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Building a Technology Platform for Smart Agriculture Deployments Using C-Band and Unlicensed Technologies

A Technical Paper prepared for SCTE•ISBE by

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Introduction

This paper demonstrates how synergies between C-Band and unlicensed wireless technologies for massive connectivity in conjunction with IoT devices can enable a Smart Farm business vertical. The purpose of this project was to investigate areas where multiple access technologies along with IoT devices can demonstrate real savings and provide the basis for a model for managed IoT services in actual deployments along with investigating the range and performance of C-Band in rural broadband applications. Using available LoRa IoT sensors for monitoring various elements around the farm we designed and deployed a complete LoRa network to collect and house the device reports. Data visualization and presentation aspects were done through partnerships. The end user can view the data either through a web-based portal or with an app that runs on either a Virtual Reality HMD or Android device (i.e. smart phone or tablet). We have also seen a sizeable potential for a new business vertical for a cable MSO who would deploy such a system across a wide geographical footprint to serve US agricultural customers. These kinds of platforms could also be expanded to address other verticals like Industrial Automation, Health Care, and Smart Cities.

Content

1. Background and Trial Purpose

Rural agricultural communities have historically been the last places to receive access to high-speed networks. Through low latency and massive connectivity, 5G is capable of improving farmers' lifestyles by making their tasks more efficient and cost effective.

The Charter Wireless R&D team is conducting a trial on a working farm in Eastern Iowa which began in the fall of 2018. The farm is family owned and operated and is just outside the town of Keystone, which is about 30 miles west of Cedar Rapids. It consists of approximately 250 acres on which both corn and soybeans are grown. In addition to these crops there are 4 hog houses nearby with about 2500 hogs in each. Our goal for this project is to develop a widely deployable and scalable platform that provides demonstrable benefits with a positive business case for both grain farms and livestock farms but can also be extendable to other business segments and verticals. This will allow an MSO like Charter to develop new service offerings in areas that are beyond the traditional scope of a cable operator.

By making use of a cloud-based platform for collecting, analyzing, and displaying IoT sensor data in an immersive environment, farmers are able to remotely access and oversee their farms from anywhere. The developed platform provides building blocks for other use cases including Home Security, Industrial Automation, Smart Healthcare, and Smart Cities.

2. Trial Network Architecture

The overall Smart Farm trial solution platform consists of 4 major components: 1) the IoT sensors, 2) the cloud service that collects and manages the IoT data, 3) the fixed wireless link that provides rural broadband connectivity to the farm, and 4) the graphical user display application that includes overlaying the IoT data on a 360 degree live video.

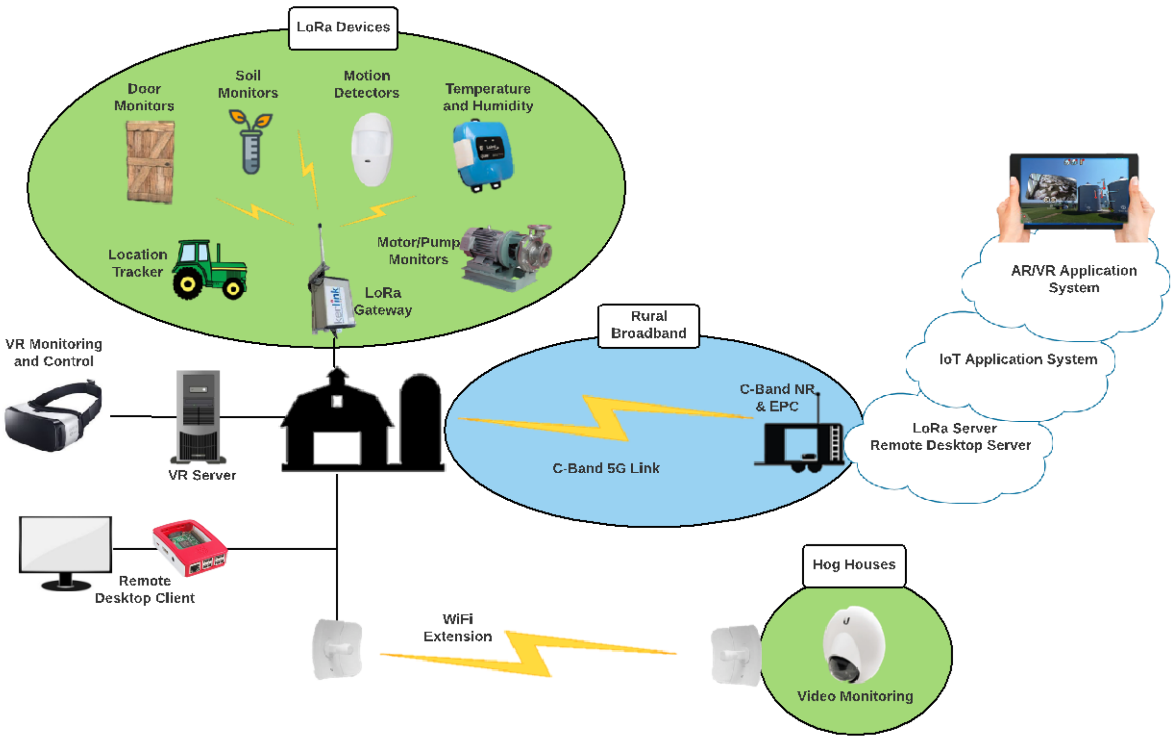

Figure 1 - Smart Farm trial network architecture

For the trial system, the deployed LoRa IoT devices utilize the 900 MHz unlicensed spectrum band. The point-to-point network WiFi extensions utilize both the 5 GHz (802.11ac) and 60 GHz (802.11ad) unlicensed bands. The IoT RF data transmissions are received by a central LoRa gateway installed at the main farm complex which then sends the data packets though a secure IP tunnel to the cloud-based LoRa server and IoT application system. A separate cloud-based AR/VR application system powers the user interface which overlays the collected IoT data onto live or pre-recorded video.

3. IoT Sensors

The Smart Farm trial deployment consists of more than 70 IoT sensors and network devices. These devices include:

- Door monitors
- Soil monitors
- Motion detectors
- Motor activity monitoring
  - Grain bin blower
  - Hog house window shade
  - Water pump monitor
- Temperature and humidity monitors
- Location tracker
- Cameras: security and thermal

The trial system includes a total of 14 moisture sensors in the surrounding fields. Moisture probes at multiple soil depths are deployed to provide readings at 1ft, 2ft, and 3ft levels. All of the soil sensors operate on the LoRa system and provide soil moisture measurements every 1 hour. The purpose of using sensors at multiple depths is to provide an understanding of the moisture levels for the entire root depths of the crops.

Figure 2: left - LoRa gateway installed on the farm house, right: installing soil moisture sensor

There are 5 grain storage bins at the main farm complex. These bins are used to store the harvested grain and provide an environment for drying the grain to optimum moisture levels before sale on the market. Multiple LoRa sensors are deployed in each of the grain bins to measure temperature and humidity levels. One sensor is attached to the underside of each bin roof and a second identical sensor is suspended from a rope and deployed inside the grain about 2 meters from the top of the bin. The reason for this is to 1) compare the readings from the two sensors to see if there is an appreciable difference between them due to placement in the bins and 2) to investigate the amount of RF penetration loss of the grain in the bin.

Figure 3 - Main farm complex with grain bins (right), machine shed (center), and farm house (left). Hog house #1 is in the background to the left of the grain bins.

There are 4 hog houses which are not at the main farm complex. Hog house #1 can be seen in Figure 3 and is roughly 600 meters to the east. Hog house #2 is about 2 km northeast. Hog houses #3 and #4 are adjacent to one another and are 4.5 km to the west. In each of the 4 hog houses there are deployed 2 different types of LoRa environment monitors. The first type is the same type as the ones that are deployed in the grain bins to monitor temperature and humidity. The second type is a more capable device and monitors temperature, humidity, CO2 levels, as well as barometric pressure.

Door monitors are deployed on each entry door of the hog houses as well as the machine shed in the main farm complex. Using an activation magnet these sensors are triggered by door open and close events and simply send an event message to the LoRa network which is recorded by the cloud-based IoT application system. The IoT cloud system can be configured to generate alarms upon door events during certain hours of the day. The generated alarms can send notifications to alert designated individuals of the events.

There are 5 instances of equipment monitors – hog house fans, hog house window shades, hog feed trough, grain bin blower, and well pump. Relays are used in each instance to trigger the accompanying LoRa devices when power is activated and de-activated. In one case there is a well pump being monitored that is over 2 km away from the main farm complex.

In another instance a custom device was constructed using a programmable LoRa module with a GPS carrier board to create a device with vehicular tracking capability. This custom device was mounted on the farm's tractor and is powered by 12V from the vehicle. Once synced to GPS it transmits a position reading in a custom LoRa message every 12 seconds. Using the coordinates from the LoRa message a location dot is then plotted on a digital map to show the present and recent locations of the tractor.

WiFi network extensions have been set up between the hog houses and the farmhouse complex. Point-to-point 802.11ac devices at 5 GHz are used for the longer distance links (500m – 4.5 km), and point-to-point 802.11ad devices at 60 GHz are used for high bandwidth shorter distance links (< 100m).

Each of the 4 hog houses has 2 HD video cameras mounted in them. This allows for monitoring of the livestock from anywhere via the user interface. The required bandwidth for the HD RTSP video streams

(~4 Mbps) is too much for the LoRa system to accommodate so the video streams are carried by the WiFi links.

Figure 4 - Image from hog house #1 video camera.

In one of the hog houses there are an additional 2 FLIR thermal cameras. With additional computing resources it could be possible to recognize deceased animals and send notifications upon detection which would provide an increased benefit to the livestock manager. This detection capability was beyond the scope of this trial, but the cameras were installed to illustrate the potentials and determine possible system requirements for such a feature.

4. C-Band Rural Broadband Connection

The transport connection for the IoT data is a fixed wireless broadband link using C-Band spectrum. We obtained a special temporary authority (STA) permit from the FCC to use a 100 MHz channel in the C-Band spectrum, in which we deployed pre-commercial 5G NR and UE equipment for this trial.

Figure 5 - Wireless field test trailer with extendable radio mast for 5G NR and EPC equipment

In the 100 MHz C-Band channel we were able to demonstrate 429 Mbps of broadband downlink throughput at a distance of 4.5 km with a prototype radio software load. Higher throughput speeds will be achieved with production software loads as more features and capabilities are incorporated into the radio products. The 5G equipment vendor estimates that they should be able to provide at least 800 Mbps at a distance of 4.5 km using full production software. One thing to note is that this estimate is based on an NR antenna height of 10 meters which is the mast height of the trailer that was used in our testing.

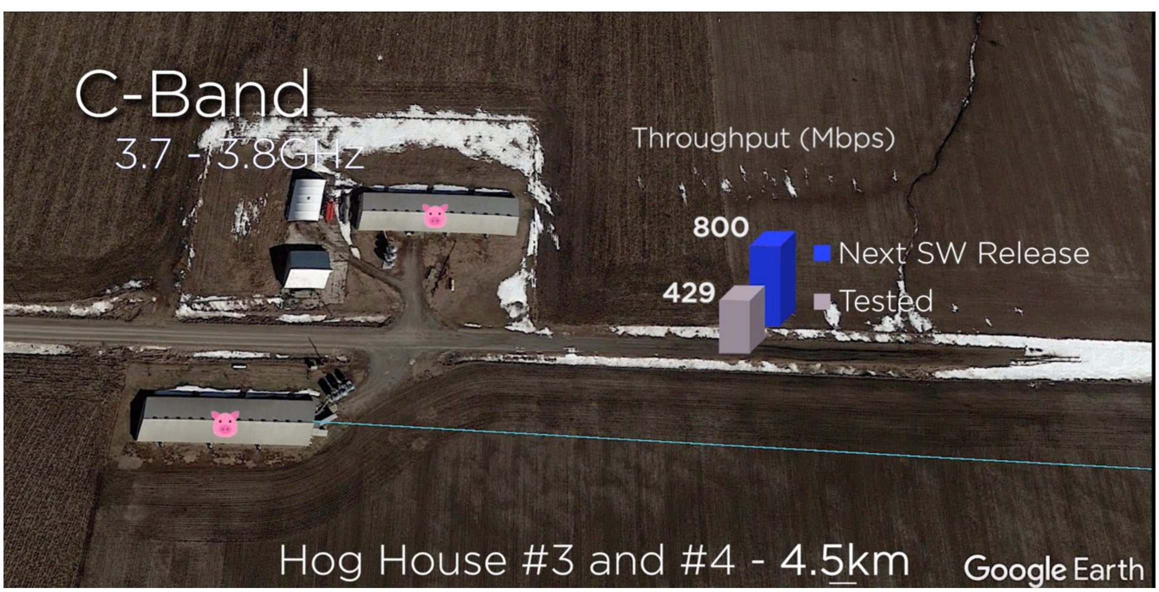

Figure 6 - C-Band rural broadband connection

For shorter link distances, e.g. 1 - 2 km, the estimated achievable throughput is well over 1 Gbps. Again, this estimate is based on an NR antenna height of 10 meters. So for typical rural deployments where the NR antenna height could be 50 – 100 meters, we could expect throughput speeds in a 100 MHz C-Band channel to be in excess of 1 Gbps for a much greater distance than what we have seen in this trial.

A farm of the size that is used in our trial (250 acres) covers a total area of 1 sq km. A rural broadband cell site with a service radius of 5 km would cover more than 78 sq km. So with a single 100 MHz channel in mid-band spectrum, a service provider could offer a 1 Gbps service to ALL of the farms under that cell footprint with an oversubscription ratio of 78. Of course, other service offerings can be created as desired by the service provider to accommodate their customers' needs.

In addition to transporting IoT data, the C-Band rural broadband connection enables new applications and services such as remote desktop. This type of service can provide high-power, low-cost and low maintenance (for the user) computing resources to users and locations where full computing platforms may be neither desirable nor cost-effective.

5. AR/VR User Interface

The main aspect of the user interface is an application that uses the IoT data from the IoT Application System and overlays it on multiple 360 degree visual environments.

The Unity Application was designed for PC-based VR HMD's as well as Android-based platforms. It is currently being ported to more lightweight standalone HMD's to decrease the initial investment.

The application consists of the following features:

- 1x 4K 360 degree livestream (35 – 50mbps)
- 1x Mavic Pro Drone livestream (5mbps)
- 2x 720p Thermal camera livestreams (3mbps)
- 6x 1080p Security camera livestreams (30mbps)

Since the number of 360 cameras and total bandwidth was limited, some of the 360 environments were pre-recorded. However, the pre-recorded environments still allow for an immersive sense of presence (Figure 7). In both versions of the application, the user can change their surroundings and "travel" between the main farm complex and the surrounding hog houses (Figure 8).

Security cameras give a live video feed of the hogs during the day, while Thermal cameras provide the ability to see them at night. Proper heat-sensing thermal cameras have the potential for predicting livestock health issues and death.

Another implemented user interface feature allows alerts to be set up to alert the farmer when parameter thresholds are triggered by sensor readings. Heaters and fans can be automatically adjusted to account for fluctuations. Two-way interaction with the sensors can also be implemented to allow for manual adjustment while the farmer is remote.

If the farmer is somehow unable to visit the surrounding hog houses or crop fields, drone interaction has been integrated into the application. The livestream from the drone's camera is viewable in the application (Figure 9). Currently, the livestream operates over LTE, resulting in an input latency that doesn't allow for precision remote control. Hence, predetermined waypoints were added to reduce the presence of latency and decrease the possibility of motion sickness.

The current iteration of the VR application interaction is agnostic of the 360 degree video feed; the visualization of your hands in virtual reality originates at the user end and is not streamed. While the 360 video feed itself may contain latency, it will never promote motion sickness as your body's representation in virtual reality is maintained in real-time. As HMD's become smaller and the processing power moves to the edge, latency issues will need to be dealt with in order to prevent motion sickness. The common accepted max value for latency in VR streaming is approximately 20ms.

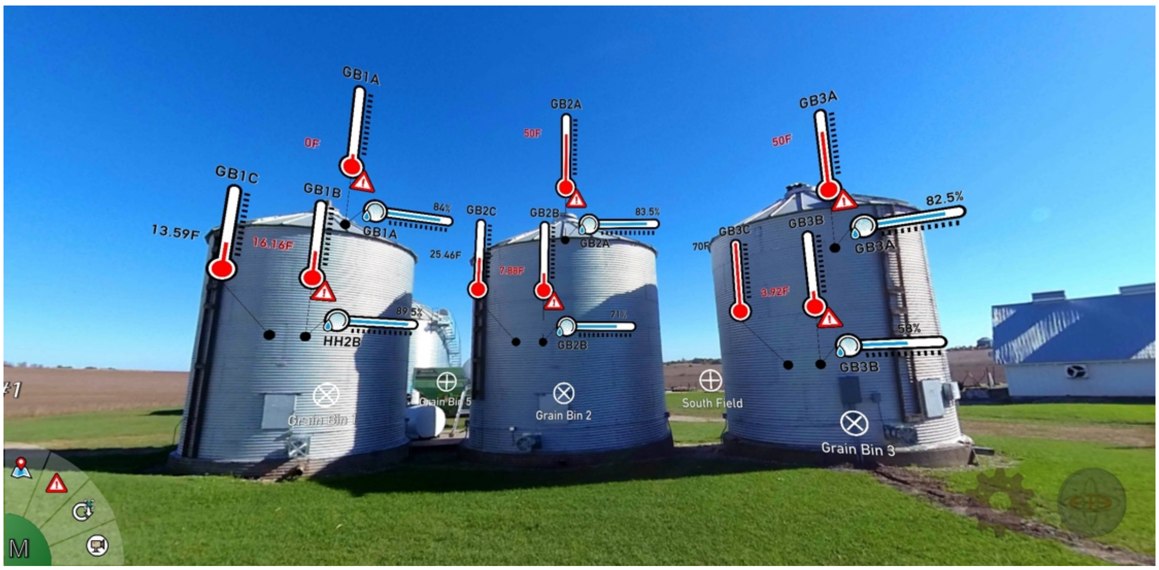

Figure 7 - Temperature and Moisture sensors in the grain bins reduce spoilage and increase yield.

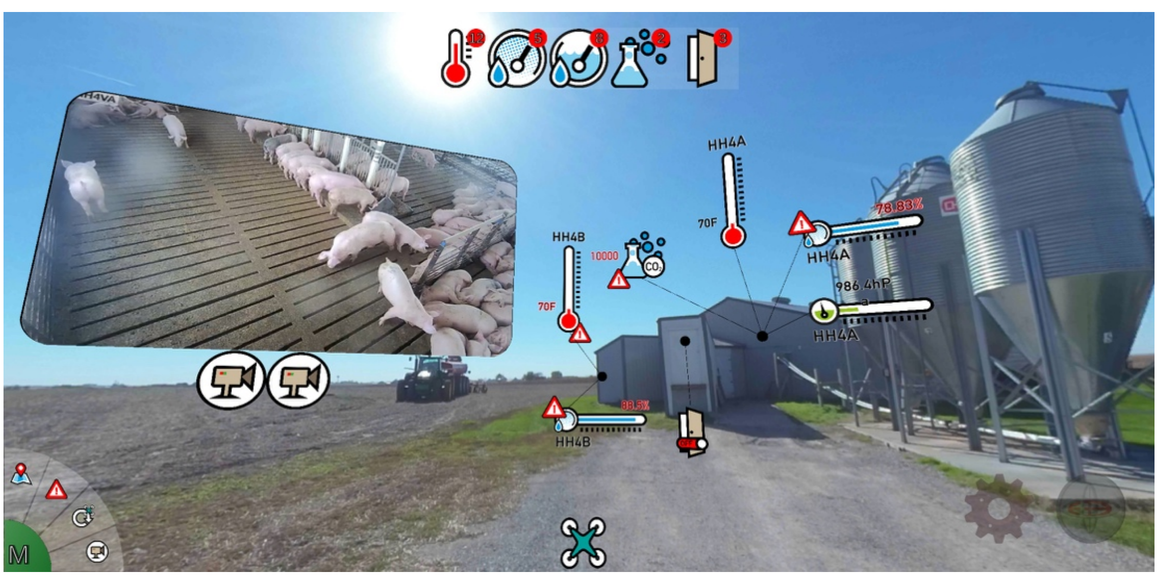

Figure 8 - Security cameras show live footage of the hogs. All pertinent information is available virtually.

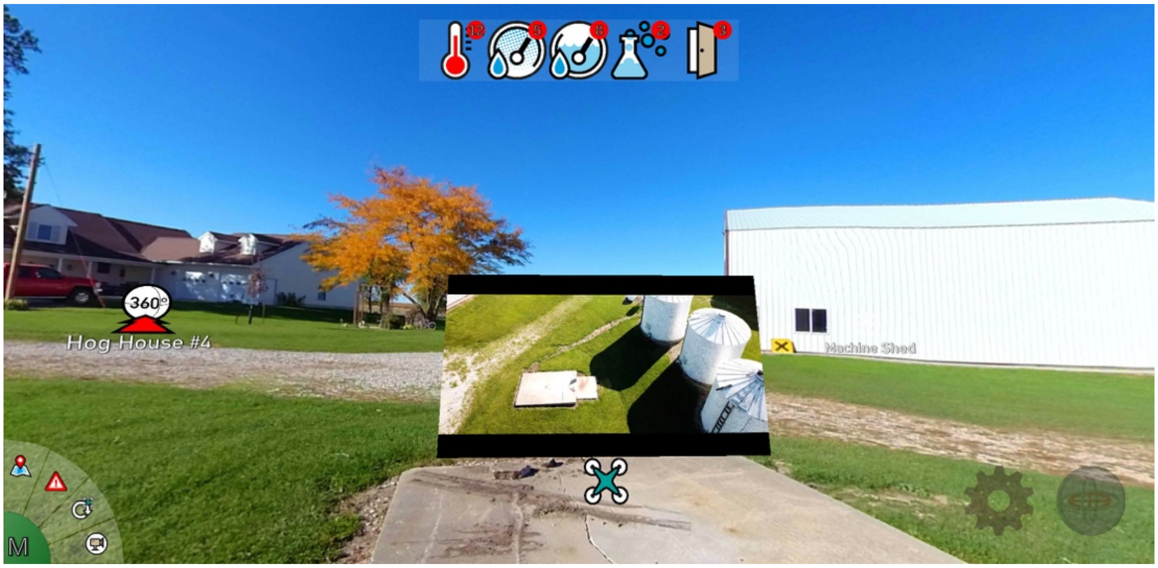

Figure 9 - Need to visit a site in real-time? Remotely fly a drone to a pre-determined waypoint.

Conclusion

Smart Agriculture is one example of a burgeoning multi-billion dollar industry that can dramatically improve cost savings while presenting an opportunity for a new MSO business vertical through rural broadband. The deployed technology behind the Charter R&D 5G-powered Smart Farm is, at its core, a true rural broadband connection with an immersive user environment for displaying mission critical IoT sensor data which enhances operational efficiency and productivity for a real working farm in two agricultural categories. By utilizing available smart devices, netcams, drones, and 360 videos, all with unlicensed spectrum, the platform can be adapted to any environment in a variety of different business verticals. This allows a cable MSO such as Charter to address new business opportunities in a cost efficient and scalable manner to enable new valuable service offerings while still leveraging their existing infrastructure and work force.

Abbreviations

5G	5^{th} Generation mobile network
AP	access point
bps	bits per second
FLIR	Forward Looking InfraRed
GHz	GigaHertz
GPS	Global Positioning System
HD	high definition
IoT	Internet of Things
JSON	JavaScript Object Notation
LoRa	long range (wireless IoT standard)
MHz	MegaHertz

MSO	Multiple System Operator
HMD	head-mounted display
RF	radio frequency
RTSP	Real-time Streaming Protocol

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