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Vehicular Traffic Intersecting Body-to-Body Communications Channels at 2.45 GHz

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Abstract – In this paper we investigate the effects of vehicular traffic on body-to-body (B2B) communications channels in an urban environment at 2.45 GHz. In particular, the impact of differing vehicle types passing in the vicinity of a B2B link are investigated for different body orientations relative to one another at the side of a busy urban street. Initial findings suggest that the average disturbance in a B2B channel can last for 2 seconds and depending on the vehicle size, fades in excess of 40 dB can occur. The body orientations are shown to be a significant factor on the effects of vehicular traffic on the B2B channel.

Index Terms—body centric communications, channel measurements, vehicle shadowing.

I. INTRODUCTION

Body-centric communications channels have recently received significant attention, particularly for use in the area of wearable technology. As consumers own more and more wearable devices capable of communicating between one another, the area of body-to-body (B2B) networking is likely to increase rapidly in the years to come [1]. This presents significant challenges to wireless systems designers as B2B networking faces many complex propagation issues. For example signal shadowing caused not only by the user's body [2] but also other people and obstacles (e.g. vehicular traffic) in the local surroundings.

Research in this area has begun in earnest over the last few years, recent work such as [3] and [4] have attempted to model the body-to-body channel to gain a better understanding of B2B networks, and ultimately improve their reliability. As with all wireless networks, the environment plays a key role in how efficient the network is, and its performance [5]. Body-to-body networks will be expected to operate in a wide variety of environments such as indoors, city centers and urban areas to name but a few. While consumers can expect to benefit from future 5G technologies [6] which are currently under development, B2B networks can be also be expected to play an important role in augmenting and supplementing these networks.

In [7], the effects of other people in the local vicinity of closely related body area network (BAN) channels have been investigated, including those not actually sharing use of the network. However, within city streets vehicles also exist and pass alongside sidewalks. The impact of vehicles on B2B channels have yet to be established. Thus, the aim of this paper

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is to experimentally investigate the effects of passing vehicular traffic on a B2B link within an urban environment.

The contents of this paper are organized as follows. Section II describes the experimental procedure, including the hardware used for the measurements. It also discusses the measurement environment and introduces some of the metrics that will be used to describe the wireless channel. The results are presented within Section III along with some initial findings before concluding in Section IV.

II. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

A. Measurement System

To perform a characterisation of the B2B channel in the presence of vehicular traffic, a bespoke wireless node was developed. The Radio Frequency (RF) section of the node contained an ML2730 transceiver chip manufactured by RF Micro Devices (RFMD), while a PIC32MX manufactured by Microchip Technology Incorporated acted as the baseband controller. For the experiments conducted here, one of the wireless nodes was programmed to transmit a continuous wave signal with an output power of +21 dBm. A second pre-calibrated wireless node was programmed to sample the received signal strength (RSS) at a rate of 10 kHz with a 10-bit quantization depth. For this measurement campaign, the wireless nodes used a +2.3 dBi sleeve dipole antenna (Mobile Mark model PSKN3-24/55S) which maintained a vertically polarized orientation throughout. The RSS measurements were stored locally on a Microsoft Surface Pro Tablet using a USB cable.

B. Measurement Environment and Procedure

The measurements were performed in a busy business district in the Titanic Quarter of Belfast, UK. As shown in Fig. 1, the measurement environment consisted of a straight stretch of road with a wall approximately 2 m in height, which ran along the sidewalk near person A. The road was subject to uncontrolled traffic and had a maximum speed limit of 30 mph (or equivalently 13.41 m/s). The wireless nodes were worn by two adult males; person A had a mass of 75 kg and height of 1.83 m and person B had a mass of 75 kg and a height of 1.72 m. The transmitter and receiver were placed on the central chest region of persons A and B respectively, using a 5-mm dielectric spacer consisting of Rohacell HF 51 foam ($\epsilon_r = 1.07$).

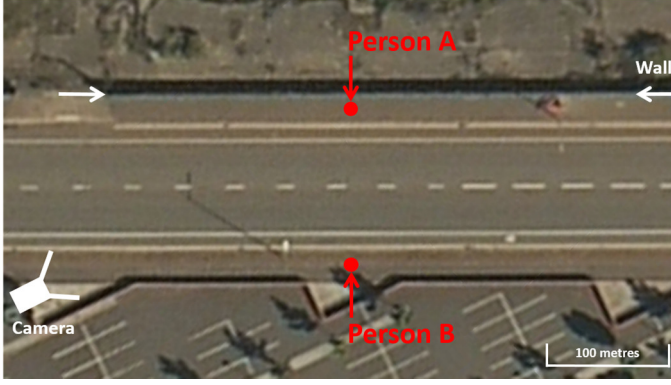


Fig. 1. Satellite view of the measurement environment highlighting the positions of both persons and a camera that was used to record the passing traffic (image courtesy of Google Maps).

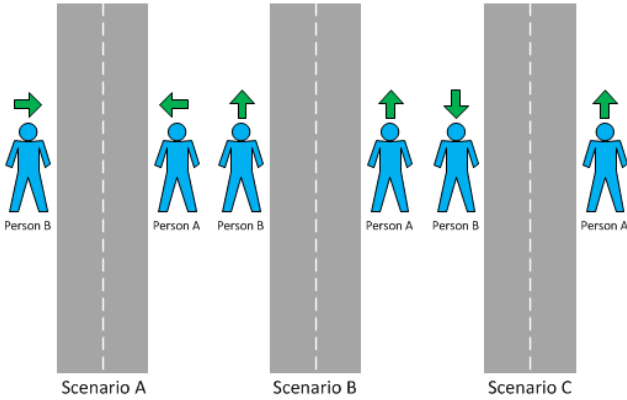


Fig. 2. Measurement scenarios considered in this study. It should be noted the road is approximately 10 m in width.

For this measurement campaign, three scenarios were considered to study how vehicular traffic intersecting the B2B link impacts its channel. Fig. 2 shows the three scenarios with the arrows indicating the orientation of the user's bodies forming the B2B link. Scenario A consisted of both people facing each other on opposite sides of the road, and maintained the line-of-sight (LOS) between the transmitter and receiver (unless obstructed by traffic). Scenario B involved both persons facing in the same direction while parallel with the roadside. Finally scenario C considered both persons facing in opposite directions while still parallel to the roadside. For each scenario the receiver sampled for 3 minutes and an HD digital video camera recorded the passing traffic (as shown in Fig. 1).

C. Channel Metrics

In this study, to quantify and compare the effects of a vehicles intersecting a B2B channel, we now define some simple metrics used to characterize our data. Fades caused by shadowing of objects within a wireless channel are often characterized by the depth and duration of the fade. In this study we define the maximum fade experienced (F_{max}) as the difference between the mean signal power of the undisturbed channel and the lowest signal power received as the vehicle intersects the B2B channel. The duration of the channel disturbance (D) is not just limited to the moment the channel is intersected, but includes the complete time that the received signal power varies from an unperturbed state (i.e. no traffic). Both of these parameters are visually illustrated in Fig. 3(b).

III. RESULTS

To analyse the effects that different sized vehicles had on the body-to-body link, the vehicles were grouped into a set of four categories. These were small (e.g. 3 door hatchback), medium (e.g. 5 door saloon), large (e.g. family car) and very large (e.g. vans or buses). The camera was time synchronised to the measurements and used to visually group the vehicles together into their respective categories.

Fig. 3(a) shows an example of (i) small, (ii) medium and (iii) large sized vehicles disturbing the channel for scenario A. It can be seen that the channel is relatively stable for the undisturbed sections with a mean (μ) and standard deviation (σ) of -36.1 dBm and 0.2 dB respectively. However, when the three vehicles intersect the channel [sections (i), (ii) and (iii)] there is significant fading observed. For each of the passing vehicles shown in Fig. 3(a) the channel metrics were calculated and are provided in Table I. In scenario A, due to the LOS aspect of the channel, it appears that vehicles only affect the channel in the immediate proximity to the B2B link. Most variations in the channel can be attributed to the shadowing of the vehicle causing the deep fades as it passed. This resulted in small disturbance times (as shown in Table I), with the effect of vehicle size generally determining the magnitude of the maximum fade.

In scenario B the more typical case where both persons are facing parallel to the road is investigated. To focus on the effects of the moving vehicles, both persons remained stationary for the duration of these measurements. In scenario A, due to the orientation of both bodies towards one another, the receive signal power consisted of a largely LOS component. However for scenario B, the change in body orientation causes a decrease in mean signal power of 20.6 dBm and an increase in standard deviation of 1.1 dB when compared to scenario A during the equivalent undisturbed phase. The decrease in the mean signal power could possibly be attributed to the shadowing effects of each person's limbs which would have partially obscured the direct signal path between the transmitter and receiver.

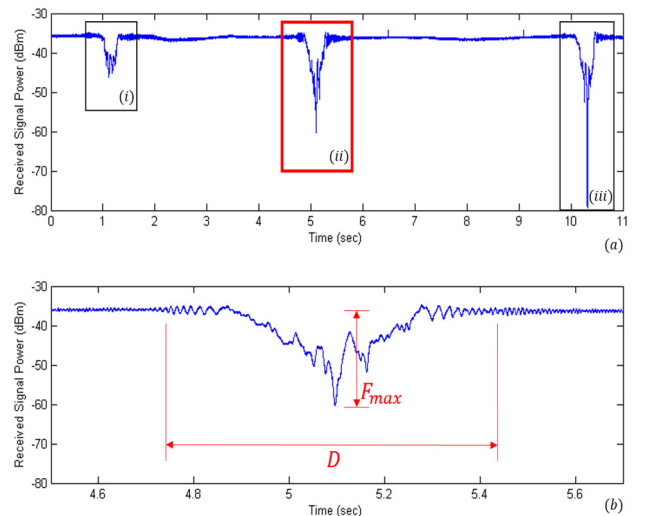


Fig. 3. (a) A sample of a received signal power measured for scenario A with three different types of vehicle; (i) small vehicle, (ii) medium vehicle and (iii) large vehicle. An expanded view of (ii) is shown in (b).

TABLE I. ESTIMATED CHANNEL METRICS FOR FIG. 3.

Vehicle Size	Small (i)	Medium (ii)	Large (iii)
Maximum Fade F_{max} (dB)	10.4	24.3	43.8
Duration, D (ms)	629	700	670

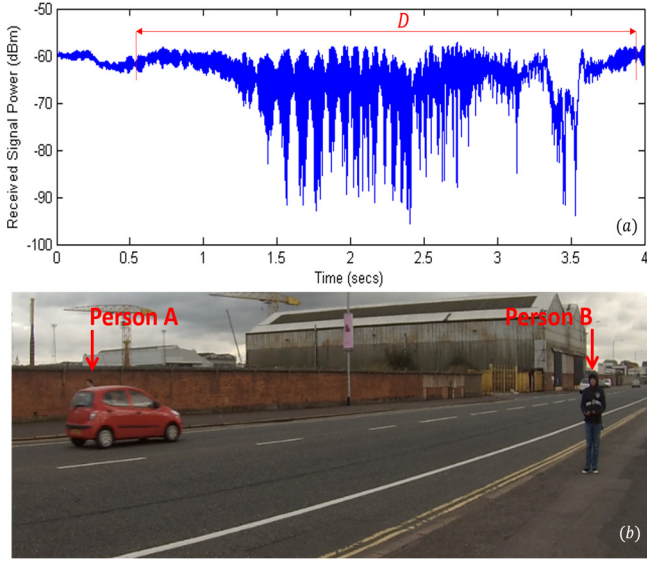


Fig. 4. (a) An example of a small vehicle intercepting the B2B channel for scenario B (occurring at 3.5 seconds) and (b) a picture of the vehicle at the moment of intersection.

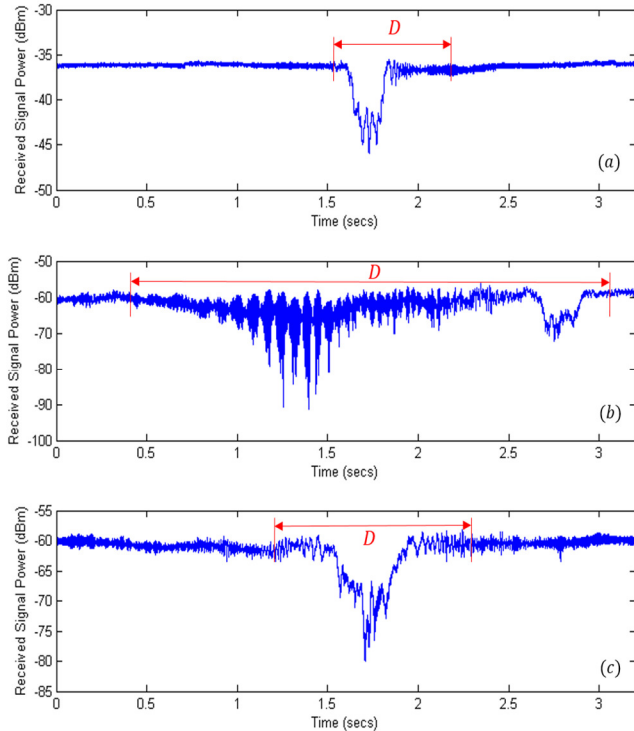


Fig. 5. Examples of a small vehicle passing through scenario A, scenario B and scenario C in (a), (b) and (c) respectively. The duration of disturbance for each vehicle is 603, 2662 and 1118 milliseconds with approximate intersection times of 1.83, 2.75 and 1.72 seconds respectively.

In Fig. 4(a) an example of a small vehicle [Fig. 4(b)] intersecting the B2B channel during scenario B is shown. Compared to Fig. 3, it is clear that the orientation of the body has a large impact on the disturbance experienced within the channel. Unlike scenario A, which shows little increase in disturbance prior to the vehicle passing both bodies, here it causes significant fluctuations in the received signal power. With the speed limit restricted to 30 mph, the disturbance began when the vehicle was approximately 40 m away from intersecting the channel (estimated based on the elapsed time from the video recording). The duration of this disturbance lasted for 3341 ms, and when compared to Table I for scenario A, this disturbance lasts significantly longer irrespective of the vehicle size.

Another situation which may arise in B2B networking is when two network users are walking in opposite directions to one another. Scenario C therefore investigated the situation in which both bodies stood parallel to the road, but facing in opposite directions. In Fig. 5(c) a small vehicle passing through the B2B channel for scenario C is presented. Since both persons are not facing in the same direction, unlike in scenario B when the vehicle was able to affect the channel from a distance, there are relatively small disturbances around the intersection point. This lack of disturbance for scenario C around the intersection point [Fig. 5(c)] produces similar results to scenario A [Fig. 5(a)], however the disturbance period is longer.

For each scenario the mean and standard deviation of the received signal power for every vehicle during the channel disturbance duration was calculated. The average statistics for each vehicle category are presented in Table II. As to be expected, the overall trend suggests that for increasing vehicle size the channel variability is larger. However, the mean signal power, when compared across vehicle types, only varies slightly, perhaps suggesting the time a vehicle takes to pass the channel is a more significant factor than the vehicle size. As shown in Table II for scenario A, the mean received signal power remains largely unchanged across all vehicle types and even including the case of no traffic present. For scenarios B and C, the mean received signal power was lower due to the relative orientation of the user's bodies. Nonetheless, the effects of vehicles intersecting the B2B channel appears to follow the same trend across all three scenarios. The influence of vehicle size is more apparent when comparing the standard deviation and maximum fade depth, with increasing vehicle size having a larger impact on the channel variability.

When both users are oriented such that their bodies face in the same direction (scenario B), it is clear an oncoming vehicle can significantly affect the characteristics of the received signal. The small-scale fading envelope for a small vehicle intersecting the channel in scenario B is shown in Fig. 6. To obtain the small-scale fading component for this channel, the local mean (or large-scale component) was calculated from the original receive signal power and then removed (using a moving window of 500 samples). A quasi-periodic variation in the small scale fading can be observed as the vehicle approaches. A possible reason for this behaviour is due to constructive and destructive interference from the radio waves reflecting back from the vehicle as it moved towards person B.

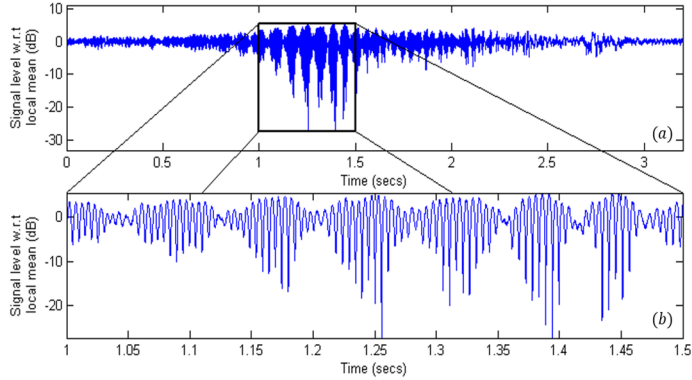


Fig. 6. (a) The small-scale fading for a small vehicle in scenario B [the same vehicle as considered in Fig. 5(b)] and (b) an expanded view between 1 and 1.5 seconds as the vehicle approaches the intersect point.

IV. CONCLUSION

The effects of uncontrolled vehicular traffic intersecting a body-to-body network in an urban environment at 2.45 GHz have been investigated. Initial findings suggest that the larger the vehicle, the greater the impact on the channel variability, in particular the standard deviation of the received signal power. Vehicle size also seemed to have a strong impact for scenario B (both nodes facing the approaching vehicle) with increasing vehicle size causing the channel to be disturbed from the no traffic state for a longer duration compared to the other

scenarios. The size of the vehicle however is not the only factor that must be considered. Indeed, although the speed limit was restricted to 30 mph, it is not realistic to assume all vehicles travelled at this velocity. Future work will not only look at controlled vehicle measurements, but how varying vehicle speed influences B2B links.

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TABLE II. AVERAGE STATISTICS OF THE MEAN, STANDARD DEVIATION AND DURATION OF THE DISTURBANCE ON B2B CHANNEL CAUSED BY A PASSING VEHICLE

Scen	Vehicle Type																	
	No Traffic		Small				Medium				Large				Very Large			
	μ	σ	μ	σ	F_{max}	D	μ	σ	F_{max}	D	μ	σ	F_{max}	D	μ	σ	F_{max}	D
A	-36.1	0.2	-37.4	2.1	7.5	854	-37.9	2.7	18.1	771	-40.0	5.5	13.2	729	-43.0	8.3	21.2	697
B	-56.7	1.3	-60.0	2.9	20.7	3343	-57.5	2.6	23.0	4749	-61.4	3.4	17.3	6299	-63.6	5.6	19.2	5791
C	-59.9	1.2	-64.2	3.6	14.6	1232	-63.1	4.0	12.5	1149	-66.7	5.6	22.8	1035	-67.9	7.6	25.9	1980

Note: μ - mean signal power (dBm); σ - the standard deviation of the signal power (dB); F_{max} - maximum fade duration (dB) and D - duration of disturbance (ms)