Propagation Modelling of RFID Systems for Road Monitoring Applications

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***Abstract*—Monitoring of vehicles on roads and tunnels is performed with the use of RFID tag technology. Unfortunately, the reliability of the current RFID-based approaches is lacking. This paper explores the possible reasons for this by performing a propagation study using two scenarios. The first scenario is a gantry based tag reading system as is typically used in tolling applications, and the second is an in-road reader scenario. The second scenario mitigates a majority of the propagation problems experienced by the first scenario. By reducing these propagation problems, lower cost RFID tags can be used for road monitoring applications. Deploying such a system which is both lower in cost and higher in reliability can allow for more ubiquitous monitoring which in-turn can allow more informed decisions to be made on future road, bridge and tunnel infrastructure.**

***Keywords*—RFID; radio wave propagation; road monitoring**

I. Introduction

Robust monitoring of vehicles on different roadways including roads, bridges and tunnels allows informed decisions to be made on future roadway infrastructure. The technology used to automate this is based on radio frequency identification (RFID). Two such technologies are considered for this; dedicated short-range communications (DSRC) [1], and RFID in the form of ISO-18000-6C [2]. For tolling applications, the first of these technologies features a tag installed in the windscreen of the vehicle and read using a reader device which is installed on a gantry, which is located above the roadway. Due to the application of this the technology, it is also known as ‘eToll’.

Several techniques are used to ensure reliability of vehicle tag’s identification, which starts with a controlled reading location over the road. Also, at least one reader is required per lane of roadway, and directional antennas are used to direct the beam to the location of the vehicles. Although these techniques are used, the successful read rate in deployment does not meet the claimed successful read rate stated by manufacturers [3]. To reduce the impact of this, some backup systems are also used including video based automatic identification and manual human identification. Also, certain vehicles may be incompatible with the tag reading process due to their design, with impediments such as the metallization of windscreens [4]. Lastly, as the tag system on current roads is an opt-in system, the backup systems are required for certain cars which may not want to install the tag technology in them.

As a whole, the installation and running of these systems can be costly, and therefore their application is limited to “toll roads” where the cost can be offset with the fees that motorists are charged for using the facility.

One of the possible reasons for the relatively low reliability of these systems could be due to the propagation environment. The location of the tag with respect to the vehicle and reader is prone to being exposed to a multi-path signal propagation environment. This environment and the fact that the reading process occurs while the car is moving additionally mean that there are Doppler effects, and hence the readability of the tags decreases.

In this paper, an alternative to this system is proposed by moving the tag and reader to new locations. The new location is inherently less prone to multi-path effects and can also result in a less costly system overall.

II. Protocols and Technology

Current tags used in tolling applications use 5.8 GHz dedicated short-range communications (DSRC). It uses RFID technology with battery assistance, but the communication from the tag to the reader is done by selectively backscattering the signal to represent digital data (zeros and ones). The use of a battery is required to handle the DSRC protocol, but also has the benefit of allowing the tag to operate over larger ranges and increases the reliability of the system overall.

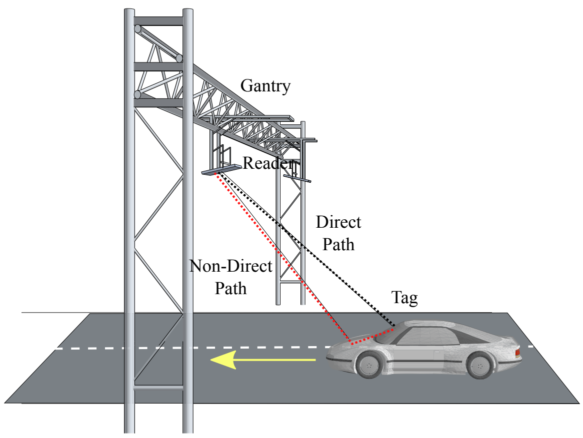

Fig. 1 Placement of current tag reading equipment for road monitoring

As seen in Fig. 1, the tag in DSRC is mounted in the windscreen of the car, and the reader is mounted on a gantry.

The propagation environment between the reader and the tag consists of a direct path (the shortest path), as well as a non-direct path. Together, these paths cause the effect of multipath, which, for a simple protocol, and low-cost tag, causes the effect of inter-symbol interference.

The protocol requires around 50 ms to read and authenticate a vehicle [5]. This means that for typical car travelling speeds of around 100 km/h, the entire reading operation is done in a space of 1.5 m. By focusing on this small reading zone and ensuring reliable reader-tag architecture, a higher antenna gain can be used to improve the link budget.

The reading of tags is done in a four-stage process. The first two stages are required to identify the tag and ensure that when multiple readers are used, the tag is read only once (e.g. pay the toll only once). The remaining stages are to provide the tag with information about the transaction. The stages formally are named initialization, presentation, receipt and finalization [6].

To avoid the multipath problem, the tag can instead be placed outside the car, in the location of, or inside, the license plate and the reader can be placed inside the road. This inherently mitigates the multi-path. A diagram of the proposed solution is depicted in Fig. 2.

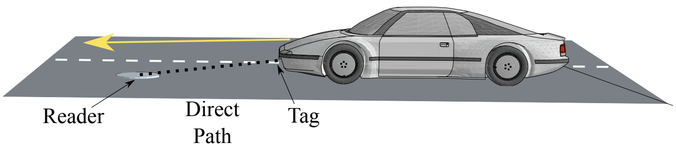

Fig. 2 The proposed placement of the tag reading equipment

In this scenario, though, the tag is no longer inside the vehicle and therefore, it longer has the luxury of battery assistance, and also it is difficult to power it using the vehicle's battery. To handle this restriction, the RFID protocol is recommended to be changed to ISO 18000-6C. In this protocol, a fully passive tag can be used, and issues of weather and theft (security) are less of a problem. The protocol operates on the 900 MHz band.

In ISO18000-6C, to successfully read a 512 bit tag at a moderate data rate, the required time to read a tag is 80 ms [7], which means that with the location of the reader, additional challenges in the antenna design for the reader are to be tackled. To ensure that the reading time of 80 ms is possible, the antenna radiation pattern needs to be directed as low as possible [8].

It should be noted that in addition to having a more beneficial propagation environment, the new proposed method has a large benefit in terms of the cost of deployment.

III. Propagation Model

To study the improvement in the reliability of these two propagation environments, they are studied using simulations. The propagation model in this paper considers path loss and delay as well as the multiple-reflections that combine at the receiver. The received signal of a single path undergoes both a change in amplitude, a time and a frequency shift, and is affected by noise, hence the baseband equivalent time domain signal is

$$r(t) = A\, x(t - \tau)\, e^{j\omega t} + n(t) \qquad (1)$$

where x(t) is the transmitted signal, A is the complex change in amplitude, τ is the time shift, ω is the Doppler shift, and n(t) represents the noise.

Next, the multi-path propagation environment is modeled using multiple paths, which follow the signal model above, added together. It should be noted that due to the signal being complex (baseband equivalent), the adding of two signals might result in either constructive or destructive interference. On metal surfaces reflections are close to ideal, which means that the incident and reflected angle are the same, the amplitude is only slightly reduced and a 180-degree phase shift occurs.

Two different mechanisms for performance degradation are going to be explored; the first is the concept of inter-symbol interference (ISI), and the second is the destructive and constructive interference between the direct path and the multi-path signals.

IV. Results

To illustrate the effect of multi-path on the performance of the system, a two-path channel model was simulated using the modulation schemes commonly used in tag based communication systems. The data rate was kept constant, and the modulation scheme was varied between FM0, Miller2, Miller 4 and Miller 8. This simulation shows the extremes of the effects of inter-symbol interference (ISI) as related to the simple modulation schemes found in RFID.

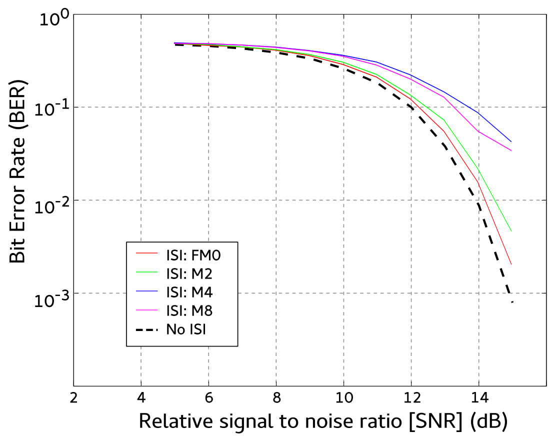

Fig. 3 RFID BER performance with/without multipath effects.

Fig 3 shows the bit error rate (BER) of the tag responses under different modulation schemes. The results are based on 100,000 different tag reading scenarios and with varying signal to noise ratio. When there is only the direct path (marked no ISI) all modulation schemes work similarly. However, when a moderate path delay is included, the higher order miller modulations suffer more than the other modulations. This is because these modulation schemes have more frequent transitions for a fixed data rate, and hence are less immune to inter-symbol interference.

In the next simulations, the typical path delay based on the location of a single vehicle is found for a scenario as described in Fig 1. The path delays are shown in Fig 4. The total path length of the direct and indirect path is calculated as the vehicle approaches the reading zone. The tag in the vehicle is assumed to be at a height of 1.7 m, and the gantry is assumed to be at a height of 5 m above the ground. The indirect path is formed by the signal that reflects from the bonnet of the car. For this scenario the path lengths of the direct and indirect paths become similar when the vehicle is far away from the reader, and have a larger difference when the vehicle is closer. The ranges of differences found are between 1 and 1.6 m for the selected model of car. This corresponds to a propagation delay difference of 2 ns.

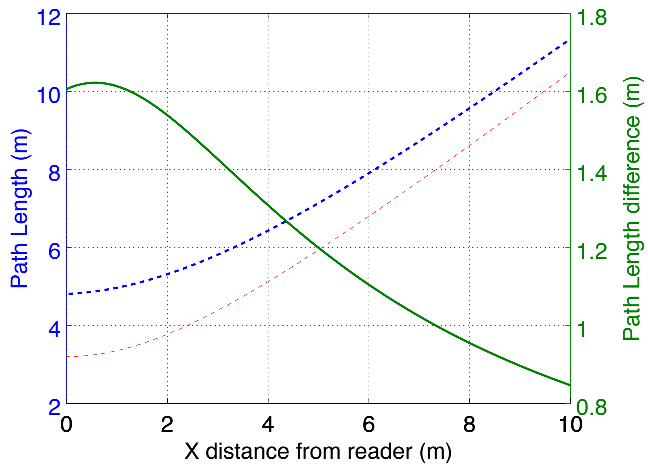

Fig. 4 Total path length of direct (red dotted) and reflected path (blue dotted) and path length difference (solid green) for a gantry based RFID tag reader.

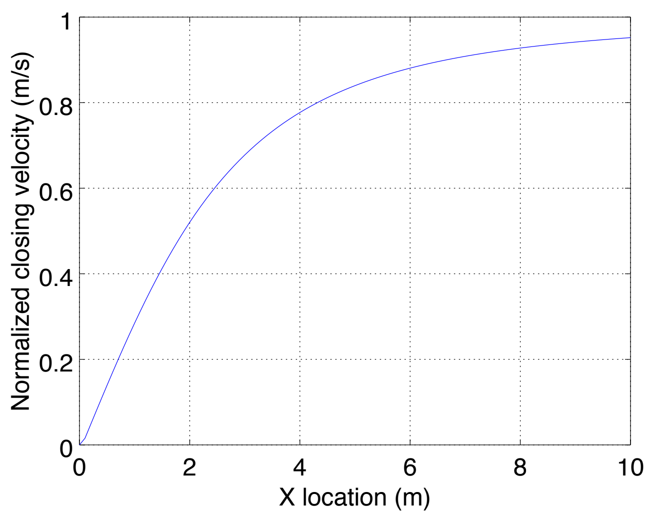

Fig. 5 Normalized Doppler frequency compared to vehicle speed, over different distances away from the reader.

As the data rate of RFID is quite slow, this delay will not cause inter-symbol interference. Depending on the frequency of operation, it may have the potential to cause inter-symbol-interference. At 5.8GHz the wavelength is about 6 cm, meanwhile at 900 MHz the wavelength is 33 cm. This means that for the scenario presented, the higher frequency will have several places with destructive interference, and the lower frequency will have at least one.

In the second scenario presented in Fig. 2, there is no non-direct path in the single vehicle scenario, which means that the performance degradation is less.

One last remaining effect in both scenarios is the presence of the frequency shift. This is shown in Fig 5. The frequency shift remains constant for the majority of the time in which the vehicle is being read, and then reduces rapidly as the vehicle approaches the reader. For this reason, the reading is done when the vehicle is at least 1 meter away in both scenarios.

V. Conclusions

A brief overview of tag technology for vehicle monitoring has been presented. Through signal propagation analysis, it is seen that the currently used locations for tags suffer from performance degradation due to the location of the tags. As a solution to this problem, an alternative signal reading arrangement, which mitigates the presence of multi-path, is presented. The proposed configuration not only provides benefits to performance, but also reduces the cost due to the easier deployment of the system.

Acknowledgment

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