Beyond Sensing: Suitability of LoRa for Meshed Automatic Section Control of Agricultural Vehicles

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***Abstract*—LoRa is a wireless communication technology that is well-known for its use in long-range sensor data collection, primarily as a part of the LoRaWAN stack. In contrast, in this paper we investigate the suitability of plain LoRa and its use for more complex and more demanding applications in the agricultural domain. We describe meshed Automatic Section Control (m-ASC) as a prototypical application of connected vehicles in the agricultural domain. It allows multiple vehicles to conduct the same work in the same field in parallel by selectively turning off sections of their equipment (e.g., individual sprayer nozzles) in regions that have already been cultivated by another vehicle. We conduct both field experiments and computer simulations to investigate the performance of LoRa. We demonstrate that LoRa is a promising basis for this use case, allowing for long-range communication even under Non-Line-of-Sight (NLOS) conditions and meeting the demands of this example application with ample room for higher-performance and more complex applications.**

I. INTRODUCTION

Modern farms are already using the Internet of Things (IoT) to monitor crops, soil, and the environment using networked sensors. In the future, however, it will also be possible to cultivate agricultural land collaboratively using many networked agricultural machines.

A common, non-networked system is Automatic Section Control (ASC), a precision agriculture technology for spraying, planting, and fertilizing that allows boom sections of an agricultural machine to be switched off automatically when it passes over previously cultivated areas. Luck et al. [1] were able to demonstrate that ASC systems can achieve a significant reduction of overapplication. To date, however, it has not been possible to use ASC for joint cultivation of areas because each machine stores only its own cultivated areas, thus would not omit areas cultivated by others.

In order to extend ASC to multiple machines working a field in parallel, it will be necessary to guarantee that all machines have a shared understanding of already-cultivated regions. We refer to this as *meshed Automatic Section Control (m-ASC)* (cf. Figure 1). To establish an m-ASC system each machine would only need to be equipped with a radio module that establishes a wireless network with other agricultural machines (in addition to upgrading its software). The agricultural machines can then exchange their cultivated areas via the wireless network.

Schlingmann et al. [2] of the Agricultural Industry Electronics Foundation AEF, one of the major industry associations, are investigating the concept of cooperative agricultural machinery using Inter-Vehicular Communication (IVC). One of the often-mentioned use cases is precisely this exchange of cultivated areas. Arguing that only 30 % of the landscape is covered by wireless connections [3], the authors suggest using IEEE 802.11p-based technology for connecting agricultural machinery. Supported by the AEF, Klingler et al. [4] thus conducted a feasibility study for the use of IEEE 802.11p in an agricultural environment. They tested Received Signal Strength (RSS), delay, and goodput of IEEE 802.11p. The result of the study was a maximum distance of 1700 m since no further data could be exchanged after Line-of-Sight (LOS) was lost. Additional RSS reductions decreasing channel quality were due to the size and shape of the agricultural machinery, in particular harvesters. Zhang et al. [5] took a different approach and used IEEE 802.15.4 to exchange the relevant control data for a leader-follower system in which an unmanned tractor can follow another one. Still, the authors state that their system does not offer a wider range.

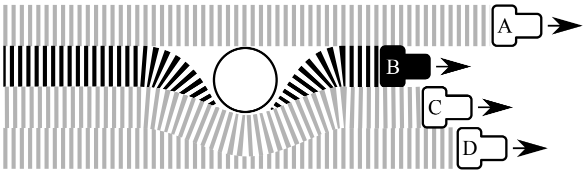

Figure 1. Concept: four agricultural machines (A, B, C, D) are jointly cultivating a field. A meshed Automatic Section Control (m-ASC) system ensures that already-cultivated areas are skipped.

In this paper, we therefore investigate another promising technology for networking agricultural machinery which can enable communication especially in large fields and in Non-Line-of-Sight (NLOS)-scenarios: LoRa. In particular, we investigate how to use mobile LoRa mesh networks (as opposed to infrastructure-supported configurations like, e.g., LoRaWAN) to support a prototypical use case of m-ASC. We investigate to which degree the requirements of such an m-ASC system are fulfilled by LoRa in challenging environments and demonstrate a very good fit – even though this use case is beyond simple sensing, which the technology is otherwise known for.

II. RELATED WORK

LoRa and LoRaWAN have been explored extensively to support wireless sensor networks at scale in the agricultural domain. To give just one example, Codeluppi et al. [6] developed a platform called LoRaFarM to monitor environmental data on a real farm in Italy.

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(a) forest 1, aerial view (b) forest 2, ground view

Figure 2. Two examples of forest *islands* in a field.

Outside of the agricultural domain, LoRa has also been explored as a technology for Vehicle to Everything (V2X) communication. For example, Haque et al. [7] explored a system for direct device-to-device communication between vehicles and between a vehicle and a road side unit. Based on field operational tests, they showed that the technology is robust, reliable, and suitable at speeds from 15–50 km/h and with data packets of 40 Byte. Moreover, Cheung et al. [8] demonstrated that a V2X communication system based on LoRa and LoRaWAN can enable robust connection between autonomous vehicles at sufficient data rates and latencies.

We go one step further and investigate the combination of both use cases, the suitability of LoRa V2X communication for typical demands on scale, robustness, data rates, and latencies of an agricultural use case under non-ideal conditions.

III. REQUIREMENTS ON COMMUNICATION TECHNOLOGIES

A key requirement of wireless communication on fields stems from the (lack of) existing radio network coverage. Bacco et al. [9] point out that fields in America, Russia, and continental Europe can be very large and that one must assume that no infrastructure is available. This makes Device-to-Device (D2D) communication technologies such as LoRa a salient choice.

An additional requirement is a consequence of the spatial dimensions and geometry of the fields to be cultivated and their immediate surroundings: In some countries of the world, fields with sizes of more than 1 km^2 account for 20 % or even more than 50 % [10] – and uniformly cultivated fields with side lengths of up to 4.25 km can be found in the U.S. [11]. Furthermore, fields are not only located in flat but also in hilly regions, which imposes additional demands on the radio technology to be used. In addition, fields can be of any shape; in particular they can contain *islands* (cf. Figure 2a) on which wind turbines, electricity pylons, buildings, or even forests (cf. Figure 2b) are located. Thus, the performance of a radio technology in NLOS-scenarios is of particular importance in agricultural applications.

IV. PERFORMANCE OF LORA ON FIELDS

We start by investigating to what degree LoRa can fulfill the requirements set out in Section III.

As the suitability of LoRa for long-range communication across open fields is well documented [12], we focus on its performance in NLOS settings. For this, we conduct two measurement campaigns.

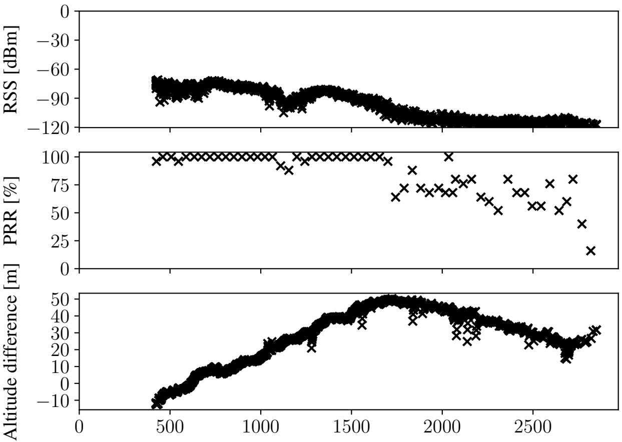

Figure 3. Received Signal Strength (RSS), Packet Reception Rate (PRR), and altitude difference vs. distance in Non-Line-of-Sight (NLOS)-scenarios caused by terrain: The field ascends up to a distance of about 1700 m, then descends again.

For both experiments we use LoRa-enabled devices with omnidirectional antennas which operate in the 868 MHz frequency band (*LILYGO TTGO T-Beam V1.1 ESP32*) and are running Sandeep Mistry's *arduino-LoRa* stack (v0.8.0). Power supply and data logging were done by a USB-connected laptop.

We mounted the transmitter and receiver on wooden poles at a height of 3 m and pointed the antenna upwards. This is because, in general, higher up, it is easier to keep the Fresnel zones clear of obstacles and thus increase the range. However, the maximum height is limited by the working machine. In Germany, for example, every agricultural vehicle must have a height of less than 4 m (Regulation StVZO §32 II). A height of 3 m can therefore be considered realistic.

We perform the experiments with a Spreading Factor (SF) of 7, a Coding Rate (CR) of ⅘ and a bandwidth of 250 kHz at a frequency of 869.525 MHz. The transmit power was configured to 100 mW – well below the 500 mW limit applicable in Europe and Germany [13], [14].

The transmitter stays in one place during the field experiments and sends a 248 Byte-packet every second (corresponding to an 8 Byte header plus 30 polygon coordinates). The receiver is mobile and logs, for every received packet, its RSS value as well as the current GPS position. Sent packets are also logged and include a sequence number to calculate the Packet Reception Rate (PRR) as the ratio of number of sent packets to number of received packets for different distances.

In the first field experiment, we investigate NLOS communication caused by the terrain. For this purpose, we conduct the field experiment on a hilly field in Thuringia, Germany.

Figure 3 illustrates the results. Only negligible packet loss can be observed up until the point where the receiver disappears behind the top of the hill, at a distance of 1700 m. Still, the PRR drops to only approx. 50 %, meaning that, well into the radio shadow of the hill, communication is still possible if adequate redundancy was contained in the data. Beyond a

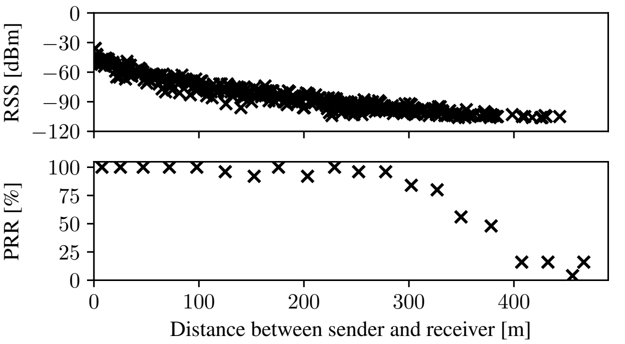

Figure 4. Received Signal Strength (RSS) and Packet Reception Rate (PRR) vs. distance in Non-Line-of-Sight (NLOS)-scenarios caused by vegetation: Dense pine forest in northern Germany (cf. Figure 2b).

distance of 2750 m, still in the radio shadow of the hill, no communication is possible any more.

In the second field experiment we analyze NLOS communication caused by vegetation. We conduct this field experiment in a dense pine forest in northern Germany (see Figure 2b).

Figure 4 illustrates the results: PRR remains above 90 % up to distances of 280 m. PRR then drops until no more communication is possible at distances beyond 400 m.

The results of both field tests indicate that LoRa can be used very well as a communication technology in agriculture: Communication (which was already known to remain stable at high distances over empty fields) can even tolerate small forested islands and hills.

V. REQUIREMENTS OF M-ASC

Having established the performance of LoRa on fields in general (see Section IV)) we now turn to the requirements of m-ASC, as defined by the amount of data to be exchanged.

We derive these requirements empirically from the following preliminary experiment. We use the agricultural machine software *Lacos LC:NAVGUIDE* to simulate an ASC-system. In outputs the data that would be recorded by a real crop protection sprayer with a total boom width of 36 m, driving at a speed of 10 km/h along a GPS track previously recorded by a real and equally-wide crop protection sprayer cultivating a 2.1 km^2 field near Fraßdorf, Germany (51.73° N, 12.13° E).

The software records cultivated areas as multipolygons, each consisting of an ID, a list of polygons, and a timestamp for the start and end time. The coordinates of each polygon consist of longitude and latitude in WGS84 format. To obtain an accuracy of at least 1.2 cm, the coordinates must be stored with at least seven decimal places.

The agricultural machine software generates a data trace of 27 300 s consisting of a total of 582 polygons. The number of coordinates per polygon ranges from 5 to 74. The exact distribution of coordinates per polygon is plotted in Figure 5. As can be seen, many polygons contain either 5 coordinates or approx. 30 coordinates.

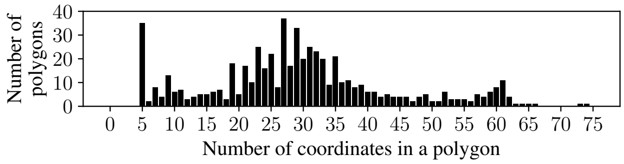

Figure 5. Distribution of number of coordinates per polygon on the simulated field as generated by the agricultural machine software.

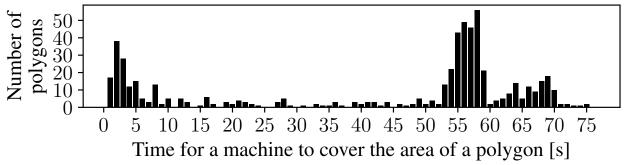

Figure 6. Distribution of time taken for cultivating the area of one polygon in the data trace generated by the agricultural machine software.

Figure 6 shows the distribution of the time for a machine to cover the area of one polygon as generated by the agricultural machine software: Times range from 1–74 s. As can be seen, many polygons required either approx. 2 s or approx. 56 s to be cultivated. The first peak at 2 s is caused because, when the machine is driving tight curves, small polygons are created. The second peak results from straight runs: many of these polygons are rectangular with a maximum length of about 150 m and a width of 36 m, which corresponds to the total boom length of the sprayer. The agricultural machine software limits polygons to this maximum length of 150 m. This distance is covered by the crop protection sprayer in approx. 55 s.

The joint distribution of the amount of data to be shared as well as of data generation intervals serves as input for investigating the suitability of LoRa for the considered use case of m-ASC.

VI. SUITABILITY OF LORA FOR M-ASC

To investigate to which degree the radio channel requirements derived in Section V are met by the radio channel characteristics of the channel investigated in Section IV, we are conducting a simulation study with *OMNeT++* 5.6.2.

We simulate a network of 5 nodes in our envisioned m-ASC system. For simplicity, every node follows a statically configured Time Division Multiple Access (TDMA) schedule with a slot length of 1 s for medium access. We conduct simulations for four different schedule lengths: 100 s, 20 s, 10 s, and 5 s. These correspond to duty cycles of 1 %, 5 %, and 10 % (complying with duty cycle limits in Europe [13] and Germany [14]) as well as a higher duty cycle of 20 %, respectively.

Simulated nodes continuously generate m-ASC polygons following the distribution of the time for a machine to cover the area of one polygon and packet sizes shown in Figures 5 and 6; generated polygons are added to a transmit queue.

During its time slot each node first tries to send all polygons in the transmit queue. If this leaves part of the time slot unused,

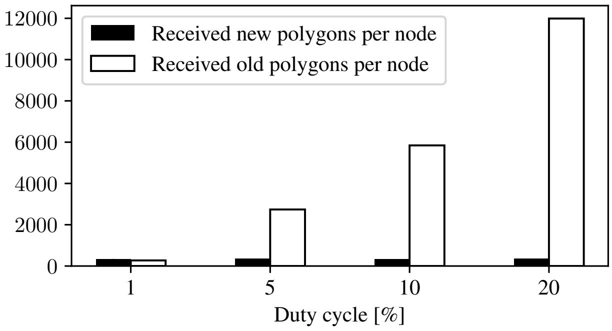

Figure 7. Number of received newly generated meshed Automatic Section Control (m-ASC) polygons and received duplicated polygons per LoRa node.

the node also sends old polygons to compensate for potential packet loss or to cater to the possibility of new machines arriving in the field.

The simulated LoRa devices are parameterized to the same channel characteristics also used in the field experiments (see Section IV), yielding a data rate of 10.9 kbit/s. Following the results of our experiments we model the wireless channel with a unit disk model which allows all simulated nodes on the whole simulated field to freely exchange data. Transmission times on the channel are commensurate to its data rate and the amount of data to transmit.

Figure 7 shows the number and ratio of new and redundant polygons exchanged after a simulated time of one hour. As can be seen, in a network with a duty cycle of 20 % each node is able to repeat each new polygon more than 35 times, to send each polygon as soon as it is generated (that is, with a maximum delay of one TDMA cycle of 5 s), and to exchange approx. 5 times the total number of polygons that make up the simulated 2.1 km^2 field within the simulation time of one hour. In a mesh network with a lower duty cycle, these ratios decrease. Still, even for a duty cycle as low as 1 % a node can send each polygon in its next transmission – while still having sufficient room for repeating older polygons.

Thus, LoRa can not only be considered a suitable basis for operating an m-ASC system on large fields – it would even offer sufficient capacity for supporting further applications.

VII. CONCLUSION AND FUTURE WORK

In this paper, we investigated the suitability of LoRa for agricultural applications beyond sensing: for creating a mobile mesh network of agricultural vehicles on fields. We focus on an advanced application, meshed Automatic Section Control (m-ASC), which allows multiple vehicles to conduct the same work in the same field in parallel: For this, vehicles wirelessly exchange information about already-cultivated regions and, in turn, use received information to selectively turn off sections of their equipment (e.g., individual sprayer nozzles).

As the long reach of LoRa under line of sight conditions is well-documented in the literature, we started by investigating the performance under Non-Line-of-Sight (NLOS) conditions in field experiments showing sufficient performance even in the presence of *islands* of dense forest on the field and on hilly terrain, given a robust physical layer configuration.

We then investigated to which degree this physical layer configuration can meet the demands of the kind of traffic an m-ASC application would generate (in terms of amount and burstiness), deriving the traffic profile from typical software used on farm equipment and feeding this into a computer simulation of an m-ASC system.

We found that even the time slots of a simple Time Division Multiple Access (TDMA) configuration of LoRa can accommodate more data than is generated, leaving enough (by a factor of 8 to 35, depending on the duty cycle) room for, e.g., redundant transmissions, opening the door to investigations of more complex and more demanding use cases.

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