Interference Analysis of Multiple In-Road Readers

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***Abstract*— In-road microwave readers and vehicle license plate tags provide superior advantages for traffic monitoring and vehicle identification. However, a single reader cannot accomplish the task of covering multi-lane roads. Multiple readers have the potential to interfere with each other, hence careful placement of readers is required. This paper analyses the propagation effects from multiple readers and calculates the signal-to-interference ratio. The result of this research indicates that simply placing the readers evenly across the road causes significant flaws in the detection system. Hence, two alternative topologies, which have much greater performance are proposed.**

Keywords—Microwave reader; RFID; channel modelling;

I. Introduction

The number of registered motor vehicles is continuously growing [1], making traffic congestion and road safety issues more pressing. To efficiently manage this situation, automated means are required to maximise the limited budgets of road owners. Functions including the ability to monitor frequently used paths, and detecting abnormal behaviour are highly valuable in achieving this goal. Additionally, reliably identifying a vehicle of interest can help with acting on hazardous driving behaviour and detecting stolen vehicles.

Traditional road monitoring methods include cameras with automatic number plate recognition (ANPR) [2], as well as radio-frequency identification (RFID) tags for tolling applications [3]. For ANPR, deliberate tampering or plate migration is difficult to mitigate, meanwhile tolling tags can have missed reads. More recently, several companies are selling RFID license plates which provide a robust way to identify a vehicle uniquely, as the RFID tag has a unique identifier encoded during manufacturing. Most existing RFID license plate readers are installed on gantries above the roads. However, the authors [4] have shown that using in-road based readers is preferable due to the superior geometry which mitigates the problematic propagation in addition to the cost.

Multi-lane roads create a new challenge to ensure successful reading capability as self-interference from adjacent readers can occur. In fact, a naive deployment of readers may produce black spots which hinder the capability to read license plates of all vehicles reliably. Even more importantly, this black spot may be present in a deterministic area making it easy for detection avoiders to circumvent detection.

This paper analyses the propagation environment between the reader and tag including all propagation effects such as interference and multipath. It then explores some topologies for a multi-lane road to provide some solutions to deliver the promised high readability and accuracy.

II. Methodology

Standard road widths in the world vary between 2.8 and 3.5 m. For a single-lane road, the in-road RFID reader can be simply placed in the middle of the road. Meanwhile, for highways and urban areas, roads contain multiple lanes, and therefore it is impossible for a single reader to cover the whole road. Therefore, multiple readers are required. Unfortunately, by simply placing each reader evenly across the road, interference can exist between the readers.

To analyse the aforementioned scenario, we calculate the signal-to-interference (SINR) power at each location across an intersection. SINR is defined as the ratio of the power of the signal of interest with respect to the power of interfering signals and the noise. This is a good predictor of the quality of the communication link and is proportional to the bit error rate (BER) of the link. In locations with a low SINR, the chance of having a successful rag read becomes low.

The impulse response power of the signal from a reader, including when the signal is an interference signal, is

$$H(d,f) = G_t(\varphi_t)G_r(\varphi_r)L(d)P(d,f) \qquad (1)$$

where f is the carrier frequency, G_t and G_r are the angle-dependent gain of the transmitting and receiving gain respectively, L is the spreading loss due to distance and P is the wrapped phase distance of the wave at the carrier frequency.

To calculate the received power, the transmitted power is assumed to be 1, and hence (1) can be used as the normalized received power for each path by using $H(\cdot)^2$. The radiation pattern of the transmitting antennas is assumed to be omnidirectional in the X-Y plane, and not dependant on the azimuth angle, whereas the tag radiation pattern is a slot antenna. The realized radiation pattern of the tag is shown in Fig. 1.

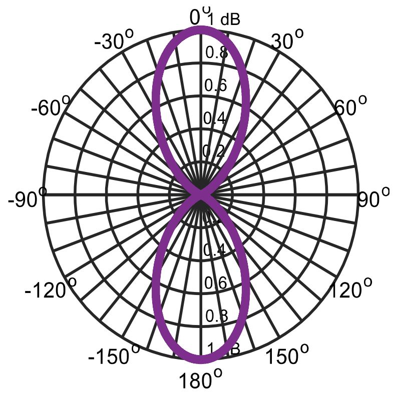

Fig. 1. Tag radiation pattern.

III. Simulation Scenario

To demonstrate the effect of interference, a naïve deployment of readers is assumed. Each reader is placed in the middle of a 3 m wide lane. The scenario is shown in Fig. 2, and the car is driving in the Y direction. The communication link uses a carrier frequency of 920 MHz, and a noise power of 1×10^{-9}W is assumed.

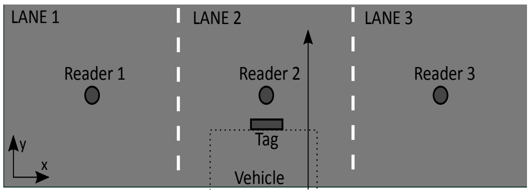

Fig. 2. Diagram showing the simulation scenario

To visualize the data, the SINR using Eq. (1) is calculated using MATLAB at each location in X-Y plane and is displayed as a heat map. The 2D map is produced with dimensions of 10x11 meters with a resolution of 1 cm. The readers are placed at locations (1.5, 0), (4.5, 0) and (7.5, 0). The heat-map for the received power of the naive geometry is shown in Fig. 3.

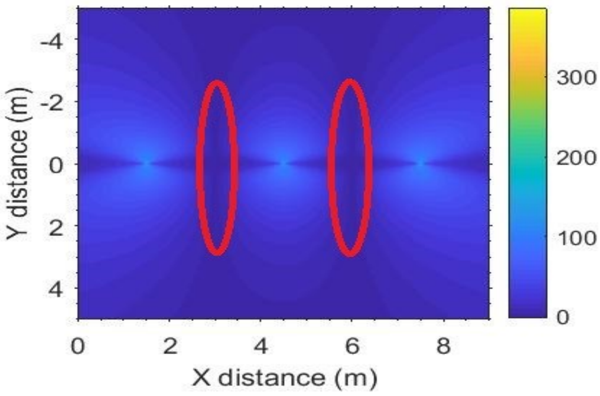

Fig. 3. Heat map showing the SINR power for inline geometry of readers.

The colour of each point on the map represents the strength of SINR value. There are three dominant points, which are the closest distance of readers and tag, and so are shown strongest power. It can be clearly seen in the red circle that there are two line of nulls in the middle of three readers at X=3 and X=6. These nulls are caused by the power from two readers being equal, which mean the SINR becomes close to 0 dB. This is a significant problem to ensure good reading rates. A car driven on these specific lines have a high possibility to avoid RFID detection, causing severe flaws in the detection system.

IV. Improved Reading Scenarios

Two alternative geometries are identified with the aim to remove the presence of the nulls. In the first of these, three readers are placed in an equilateral triangle shape (1.5, -2), (4.5, 1) and (7.5, -2) aiming to separate the distance readers, thereby decreasing the interference and crosstalk. The second of these, readers are placed in a diagonal line (1.5, -2), (4.5, 0) and (7.5, 2) for the same reason.

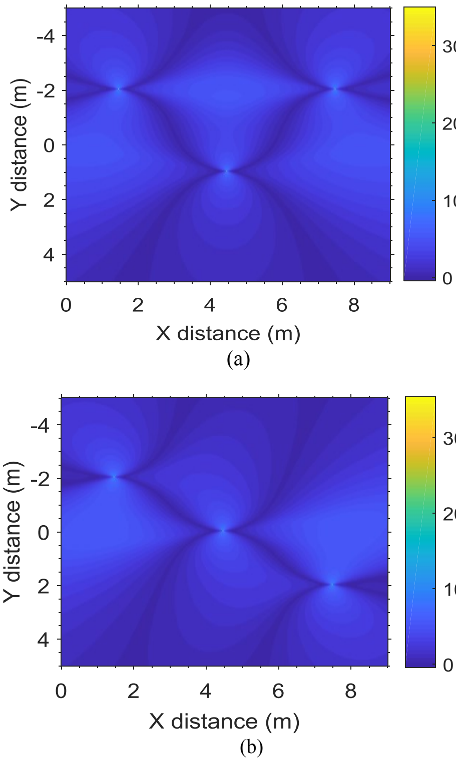

Fig. 4. Heat map of SINR power for (a) diagonal topology and (b) triangle topology of readers.

These two alternatives are shown in Fig. 4. Although the three strongest points are still the readers' location, the shape of the nulls are not simple lines. These trajectories are irregular arcs, as the geography location difference. Furthermore, the radiation covers almost all critical areas in the lanes, so drivers cannot avoid detection.

V. Conclusion

In this paper, we analysed interference of on-road RFID readers by calculating SINR. The simulations show that naïve placement can reduce the reliability and produce black spots. Two alternative topologies are presented which provide superior reading coverage.

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