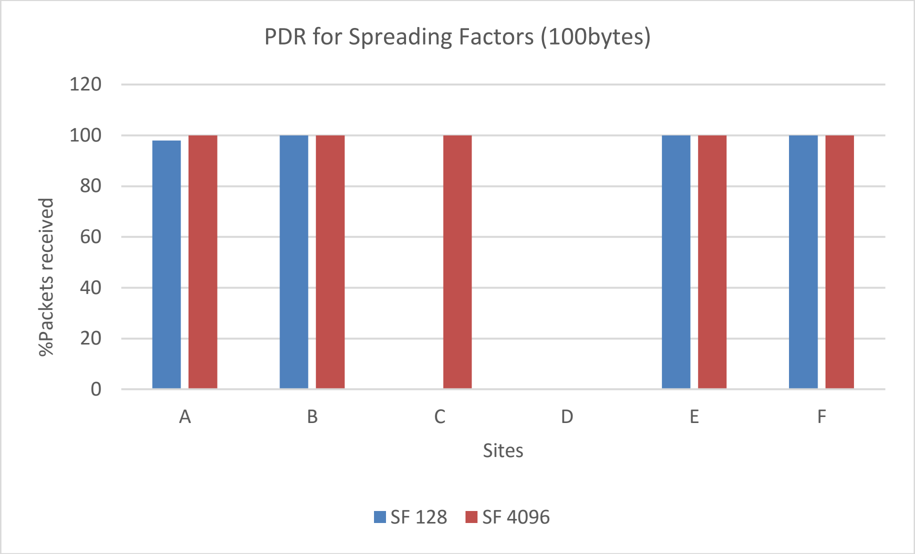

Figure 8: PDR for SF=128 and SF=4096 with payload size 0f 100bytes

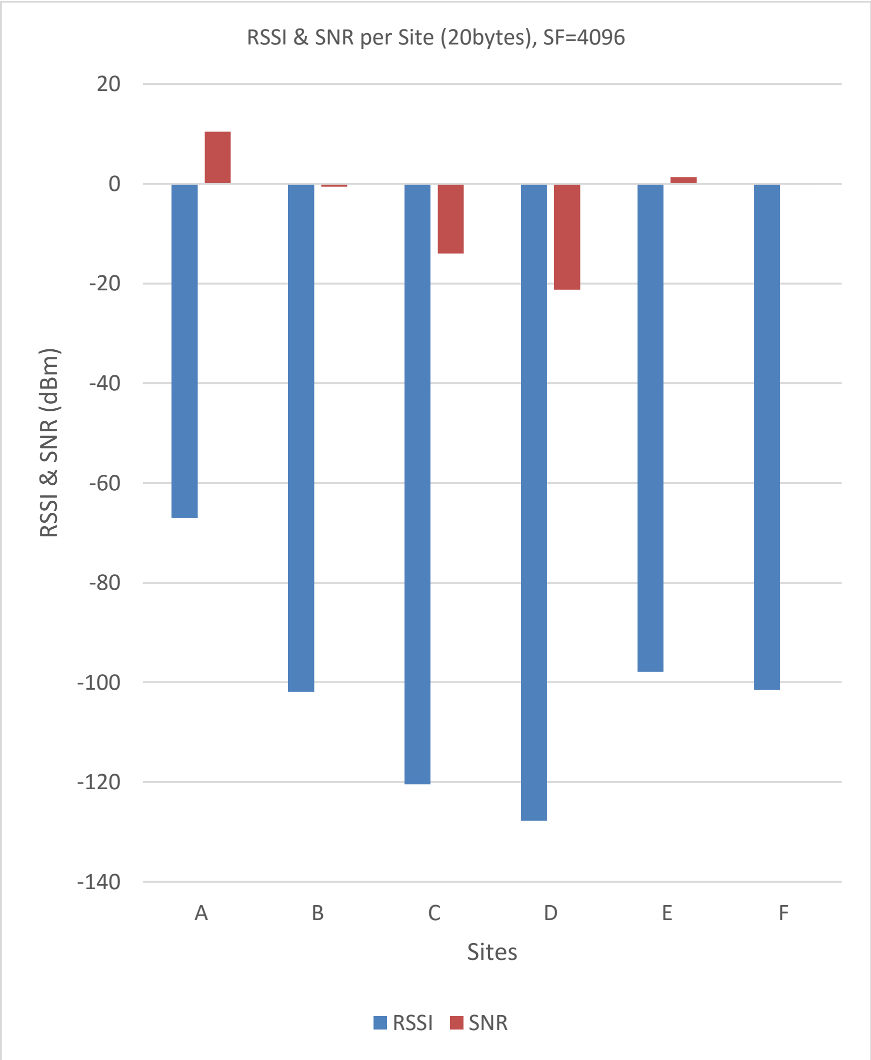

Figure 9: RSSI values for payload size of 20bytes

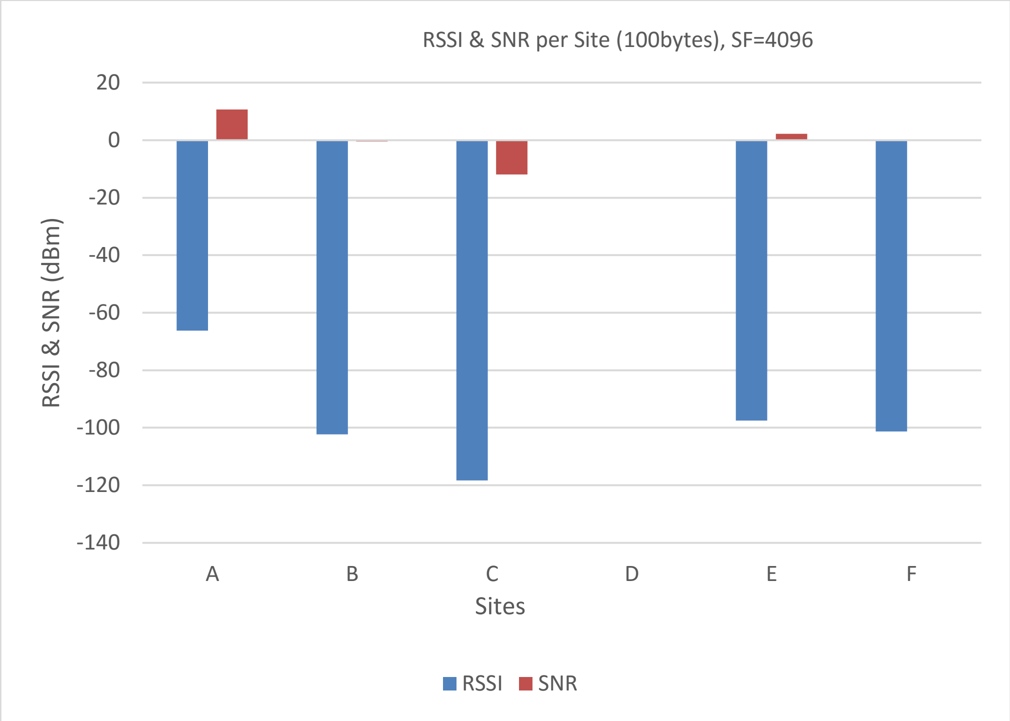

Figure 10: RSSI values for payload size of 20bytes

6. Conclusion

The goal of the paper was to conduct measurement tests on a LoRa network to investigate its coverage, effect of payload size and selection of parameter settings. From the experiment it can be concluded that higher SF and Cr offer better coverage and range. In an urban environment more than 900m was reached with RSSI still below -120dB. A smaller payload size increases the PDR. In a partial line of site, 1km can be reached before packet loss was experienced. The quality of the network can be improved by elevating the nodes to higher altitudes. Several limitations were experienced during the study. There was restricted access to the rooftop to setup the base station and when access was granted there was a time limit. This only allowed for 1 set of test data to be collected when ideally tests must be repeated for accuracy. Similarly, there were insufficient funds to purchase the necessary equipment. More case studies are still to be conducted using LoRa in different terrains. This work has shown that LoRa can provide reliable communication connectivity in rural areas as they are less dense.

7. Recommendation

Further tests are still required in other none tested terrain settings. The findings do show that financial resources can be allocated to research and development of market ready LoRa based products for rural implementations. This technology will be beneficial for smart farming applications.

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