

Sensor Connectivity Enhancement using Diversity Antennas in Cold Chain Logistic Applications

Bo-Ren Hsiao¹, Hsin-Hsiung Chen¹, Wen-Jiao Liao¹, Troy-Chi Chiu², and Chin-Chung Nien²

¹Department of Electrical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan, R.O.C.

²Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C.

Abstract - A renovated delivery approach is proposed for cold chain logistic services to reduce operation cost. Deliveries are conducted using ordinary vehicles without refrigeration equipment. To ensure that perishable goods arriving destinations in good conditions, insulated containers are used to hold the shipment and the temperature data are monitored by wireless temperature sensors. Due to the variations in the propagation environment as well as attenuations in lossy frozen goods, a reader antenna system composed of multiple antennas of different polarizations and locations is proposed to mitigate the multipath fading issue. Rigorous simulations are performed to validate the improvement in reader coverage with this diversity antenna scheme. An optimum antenna displacement scheme is proposed for the propagation environment in a pickup truck using this method.

Index Terms — Diversity antennas, indoor propagation, multipath interference, RFID, Bluetooth.

I. INTRODUCTION

The cold chain logistics (CCL) is implemented to meet the consumers' demand in diversified food sources and health care services. Usually, the frozen perishable goods are transported via refrigerated truck to keep products fresh. However, for short range hauls, transporting with refrigerated truck may accounts for a certain share of operation overhead. To reduce the cost, the radio frequency identification (RFID) technology can be used. Several examples of the applications of RFID technology in CCL have been proposed [1-3]. However, substantial attenuations are expected for propagation within an environment full of highly lossy materials. The elevated path loss may deteriorate the transmission quality between the reader and the sensor.

Note in this operation scenario, the temperature data are only needed periodically. Hence, the sensors don't have to connect to the reader all the time. As a result, a diversity antenna scheme can be employed to enlarge the coverage area of the reader. In [2], the reader antenna provides two radiation polarizations, which are orthogonal to each other. Via switching the antenna polarization, the probability of transmission zero caused by destructive interfere may be reduced. In this paper, a reader antenna system composed of multiple antennas of polarization and antenna diversities is proposed to improve the transmission quality in a pickup delivery truck. The benefit of using such an approach is demonstrated with numerical simulation results. An optimum

reader antenna deployment plan can be devised by maximizing the diversity gain.

II. MULTI-ANTENNA SYSTEM

To reduce the operation cost, an ordinary pickup truck may be a good alternative for short-range transportation. Figure 1 shows the pickup truck and the arrangement of cooler boxes in its cargo space, which is surrounded by aluminum panels except the floor. Those cooler boxes are stacked in rows and columns. In such an environment, EM waves propagating paths can be complicated. Constructive and destructive multipath interference caused by in-phase and out-of-phase EM wave combination are likely. The connection performance of the reader antenna in the cargo room can be unstable and unreliable.

Figure 2 shows the reader antenna configuration, which is a 4-by-1 patch array antenna. Antenna dimensions are 140 mm × 70 mm × 6 mm. The signal is fed with a pair of 4-by-1 Wilkinson power divider to provide two perpendicular linear polarizations. Since the temperature sensors are made of Bluetooth modules, the impedance matching bands of the two ports are tuned to cover the entire Bluetooth band. The in-band coupling between the two ports is less than -20 dB. Simulation results show directive patterns and the cross-pol isolation is greater than 20 dB.



Fig. 1. The pickup truck used for the proposed CCL delivery scenario.

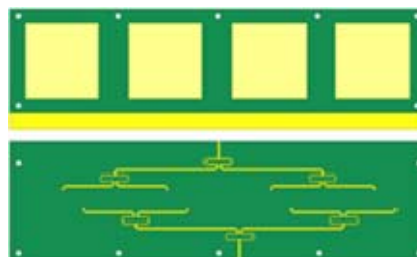


Fig. 2. Top and bottom layers of the two-polarization reader antenna used.

III. PROPAGATION SIMULATION MODEL

To evaluate the connection performance of the proposed reader antenna deployment scheme, a series of simulations is conducted via CST. Figure 3 shows the propagation environment, which emulates the cargo room of the pickup truck shown in Figure 1. The cargo room can be separated into two parts. The yellow part is aluminum boards and the blue part is made of wooden floors. The arrangement of the cooler boxes is also shown in Figure 3, which contains a total of 18 boxes stacked in two layers. To find the loss caused by the frozen perishable goods, dipole antennas that represent sensor antennas are placed normally on the surfaces of the cooler boxes. In particular, three dipoles, which are placed on the boxes in the bottom layer and remarked as R1, R2 and R3, are used to monitor the path losses from the reader antennas. In Figure 3, two reader antenna panels are hanged high at the two corners of the cargo rooms. Note 80% of the cooler box space is filled with frozen beef, which is somewhat lossy. The corresponding dielectric constant and loss tangent are 0.5 and 0.15, respectively.

The transmission spectra of the two polarizations from the reader antenna at the center of the ceiling to the three dipoles on cooler boxes are plotted in Figure 4. The ripple patterns in transmission spectra indicate obvious multipath interference. Because the fading phenomena are different, diversity gains are available if the connection can be made by either one of the two channels. The variation in path loss can be as large as 20 dB. Since the transmitted power from an ordinary Bluetooth module is around 0 dBm and its sensitivity is approximately -95 dBm. If the transmission level is below the green line shown in the plot, which is 95 dB path loss, the connection may fail. In general, the transmission loss is proportional to the path distance. This implicates that the diversity gain can be further enhanced if the reader can employ more reader antennas in different locations of the cargo room.

To take advantage of antenna diversity for improving the temperature sensor coverage and connection stability in multipath-rich propagation environment, we conduct a series of simulations of various reader antenna locations. The positions examined include the top and middle of the corners as well as centers of walls and the ceiling. In Figure 5, transmission spectra for antennas placed at top-right corner and middle left corner are plotted. The solid black line joins the maxima from individual spectra. Note because of polarization and antenna diversities, the path losses observed in the jointed spectra are less than 75 dB over the interested band for all three sensors. The 20 dB margin is enough to ensure stable Bluetooth connections.

IV. CONCLUSION

A simulation method applicable to optimize the reader antenna deployment scheme in CCL is proposed. The simulation results confirm that the reader antenna coverage in a hostile propagation environment can be expanded by exploiting polarization and antenna diversities. The optimal antenna displacement scheme can be derived by maximizing

the jointed transmission coefficient using simulation results of various reader locations.

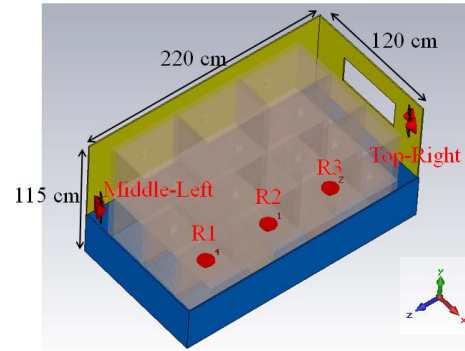


Fig. 3. Propagation simulation model of cargo space of the pickup truck.

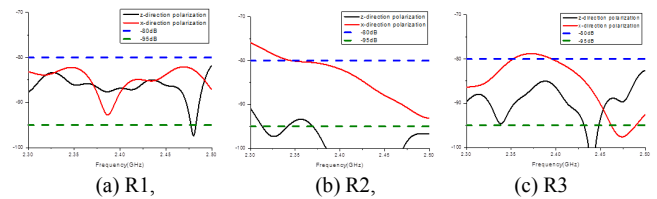


Fig. 4. Transmission coefficient spectra from the reader antenna at the center of the ceiling to the three sensors on cooler boxes.

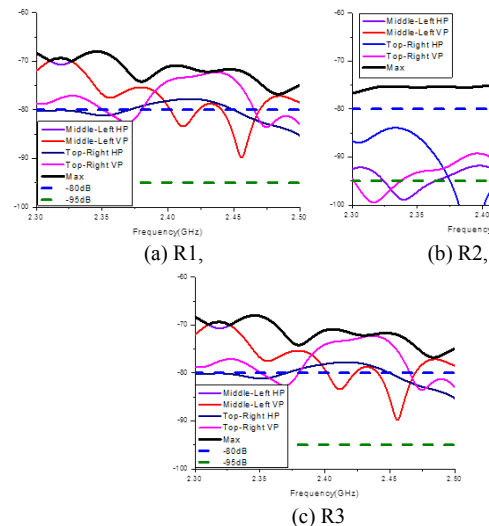


Fig. 5. Jointed transmission coefficient spectra from the reader antenna on the middle-left and top-right corners to the three sensors on cooler boxes.

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REFERENCES

- [1] I. Schumacher, J. Woellenstein, and J. Kalbitzer, "Low-power UHF-RFID sensor tags for a complete monitoring and traceability of the cold chain," in *Proc. of 2012 European conf. on SmartSys Tech.*, Jun. 2012, pp. 1-6.
- [2] W.-J. Liao, Y.-T. Tu, B.-R. Hsiao, C.-F. Yang, "Optimization of RFID reader antenna deployment in containers loaded with lossy materials," in *2013 Asia-Pacific Radio Science Conference.*, Sep. 2013, pp. 1-1.
- [3] H. Ding, R. Li, S. Li, J. Han, and J. Zhao, "MISS: multi-dimensional information sensing surveillance for cold chain logistics," in *Proc. IEEE 10th Int. Conf. Mobile Ad-Hoc and Sensor Systems (MASS)*, Oct. 2013, pp. 519-523.