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An Experimental Evaluation of Spatial Diversity for Body-to-Body Communications within an Urban Environment at 2.45 GHz

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***Abstract*—In this paper, we investigate the potential improvement in signal reliability for body-to-body communications using spatial diversity. The measurements were made at 2.45 GHz in an urban environment with uncontrolled pedestrian and vehicular traffic. The virtual array of four distributed receive antennas were situated on the central chest and waist and the left wrist and waist of the user's body. The correlation coefficient between the signal fading measured at each of these locations was generally less than 0.7. Selection, maximal ratio, and equal gain combining of the received signal has shown that a diversity gains of up to 6.1 dB can be achieved when using only two distributed antennas and a maximal ratio combining scheme.**

I. INTRODUCTION

Body-to-body (B2B) communications are a branch of body centric communications which occur when a wireless device situated on one person communicates with wireless devices situated on other persons in the local vicinity. As wireless devices in body centric systems are operated in close proximity to the human body, they are prone to antenna-body interaction effects such as near-field coupling, radiation pattern distortion, and shifts in antenna impedance [1]. Moreover, variations of the received signal can occur due to shadowing and scattering of the signal caused by the body and surrounding environment [2]. The net effect of these factors may lead to a degradation in the quality of the radio link and a reduction in the overall signal reliability [3].

One possible method to mitigate these deleterious effects is to employ a spatial diversity configuration at the receiver. The key concept of spatial diversity is to combine multiple signals transmitted over different propagation paths with the aim of reducing the impact of deep fades. If diversity branches are suitably uncorrelated and have comparable mean signal levels, then it is expected that the combination of these signals will have a higher signal-to-noise ratio (SNR) compared to the case when only one branch is used [4]. To date, there have been relatively few studies which have investigated the benefits of spatial diversity techniques for B2B communications [5, 6]. In [5], it was shown that using multiple distributed antennas for B2B communications between emergency first responders improved the signal reliability for B2B channels during an indoor sweep-and-search-type operation. As shown in [6], spatial diversity for outdoor B2B communication systems can also be expected to improve signal reliability. In [6], it was shown that by using front and back position antennas it was possible to mitigate the effects of shadowing caused by the human body.

II. MEASUREMENT SYSTEM AND EXPERIMENTS

The virtual receiver array consisted of four bespoke wireless nodes distributed across the surface of the body of an adult male of height 1.83 m and mass 74 kg (person A). These positions were: the central chest and waist, the left wrist, and the left waist. The purposely developed wireless nodes consisted of an ML2730 transceiver and a PIC32MX which acted as a baseband controller. This configuration allowed the analog received signal strength output by the ML2730 to be sampled with a 10-bit resolution. The sample rate used in this study was 2 KHz and the shortest signal envelope considered for the analysis performed here was 14 seconds long. The transmitter node was mounted parallel to the body surface of an adult male of height 1.70 m and mass 75 kg (person B). It was configured to generate a continuous wave signal at 2.45 GHz with an output power of +21 dBm. During the measurements, the transmitter was alternated between four different body locations namely: the central chest region, the central waist region, the right wrist, and the right waist. The antennas used by both the transmitter and the receiver were +2.3 dBi, sleeve dipole antennas (Mobile Mark PSKN3-24/55S).

The measurements were performed in an urban environment within the city of Belfast in the United Kingdom. As illustrated in Fig. 1, five individual scenarios likely to be encountered in everyday life were considered.

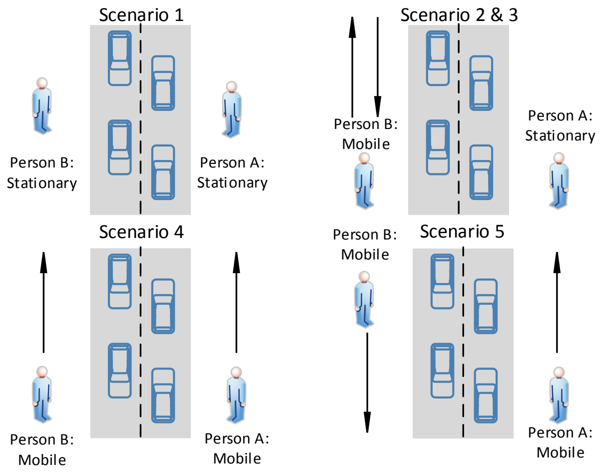

Fig. 1 Measurement scenarios considered in this study. It should be noted that the road was 5 m wide and the maximum displacement between persons A and B for scenarios 2, 3 and 5 was 20 m.

These were: (1) both person A and B stationary on opposite sides of the road; (2) person B walking away from and then (3) towards person A in a line parallel to the direction person A is facing; (4) both person A and B walking in parallel and in the same direction and then again in the (5) opposite direction.

III. Results

Prior to the diversity analysis, the correlation coefficient between the signal envelopes observed at each receiver was calculated. Normalization was performed by removing the global mean from the raw data in stationary scenarios and the local mean in the mobile scenarios. The local mean signal was calculated by averaging the signal over 500 samples. As an example, Table I shows the complete correlation results for scenario 1 and 4 for the transmitter at the central waist region of person B. As expected, for the scenarios when the at least one of the test subjects was mobile, the majority of correlation values were close to zero, with a range between -0.1 and 0.2. This was most likely due to the increased variability in the channel caused by movement and the associated increase in multipath interference from the surrounding environment. For all scenarios, the chest / central-waist and central-waist / left-waist receiver pairs had the greatest correlation values compared to other pairs. This was because of the close distance between these receiver locations. Across all scenarios, for all four transmitter body positions, the estimated correlation coefficients were less than 0.7. Since two signals are said to be suitably de-correlated if their cross-correlation coefficient is less than 0.7 [7], this suggests that a receiver with multiple antennas should provide sufficient dissemination of transmitted signal to supply worthwhile diversity gain.

Table I also shows the diversity gain for each of the three commonly used combining schemes namely selection combining (SC), equal gain combining (EGC), and maximum ratio combining (MRC) for all of the possible two branch diversity configurations in scenarios 1 and 4. The combined signal at the output of the virtual receiver array was calculated using the process described in [3]. All diversity gain calculations in this paper were made at a signal reliability of 90%. As expected, MRC combining scheme provided the highest overall diversity gain. Fig. 2 shows the cumulative distribution functions (CDFs) for scenario 5 for each transmitter location with different number of diversity branches to illustrate the advantage of having more than two available diversity branches. Here, it can be seen that the diversity gain obtained using the MRC combining scheme can be improved by a further 3.2, 3.8, 4.2 and 4.5 dB for the central chest region, the central waist region, the right wrist, and the right waist, respectively, when moving from a two-branch to four-branch receiver.

IV. Conclusions

The improvement in signal reliability for B2B communications using spatial diversity with distributed branches on the human body in a populated urban environment has been investigated. Using three commonly used combining schemes with chest, wrist and central and left waist positioned antennas, it has been shown that worthwhile diversity gains can be obtained.

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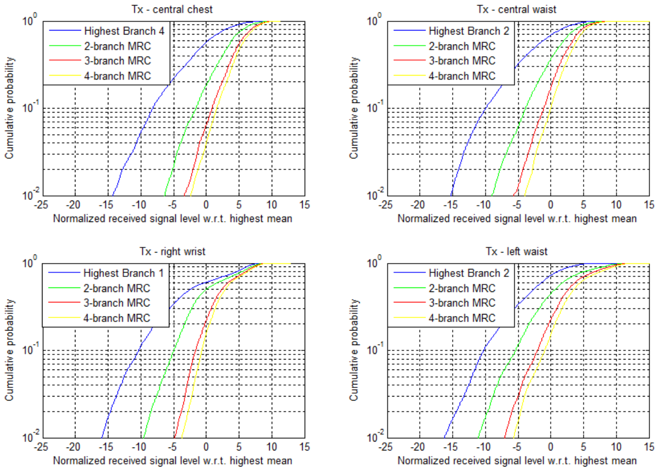

Fig. 2 CDFs of two-, three- and four- branch MRC diversity scheme for each transmitter antenna location in scenario 5.

TABLE I. Correlation Coefficients and Two-Branch Diversity Gains for Scenarios 1 and 4 with the Transmitter at the Central Waist

Receiver Pair	**Scenario 1 (both persons are stationary)**				**Scenario 4 (both persons are mobile)**			
	Correlation	SC (dB)	EGC (dB)	MRC (dB)	Correlation	SC (dB)	EGC (dB)	MRC (dB)
Chest / Centr. Waist	0.59	0.51	2.09	2.30	0.16	3.43	4.55	5.00
Chest / Wrist	0.36	0.73	1.97	2.26	0.05	4.21	5.16	5.61
Chest / Left Waist	0.33	0.48	1.94	2.25	0.06	4.63	5.60	6.07
Centr. Waist / Wrist	0.34	0.78	2.12	2.40	0.03	2.93	4.00	4.46
C. Waist / L. Waist	0.52	0.71	2.73	2.84	0.16	3.67	4.86	5.33
Wrist / Left Waist	0.16	3.27	4.53	4.91	0.03	4.44	5.77	6.10