Feasibility of Networking Technology for Smart Farm: LoRa vs APRS

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***Abstract*—Smart farms and IoT (Internet of Things) have an inseparable relationship. Sensors, gateways, servers, databases, web-based applications, are all widely used by connected smart farms. Also, the range of communication availability, the amount of power required for communication, and required equipment are differs depending on the networking technology. Hence, the decision of networking technology is very important when implementing a smart farm. While there are many networking technologies, LoRa (Long Range) is one of the most common Low Power Wide Area Network (LPWAN) in use by smart farms in the United States. Theoretically, APRS (Automatic Packet Reporting System) can communicate at greater distances than LoRa. Therefore, the study compares the feasibility of LoRa and APRS in smart farms by measuring the distance coverage of the two networking technologies. All three tests were conducted at the Purdue Agronomy Center for Research and Education where the transmitting antennas were mobile that moved via cars, and the receiving antennas were installed at the same tower. The distances were calculated by using Google Maps, where all the locations for the transmitting points were saved. From evaluating the test results, this paper concludes that LoRa is a more feasible wireless connection than APRS in the smart farm IoT system.**

***Index Terms*—Area coverage, automatic packet reporting system (APRS), comparison, feasibility, long range (LoRa), range, smart farm.**

NOMENCLATURE

D	Distance.
D_r	Distance.
F	Frequency.
F_0	Frequency.
G_{rx}	Receiver antenna gain.
G_{tx}	Transmission antenna gain.
P_{tx}	Transmitted power.

I. INTRODUCTION

With the fourth industrial revolution and the advancement of IoT technology, ICT (Information and Communication Technologies) has been integrated into agriculture and increased not only the quantity and quality of products but also convenience for the farmers. In IoT-based smart farming, data from weather conditions, light, soil moisture, or crop's growth is collected by IoT device sensors. With the data, farmers can monitor the field conditions from anywhere with smart devices. Also, irrigation systems can be automated so that water will be used more efficiently and the yields will be improved. In recent years, research on solutions to increase the performance and productivity of the smart farm while lowering the cost has become very popular. Previous studies like [1] show that the main technologies of IoT based smart farming are network technologies, security, and IoT agriculture applications.

There are numerous network technologies for wireless connection of the sensors and actuators in an agricultural IoT system. The network technologies focus on providing scalability, extended range, low cost, and energy efficiency for the end-user devices [2]. Since the IoT agricultural network

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helps to monitor agriculture data and facilitate the transmission and reception of agriculture data, it is one of the vital elements of IoT in agriculture [1].

Although a lot of researches focuses on implementing an IoT system with a suitable communication network for smart farming, little attention has been given to comparing alternative radio systems to choose better network technology. Therefore, this study focuses on two network technologies, LoRa and APRS, for the smart farm IoT system. The objective of this paper is to question the feasibility of APRS, as compared to LoRa, in the smart farm IoT system. In this paper, the range of LoRa and APRS was evaluated at the Purdue Agronomy Center for Research and Education.

II. Related Work

This section discusses the existing IoT communication protocols, explaining why LoRa and APRS were particularly chosen for this study.

A. LoRa

As this study focuses on IoT devices for smart farms, protocol selection was made within Low-Power Wide Area Networks (LPWANs). Two main factors should be considered when developing smart farm IoT devices: i) wide area coverage; ii) long battery life. Therefore, short-range communication protocols like Bluetooth or ZigBee are not likely used for IoT devices that require long-range communication and wide area coverage. LPWAN, on the other hand, provides long-range connections with low data transmission rates [3]. Hence, LPWAN should be used for low power IoT devices that transmit a small amount of data and require battery efficiency [4]. Smart farm IoT devices suite these descriptions, comparatively small data collected by sensors transmitted for long-range communication.

LoRa, NB-IoT, Sigfox, Weightless are some of the leading LPWAN technologies. This study specifically tests LoRa as it is known to provide long-range communication and long battery life on a low budget [5]. LoRa's advantages are shown in many studies. Ji et al. [6] successfully transmitted image data using LoRa technology. Kodali et al. [7] implemented an irrigation system in a smart farm through a web interface.

B. APRS

Automatic Packet Reporting System (APRS), based as 'amateur' or 'ham' radio frequencies, was designed by Bob Bruninga over 25 years ago. APRS enables real-time information exchange between multiple nodes and the processed data are visualized on APRS-Internet Service (APRS-IS) websites as the APRS infrastructure [8], [9]. APRS is transmitted on a shared local VHF frequency, depending on the country. North America uses 144.39 MHz. Although APRS was designed for large local areas, easy digital repeating with callsigns allows fast global communications [10]. Due to these characteristics, APRS has been used for real-time tactical, emergent situations.

There are many attempts such as Hajdarevic et al. [9] on building low-cost, low-energy APRS transceivers on micro-controllers or single-board computers such as Arduino and Raspberry Pi. Despite the increasing interest in building low-cost APRS transceivers and the characteristics of APRS suits for IoT devices, there was no available research that tested APRS as a networking technology for smart farms. This raised the question of why APRS is not applied in the IoT field. Therefore, this study ultimately aims to answer the question of the feasibility of APRS for long-range IoT device communications.

III. Approach

At first, the results were very different from our expectations. To minimize any errors, many attempts were made.

Both LoRa and APRS communication distance results were much shorter than calculated, theoretical results. After modifying LoRa's transmitter and receiver code by LoRa's TX power to 13, signal bandwidth to 125E3, and coding rate to 5 using LoRa Arduino API, the communication range results increased from 100 m to 1 km, as shown in Fig. 1. LoRa's communication distance could have been more than 1 km, but any further simplified distance tests were not made because 1 km would be enough to test on the farm.

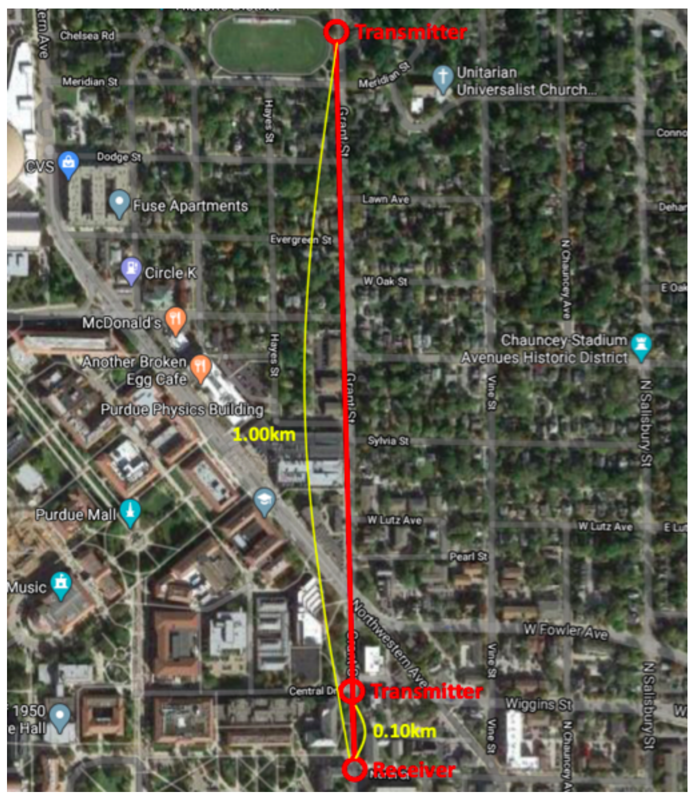

Fig. 1. Change of LoRa's range.

After realizing that there were initial problems with our APRS antenna, the antenna's ground condition, height, and whether the two antennas were properly polarized were checked. Since the antenna had a magnetized bottom, grounding was a crucial factor. Therefore, by attaching the antenna to a metal surface improved the performance. Also, to increase the communication range, the antenna needed to be installed higher, so the placing of the receiver antenna was changed from near ground to 4.5meters above the surface. Moreover, to transmit radio waves efficiently, the antennas needed to be installed in the same polarity. From these modifications, the communication range increased from 50 m to 890 m, as shown in Fig. 2. Since the test environment was an open space which was at most 890 m, the result could not be further. Due to the 10 m height difference between the transmitter and receiver antenna, the communication range increased than the previous setting when there was no height difference. Based on these attempts, we recognized the features of the antenna and were able to conduct proper experiments later on while adjusting the parameters given above.

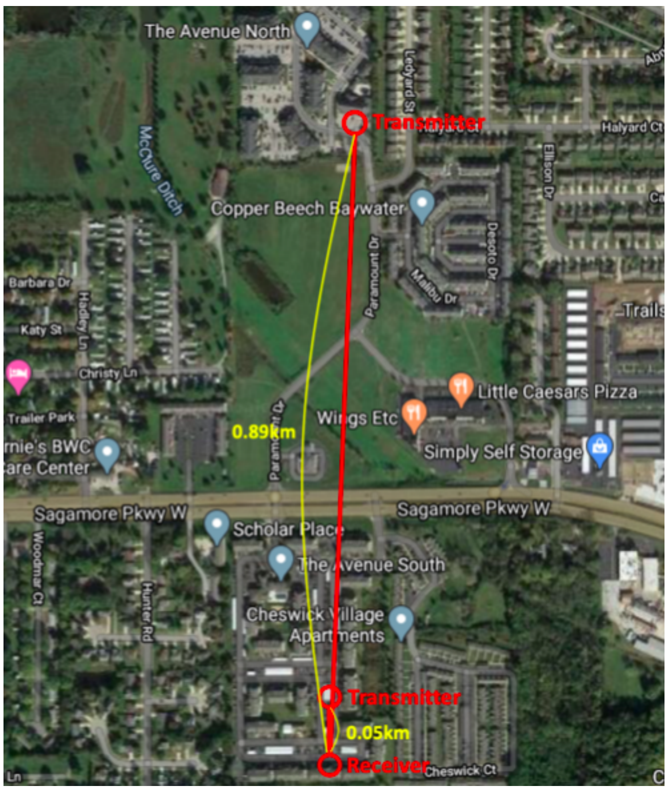

Fig. 2. Change of APRS's range.

Also, since LoRa and APRS used different kinds of antennas, it was difficult to find respective antennas for both the transmitter and receiver with the same gain. Thus, the experiments were conducted by making the sum of the gain of LoRa's transmitter antenna and LoRa's transmitted power as similar to the sum of the gain of APRS's transmitter antenna and APRS's transmitted power. This allowed LoRa and APRS EIRP to be equal. The transmitted power of LoRa and APRS was checked by using a spectrum analyzer. Since the transmitted power of the antenna connector was measured, this is the final output power that includes the cable and connector loss. This indicates the transmitted power discussed later in the paper.

IV. Results

For the feasibility test of LoRa and APRS, several tests have been conducted outside at the Purdue Agronomy Center for Research and Education. This section describes the test environments, multiple test results, and result evaluation for the range comparison of LoRa and APRS.

A. Test Environment

The range comparison tests between LoRa and APRS were conducted at the Purdue Agronomy Center for Research and Education. The tests were conducted by placing the receiving antenna at the weather station of the Purdue Agronomy Center for Research and Education. The receiving antenna of LoRa and the receiving antenna of APRS were installed on the same tower at the weather station building, but the height of the two antennas differed because the lengths of the two antennas themselves were different. The receiving antenna of LoRa was 4.0 meters high from the ground, and 6.4 meters high for APRS. Transmitting units were mobile while checking if the data were properly received at the receiving end via cell phone. Both mobile transmitters were moved via car. The antenna of APRS was securely attached to the roof of the car, while LoRa's antenna was held at the same height as the transmitting antenna of APRS, approximately 2.35 m. The locations of the transmitting points were all saved on Google Maps, which was later used to calculate the distance from the weather station to the transmitter. To minimize radio interference during testing, LoRa and APRS were tested alternately. In addition, cell phone calls were delayed until after transmissions. If the data were consecutively received, the transmitters were moved forward to a further distance from the receiving station. If not, the transmitters moved back closer and tested again. This process was repeated to find the last transmitting point where data was successfully received. All of the following results were derived by calculating the distance between the weather station and the last transmitting point using Google Maps.

B. Tests

Table 1 shows the overall range results from each test while Tables 1 and 2 show the antenna specifications for LoRa and APRS.

1) 1st Test: The transmitter and receiver of LoRa consist of Arduino and LoRa Shield v1.4. The antenna gain for both transmitting and receiving ends is 2.14 dBi. Both antennas were held by a hand on about 1 m above ground. The transmitted power measured by the spectrum analyzer was 16 dBm. Due to weather conditions, the receiver antenna was inside the weather station. The maximum range was 160 m.

TABLE I
RANGE RESULTS FROM MULTIPLE TRIALS

# Test	LoRa	APRS
1st Test	0.16 km	1.30 km
2nd Test	4.2 km	0.70 km
Final Test	4.2 km	0.86 km

TABLE II
LoRa Antenna Specifications

Specifications	1st Test	2nd Test	Final Test
Transmitter Antenna Gain	2.14 dBi	9 dBi	9 dBi
Transmitted Power	16 dBm	16 dBm	16 dBm
Receiver Antenna Gain	2.14 dBi	6 dBi	6 dBi

TABLE III
APRS Antenna Specifications

Specifications	1st Test	2nd Test	Final Test
Transmitter Antenna Gain	2.14 dBi	2.14 dBi	1.17 dBi
Transmitted Power	15 dBm	20 dBm	24 dBm
Receiver Antenna Gain	6 dBi	6 dBi	6 dBi

APRS used Arduino and HX1 transmitter while the antenna was connected using patch cables. Software Defined Radio (SDR), powered by a laptop and an antenna was used as the receiver for APRS. The gain of the transmitter antenna for APRS was 2.14 dBi and the transmitted power was 15 dBm. For the receiver, the antenna gain was 6 dBi. At that time, the maximum distance was 1.3 km. Transmitting and receiving conditions were generally good, although some of the data was missed from time to time.

2) 2nd Test: LoRa had both transmitter and receiver antenna changed. Previously, the antenna gain for both antennas was 2.14 dBi. With the new antennas, the transmitter antenna had 9 dBi gain and the receiver antenna had 6 dBi gain. The transmitter antenna was attached to the car roof at about 1.8 m above the ground. With the new antenna specifications, LoRa was able to cover 4.2 km, successfully receiving data.

For APRS, the setup for both sides was the same as before, except for a slight circuit modification. A transistor was added to amplify the output power of the transmitter. While the transmitter antenna gain was identical to 2.14 dBi, the output power increased to 20 dBm by using the transistor. Two tests were conducted on this second test: i) without transistor; ii) with the transistor. APRS covered 670 m without using the transistor, while it covered 700 m using the transistor. The result was significantly different from the first test because there was a connection problem in the transmitter antenna. It was found after the test.

3) Final Test: LoRa used the same specifications for the entire transmitter and receiver system as the previous test. The results were also identical to the second test, covering 4.2 km, as shown in Fig. 3.

To reduce the signal attenuation in the APRS circuit system, 50-ohm cable (RG213 50 Ohm Coax Cable) was used instead of the patch cable to connect HX1 and the transmitter antenna. By doing so, the output signal from the HX1 increased, and the transmitted power measured by the spectrum analyzer was 24 dBm after removing the transistor. Since HX1 can handle signal power up to 24.7 dBm, the transistor was removed from the circuit. APRS also changed the transmitter antenna after the second test. As the transmitted power of APRS increased, the transmitter antenna was changed to make it similar to LoRa's EIRP of 25dBm. The APRS's EIRP was 25.17 dBm.

TABLE IV
Final Hardware Setup for LoRa and APRS

LoRa	Arduino Uno Arduino LoRa/GPS Shield v1.4 wlaniot 900MHz Antenna 824-960 MHz 6 dBi 900MHz Omni Antenna
APRS	Arduino Uno Radiometrix HX1-144.390-3 USRP b200 USB Software Defined Radio X2200A Dualband Base/Repeater Genuine Nagoya UT-72

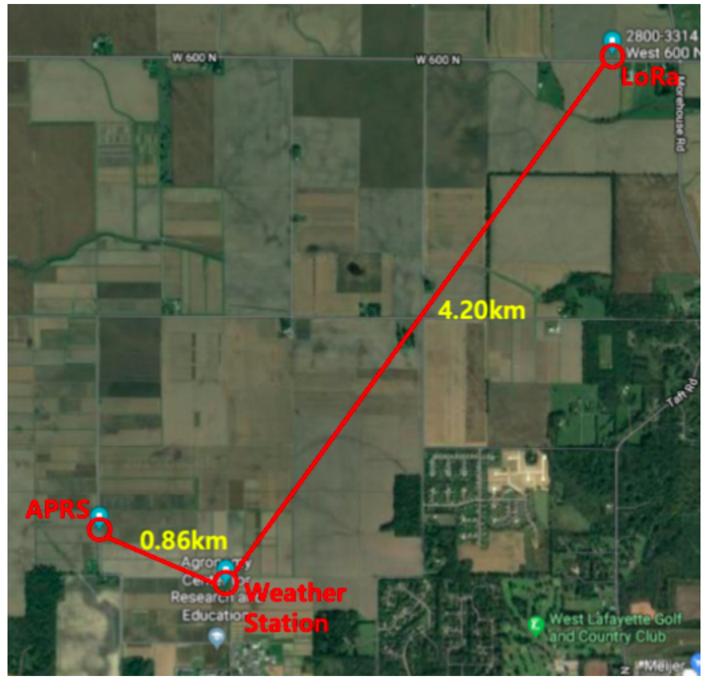

Fig. 3. LoRa and APRS final range.

With the newly alternated APRS circuit and antenna, APRS was able to cover 0.86 km.

C. Final Setup

Tables 3 and 4 list all the hardware that was used to build the transmitter and receiver system for LoRa and APRS.

1) LoRa: To facilitate the use of LoRa network, LoRa/GPS shield attached to an Arduino was used, as shown in Fig. 4. The 915 MHz transmitter and receiver antenna had 9 dBi and 6 dBi gain. The transmitted power by the spectrum analyzer was 16 dBm. This resulted in the LoRa radio's EIRP of 25 dBm.

2) APRS: Arduino Uno and HX1 chip were used to transmit APRS packets at 144.390 MHz, as shown in Fig. 5. Since the lack of a radio shield for APRS, the HX1 was directly controlled to send signals. The transmitter antenna was suitable for 144-148 MHz frequency, with 1.17 dBi gain. The transmitted power measured by the spectrum analyzer was 24 dBm. 50-ohm cable was used to connect the antenna and the HX1 transmitter to reduce signal loss. To receive APRS data packets, USRP b200 and antennas were used for hardware

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Fig. 4. LoRa's transmitter and receiver (antenna varies).

as shown in Fig. 6, and GNU radio running on Ubuntu. The receiver antenna had 6 dBi gain, making APRS's EIRP 25.17 dBm.

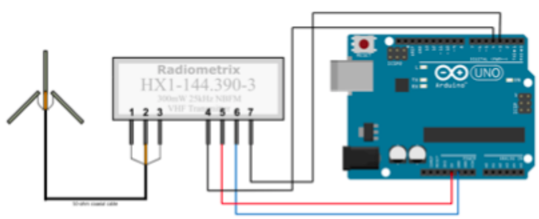

Fig. 5. APRS's transmitter.

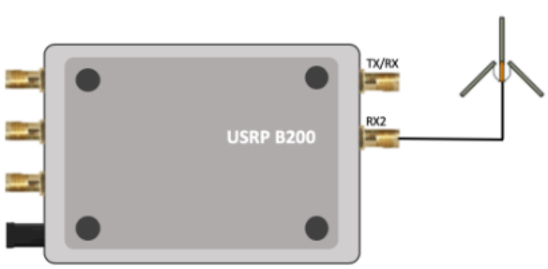

Fig. 6. APRS's receiver.

D. Test Evaluation

With the antenna specifications that were used for the final test, the Friis transmission formula was used to review the final range results:

$$P_{rx} = P_{tx} G_{tx} G_{rx} \left(\frac{c}{4\pi D_r f_0} \right)^2 \tag{1}$$

$$P_{rx}\,(dB) = P_{tx} + G_{tx} + G_{rx} + 20\log_{10}\left(\frac{\lambda}{4\pi D_r} \right) \tag{2}$$

"The Friis Transmission formula is a basic equation used to calculate the received power of a basic receiver at a fixed distance from a transmitting system" [11].

According to the Friis Transmission formula, theoretically, APRS should have covered a longer range than LoRa, as shown in Table 5. However, according to the final results, APRS's range was much shorter than LoRa's. To understand the reasoning of the final test results, the Fresnel zone radius was calculated.

The definition of Fresnel zone is the size of the elliptically-shaped area of RF propagation between a transmitter and receiver antenna.

Objects within the area of the Fresnel zone can reflect radio waves and induce multi-path propagation issues between the transmitter and receiver, where direct path line-of-sight radio waves and the reflected path radio waves are received out of phase from one another. [12]

Therefore, to have no interference, it is important to have no obstacle in the Fresnel zone. This zone could be calculated by a Fresnel Zone Calculator:

$$Radius\,(mts.) = 17.31 \times \sqrt{\frac{D\,(in\,km)}{4 \times f\,(in\,GHz)}} \tag{3}$$

The antennas must be located within the 60% of the radius obtained through the Fresnel zone theory, shown in Table 5, for seamless communication [13].

The result of the Fresnel zone radius indicated that to communicate around the theoretical 59.7 km, the theoretical distance, away using APRS, the antennas for both transceiver and receiver antenna must be at least 105.61 m above the ground. However, the antennas for testing were installed within 6.4 m above the ground. Additionally, to calculate the efficiency constrained by height, the tested distance was divided by the theoretical distance. LoRa was 45.16%, while APRS was 1.44%, as shown in Table 5.

V. Conclusions

This study was proposed to determine whether LoRa or APRS is more feasible for networking technology in smart farms. The location of the experiment for the range of both networks was at the Purdue Agronomy Center for Research and Education. According to the test results, LoRa's final range was 4.2 km, when the transmitter antenna gain was 9 dBi and the receiver antenna gain was 6 dBi. While APRS range was 0.84 km, with 1.17 dBi of transmitter antenna gain and 6 dBi of receiver antenna gain.

The efficiency constrained by height from the final test results was 45.16% for LoRa and 1.44% for APRS.

Both of the estimated antenna installation heights calculated from the Fresnel zone radius are at a considerable height above the ground (AGL), that the majority of the smart farm system cannot meet the circumstances. When comparing the installation possibility of the two networking technologies, LoRa's theoretical distance was more achievable than APRS. Therefore, the result indicates that LoRa is more feasible than