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Millimeter-Wave Agricultural Channel Measurements in Corn and Soybean Fields at Different Growth Stages

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***Abstract*—Extensive agricultural field experiments in the millimeter-wave spectrum have been conducted for the first time in corn and soybean fields to study the impacts of crop type, crop growth stage, and antenna height on the path loss. Path loss analysis is conducted based on the field measurements and control experiment data. Based on experiments with over 6,860 data points collected over a five-month period in three crop fields, our results suggest that common crops, such as corn and soybean, impact the mmWave channel. The observations provide essential guidelines for the deployment of agricultural millimeter-wave wireless networks.**

I. Introduction

The use of millimeter-wave (mmWave) constitutes a significant potential in building large-scale agricultural networks. Future agricultural Internet of Things (Ag-IoT) [1] requires wide bandwidth accessible to both static and mobile devices to achieve high throughput and multi-user access. The mmWave spectrum offers abundant bandwidth resources to support multi-Gbps links. In the mmWave spectrum, channel conditions easily vary with the environment due to the millimeter-level wavelengths. Hence, an initial step to build the next-generation intelligent agricultural networks is a comprehensive characterization of such channels. However, existing channel models are inadequate due to the presumed setting of rural macrocells and the limited frequency bands considered only in the microwave spectrum [2]. We tackle this challenge.

II. Measurement Methodology

We conducted extensive experiments at 60 GHz in three fields to address these open questions: a 1-acre maize field in Eastern Nebraska Research, Extension, and Education Center (ENREEC), a 2.7-acre maize field, and a 2-acre soybean field at Rogers Memorial Farm (RMF) in Summer and Fall 2021 (Fig. 1). The comprehensive experiment information (dates, locations, crop types, and crop heights) is shown in Table I.

A. Transmitter and Receiver

This measurement campaign was performed using a pair of TerraGraph (TG) mmWave channel sounders transceiving IEEE 802.11ad waveform at V-band[1]. TG includes 8×36 phased array transmit and receive antennas, resulting in a half-power beamwidth of $2.8°$ and $12°$ on the azimuth and elevation planes, respectively. TG can generate 64 distinct beams in the sounder mode, resulting in $4,096$ combinations of beam pairs between a transmitter and a receiver [3].

Fig. 1. ENREEC (left) and RMF (right) experiment sites.

To synchronize the TX-RX and control the receiver remotely, a network bridge between the two nodes is established using a pair of Ubiquiti nanobeams[2] at each side. An edge computing machine operates the channel-sounding application and collects the measurement data on one side of the link (typically, the transmitter). The measurement equipment includes a TG mmWave node and a nanobeam node on a tripod (up to 20 ft height, with a base diameter of 4.6 ft), a generator, and at the transmitter side, edge computing equipment.

B. Field and Control Experiments

The TX-RX pair is placed either around the crop field (ENREEC) or at trenches within the field (RMF) to sample the channel at different TX-RX distances. The transceivers were aligned boresight for each experiment such that the mmWave channel is exposed to the crops. Due to the $12°$ half-power beamwidth in the elevation plane, in the majority of the cases, the main beam is exposed to the crops, potentially leading to reflection and diffraction and influencing the received signal. The transceivers are set at different pairwise heights (6 ft, 8 ft, and 10 ft) depending on the crop height such that a line-of-sight view is possible above the crops (Table I). The crop height was measured at the transmitter site and represents an approximate measurement with variations across the field. Beam sweeping is performed at each transceiver location to

[1]https://terragraph.com/product/

[2]https://dl.ubnt.com/datasheets/NanoBeam_ac/NanoBeam_AC_Gen2_DS.pdf

TABLE I
EXPERIMENT DETAILS WITH CROP TYPE, CROP & MEASUREMENT HEIGHTS, AND MEASUREMENT DISTANCES

Date	Location	Crop type	Crop height	Measurement heights	Measurement distances
July 7	ENREEC	Corn	5ft	6ft, 8ft	253ft, 254ft
July 16	ENREEC	Corn	7ft-7in	8ft, 10ft	63ft, 135ft, 203ft
Sept. 23	RMF	Corn	7.9ft	8ft, 10ft	367ft
Sept. 28	RMF	Corn	7.9ft	8ft, 10ft	246ft
Oct. 7	RMF	Corn	7.9ft	8ft, 10ft	164ft
Oct. 8	RMF	Soybean	2ft-2in	8ft, 10ft	164ft, 217ft, 292ft
Oct. 12	ENREEC	Corn	7.9ft	8ft, 10ft	253ft, 254ft
Nov. 16	ENREEC	Empty	0	8ft, 10ft	63ft, 135ft, 203ft, 253ft, 254ft
Nov. 23	RMF	Empty	0	8ft, 10ft	164ft, 217ft, 246ft, 292ft, 367ft

record the received signal strength for each $4,096$ beam pairs in an azimuth range of $\pm 45°$. The beam indices, as well as received signal strength values, are recorded instantly. The experiments are repeated in different parts of the season to capture the growth stages of the crops, depending on the availability of the fields, the weather, and the crew.

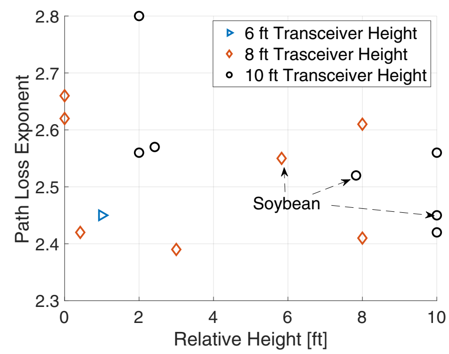
At the end of the harvesting season, the measurements are conducted in the empty fields, where the TX-RX pair is placed precisely at the same positions as before harvesting. These measurements provide a free space propagation insight for these field locations.

C. Data Processing

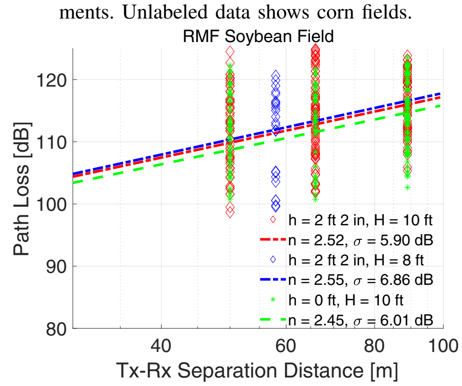
TG sounder application provides effective isotropic radiated power (EIRP), received power, signal-to-noise ratio, and channel impulse response after the experiment is finished. These data are then utilized for post-processing and further analysis. Among all swept beams, the main beam region with $\pm 5°$ around the best beam (to account for slight tripod motions) is used to compute the path loss of obstructed LoS path, which is approximately 10% of all data points collected.

III. PATH LOSS WITH CROP TYPES AND GROWTH STAGES

The path loss is calculated based on the 1-m close-in free-space path-loss reference model [4]. Corn is shown to obstruct LoS links with a higher variance. In particular, when corn height is closer to the transceiver height (with the relative heights closer to 2 ft), the path loss exponent is typically higher than $n = 2.5$. This is due to multipaths from diffuse scattering over crop canopies. Especially when the transceivers are at 10 ft height (shown as black circles in Fig. 2(a)), as crops grow and the relative height decreases, the path loss exponent increases significantly (from an average 2.5 to a maximum of 2.8). In addition, it can be observed in Fig. 2(b) that the LoS path partially obstructed by soybean has a similar path loss exponent because soybean generally has lower heights compared to corns. The distinct path loss behavior across crop types and growth stages implies a dynamic power deployment and distribution strategy in agricultural mmWave network design.



(a) Path loss exponent from field measurements. Unlabeled data shows corn fields.



(b) Path loss scatter plot from soybean field (h is crop height and H is transceiver height).

Fig. 2. Measurement results on path loss over crops.

IV. CONCLUSIONS

In this work, to the best of our knowledge, we report the first millimeter-wave agricultural field experiments in corn and soybean fields that capture the effect of crop growth on wireless line-of-sight links. Extensive field measurements have been conducted for a period of over five months, and path loss has been analyzed based on different transceiver configurations over various link distances to demonstrate the partial obstruction effect due to crops.

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