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# First-Order Characteristics of the Person-to-Vehicle Channel at 5.8 GHz

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**Abstract**— In this paper we investigate the first order characteristics of the radio channel between a moving vehicle and a stationary person positioned by the side of a road at 5.8 GHz. The experiments considered a transmitter positioned at different locations on both the body and receivers positioned on the vehicle. The transmitter was alternated between positions on the central chest region, back and the wrist (facing the roadside) of the body, with the receivers placed on the outside roof, the outside rear window and the inside dashboard of the vehicle. The Rice fading model was applied to the measurement data to assess its suitability for characterizing this emerging type of wireless channel. The Ricean  $K$  factors calculated from the data suggest that a significant dominant component existed in the majority of the channels considered in this study.

**Index Terms**—channel measurements, channel characterization, vehicular communications, body centric communications.

## I. INTRODUCTION

In recent years, society has been transformed by increased ubiquitous wireless connectivity. This has been seen in many areas, but most notably through the embracement of smart devices carried or worn by people. It has also been observed in the advancement of vehicular networks. Here, vehicles have become mobile information systems, communicating with each other and a unified infrastructure [1]. A natural extension of both types of networks will be their eventual wireless integration. Consumers already have rising expectations for seamless interconnectivity of these smart devices, as they want access to many features available on their smart phones inside their vehicles. Both vehicles and people may form integral parts of future mobile networks of people and things.

To date, there has been some research interest devoted to the characterization of vehicular networks [2] and off-body communications [3, 4], but limited research into the wireless channels which involve both people and vehicles. As the person-to-vehicle (P2V) channel and also the reciprocal vehicle-to-person (V2P) channel will be subject to different signal propagation characteristics than either type of communication system considered in isolation, it is imperative the characteristics of the wireless channel must first be fully understood. Therefore the aim of this paper is to statistically characterize the first order characteristics of the 5.8 GHz P2V channel in an everyday urban environment. The 5.8 GHz Industrial, Scientific and Medical (ISM) band was chosen for this study for a number of reasons: firstly it offers a higher

bandwidth than the competing 2.45 GHz ISM band and secondly it is close to the 5.9 GHz frequency band already assigned for dedicated short-range communications (DSRC)/vehicle-to-vehicle (V2V) communications [5].

The remainder of this paper is organized as follows. The person-to-vehicle measurement system, environment and experimental procedure are described in Section II. Section III presents some examples of the received signal power waveform obtained in P2V channels as well as presenting a characterization of the small-scale fading using the Ricean  $K$  factor. Finally, Section IV provides some concluding remarks.

## II. MEASUREMENT SYSTEM, ENVIRONMENT AND PROCEDURE

The measurement system used for the experimental part of this study consisted of four purposely developed wireless nodes, one acting as a transmitter and the other three as receivers. The Radio Frequency (RF) section of the bespoke wireless nodes featured an ML5805 transceiver chip manufactured by RF Micro Devices (RFMD). The radio registers on the ML5805 transceiver were programmed using a PIC32MX microcontroller which acted as a baseband controller. The transmitter was configured to continuously broadcast data packets every 7 ms with an output power of +21 dBm. Each transmitted packet contained 130 bytes in total, 100 of which contained a data payload. The three receivers recorded the incoming data packets and stored the Receive Signal Strength Indication (RSSI) at a 10-bit quantization depth. This setup gave an effective RSSI sample rate of 142 Hz. A total of 268,740 RSSI samples were collected for the data analysis presented in this study. The antennas used at both the transmitter and receivers were +2.3 dBi sleeve dipole antennas (Mobile Mark model PSKN3-24/55S). These were connected directly to the wireless node's using a subminiature version A (SMA) connector. For the duration of the experiments all of the antennas were vertically polarized.

The measurement environment considered in this study was a business district environment in the Titanic Quarter of Belfast, UK. As shown in Fig. 1, the area consisted of a straight road with office buildings surrounding the immediate vicinity. The receivers were placed on three different locations of a 2005 Vauxhall (Opel in Europe) Astra Club for the duration of all the experiments. These were the outside roof, the outside rear window and inside on the dashboard. A single transmitter was placed on the body of a stationary pedestrian

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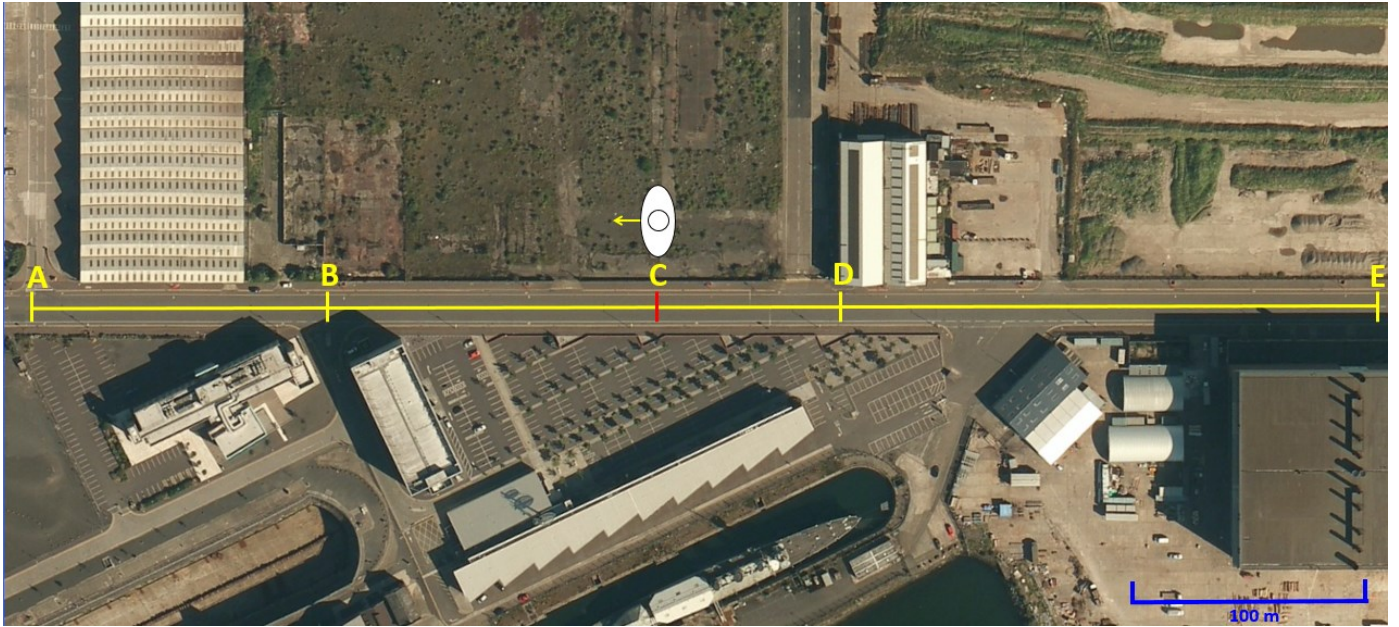


Fig. 1 Satellite view of measurement environment showing vehicle trajectory from point A to E; with transmitter on a stationary body at point C as shown. For the duration of the measurements, the test subject was oriented such that they faced directly towards point A.

at three alternate locations; these were the central chest region, the back and then the wrist facing the roadside, with the experiment repeated for each body position. This setup allowed nine different P2V channels to be analyzed. Furthermore, all of the experiments were repeated at the four different vehicular speeds of; 0 mph ( $0 \text{ ms}^{-1}$ ), 10 mph ( $4.47 \text{ ms}^{-1}$ ), 20 mph ( $8.94 \text{ ms}^{-1}$ ) and 30 mph ( $13.4 \text{ ms}^{-1}$ ). Depending on the speed of the vehicle and transmitter-receiver configuration, each channel experienced varying lengths of time under line of sight (LOS) and non-LOS (NLOS) conditions. It should also be noted that all of the channel measurements made in this study were also subject to perturbations caused by the movement of nearby pedestrians and other vehicular traffic.

### III. RESULTS

To facilitate a first-order characterization of the small-scale fading observed in mobile person-to-vehicle channels, a moving average window of 5 samples was applied to the original signal to obtain the local mean. This local mean signal was then removed from the measured channel data to obtain the small scale fading. For the 0 mph measurements, a local mean window of 1000 samples was used due to the much slower channel variations. As an example of this procedure, Figs. 2(a) to (c) show the original received signal power profile, local mean signal power and small scale fading amplitude relative to the local mean for the chest to car roof scenario while the vehicle moved at 20 mph.

The initial section of Fig. 2(a) (section A to C) shows the received signal power as the vehicle moved towards the stationary pedestrian. As we can see from the plot, the surrounding environment has a significant effect on the characteristics of the received signal. Using elapsed time, based upon the received packet number, and vehicle speed, the received signal power time series can be compared to the vehicle trajectory shown in Fig. 1. As we can see, the buildings near point B, create deep fades of approximately 15 dB in the local mean signal receive power [Fig. 2(b)]. Between points B and E in the test environment, a large brick wall runs parallel

to the road. As we can see, these construction types cause increased multipath interference which in turn leads to a much more rapid fluctuation of the received signal as shown in Fig. 2(c). The shadowing effects of the body [6] were also evident from the 30 dB decrease in the local mean received signal power [Fig. 2(b)] after the vehicle moves from LOS of the transmitter on the front of the body to NLOS (point C).

In this study, the small-scale fading component of the received signal was modeled using the Rice fading model [7]. Ricean fading channels are often characterized using the  $K$  and  $\Omega$  parameters, where  $K$  is defined as the ratio of the signal power of the dominant component over the total scattered power, and  $\Omega$  is the mean power. Table I shows the estimated Rice  $K$  factors for all of the channels measured in this study which were obtained using maximum likelihood estimation performed in MATLAB.

For the wrist and chest to vehicle channels, it was observed that as the vehicle speed increased, the  $K$  factor decreased. This can be attributed to Doppler effects causing increased fluctuation of the received signal power. Despite this, the estimated  $K$  parameters showed that a strong dominant signal is maintained in these channel, even at higher speeds. Conversely, when the transmitter was positioned at the back of the body, the person to vehicle channel had a different response. In particular, the  $K$  values obtained when the vehicle was stationary suggest the receive signal contains mostly scattered power (Table I). This response was expected since the vehicle remained in the same location (point B in Fig. 1) and the back position was in NLOS meaning that the received signal would have been largely due to scattered multipath contributions.

When the vehicle was mobile, the back to car dash channel consistently experienced fading with the lowest  $K$  factor (although  $K$  was still greater than zero). This observation can be attributed to the fact that the body shadows the transmitted signal as the vehicle moves towards the pedestrian. When the vehicle passes the pedestrian, even though the body positioned transmitter is now on the same side as the vehicle, the receiver

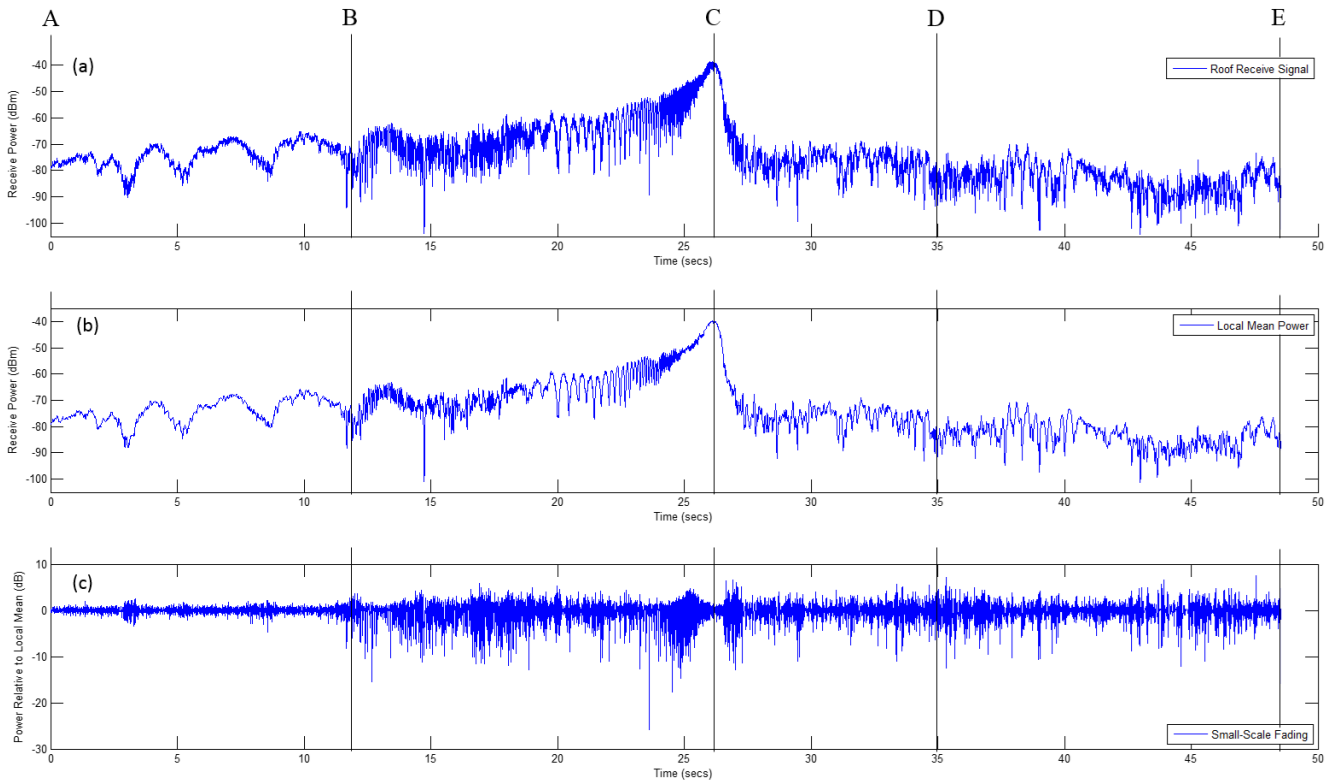


Fig. 2 Received power profile (a) for the chest to roof channel with the large (b) and small scale fading (c) signals extracted at 20 mph.

on the dash is still obscured by the back of the vehicle (car seats, boot, bumper etc.) which reside in the direct signal path. Using the chest to car roof channel as an example, when the LOS and NLOS portions are considered separately (i.e. sections A-C and C-E respectively of Fig. 1), the  $K$  factors were found to be 10.36 and 8.01 respectively. This is in direct comparison to the  $K$  factor of 9.13 calculated for the overall measurement scenario. This suggests even when a vehicle passes a person on the roadside and the person-to-vehicle channel changes from LOS to NLOS a strong dominant signal may be maintained.

As an example of the model fits obtained in this study, the empirical cumulative distribution function (CDF) plots for the chest to vehicle channels for each of the vehicular speeds considered in this study are shown in Fig. 3. As we can see, the Rice fading model provides an accurate fit for the stationary scenario [Fig. 3(a)], with a decrease in model accuracy at lower probability levels as the vehicle speed increases [Figs. 3(b) through to (d)].

#### IV. CONCLUSION

The communication channel between a person and vehicle in an urban environment has been investigated. The Rice fading model has been used to characterize the small scale fading observed in these channels. It has been shown that a significant dominant component existed in the majority of the P2V channels considered in this study with the Ricean  $K$  factor found to be typically much greater than 0. The dynamic nature of person-to-vehicle communications channels, including increasing vehicular speeds and varying body postures will mean that other fading models which are able to encompass more complex propagation mechanisms may be more suited. Future work will investigate the applicability of

emerging fading models such as  $\kappa$ - $\mu$  and  $\eta$ - $\mu$  [8] for use in person-to-vehicle channels. Finally, as channel characteristics will be expected to vary between persons, vehicles and operating environments, the work will also be extended to study the effects each of these factors have on the person-to-vehicle channel.

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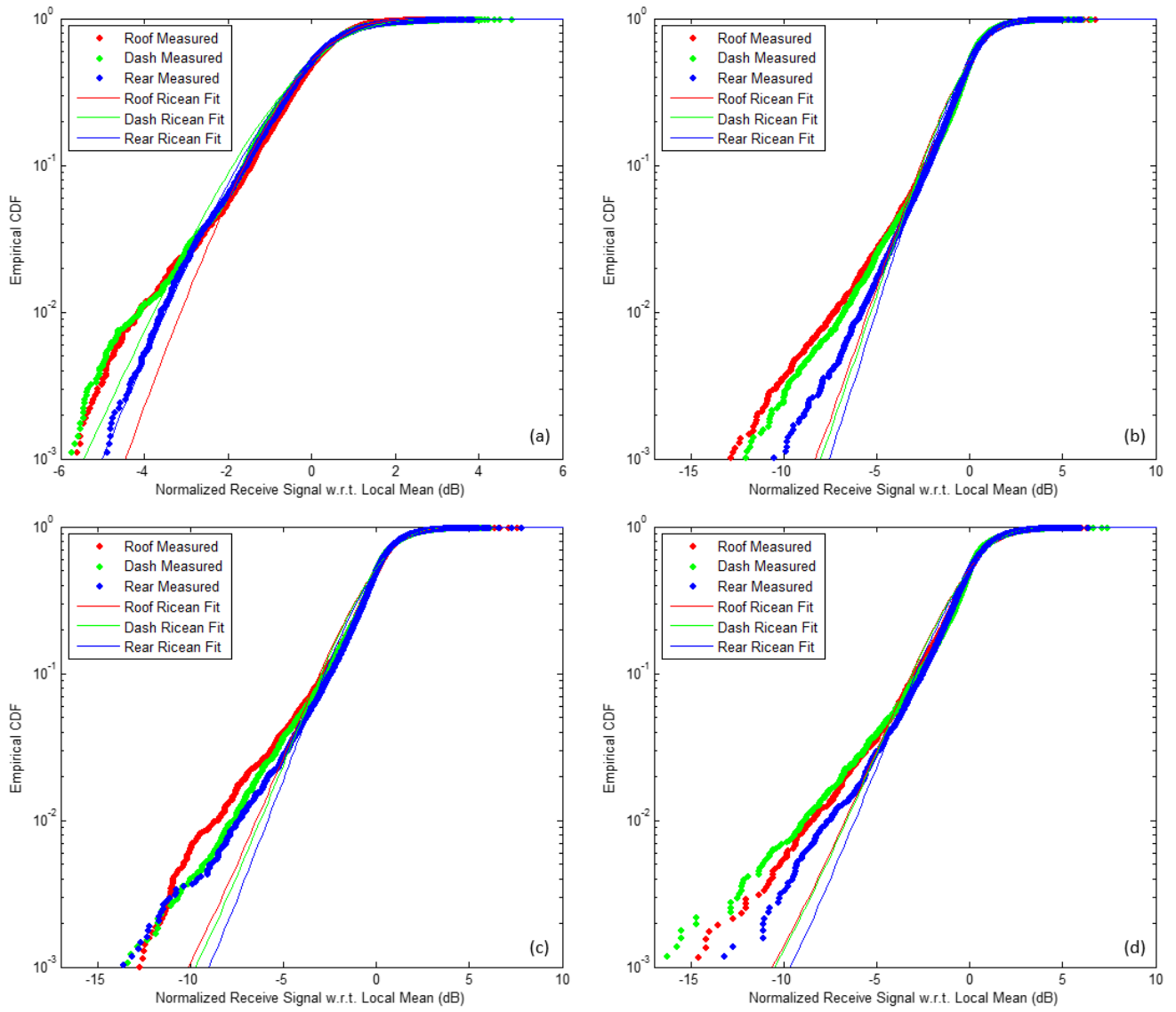


Fig. 3 Empirical CDF showing the Ricean model applied for the chest to vehicle (roof, dash and rear) at (a) 0 mph, (b) 10 mph, (c) 20 mph and (d) 30 mph (fit decreases with speed).

TABLE I. RICEAN  $K$  FACTORS FOR ALL EXPERIMENT SCENARIOS.

Car Position/ Body Position	Roof				Dash				Rear			
	0 mph	10 mph	20 mph	30 mph	0 mph	10 mph	20 mph	30 mph	0 mph	10 mph	20 mph	30 mph
Wrist	53.08	21.78	13.90	10.96	71.03	10.15	8.72	7.38	53.25	20.01	16.43	12.25
Chest	29.02	11.77	9.13	8.60	21.14	12.29	9.59	8.72	23.99	13.27	10.52	9.65
Back	0.00	6.93	8.77	7.67	0.00	5.85	5.80	5.47	2.22	11.97	13.74	9.33