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An Evaluation of Micro and Macro Based Diversity Combining for Wearable Communications

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***Abstract*—In this paper, the performance of micro- and macro-diversity based combining for indoor wearable communications at 5.8 GHz has been empirically evaluated using diversity gain. The virtual diversity system used consisted of four spatially separated base stations, with each of the base stations availing of two micro-diversity branches. To combine the received signal power, we considered maximum ratio combining (MRC) at the micro-level (i.e. at each base station), while pure selection combining (PSC) was used at the macro-level to switch between the best performing base stations. This approach was chosen to concurrently mitigate against the effects of fading and shadowing. Two different wearable positions were considered, namely the front central-chest and right wrist regions. It was found that using macro-diversity in isolation continuously realized a greater diversity gain than that offered by micro-diversity. Moreover, using cascaded MRC and PSC stages provided worthwhile signal improvements, with up to 14.6 dB of diversity gain achievable.**

I. Introduction

In wireless communications, the received signal may be subject to multipath fading and shadowing. This situation is particularly prevalent in wearable systems, where multipath is caused by the reflections and scattering from nearby objects whereas shadowing manifests when the transmitted signal is obscured by the wearer's body or surrounding obstacles (including other people). All of these factors can significantly impact the performance of wearable communications [1] and it is therefore important that techniques are investigated to mitigate their potentially deleterious effects. One straightforward approach, often employed to overcome both fading and shadowing in wireless channels, is the use of spatial diversity at the receiver. This can be achieved using micro-diversity which features co-located antennas and is aimed at overcoming small-scale fading or macro-diversity which uses spatially distributed antennas to counteract shadowing.

Over the last few decades, a number of studies on spatial diversity techniques have been performed in the context of wearable communication systems. Micro-diversity was considered in [2], [3], while macro-diversity, considering multiple base stations [4] or using spatially separated antennas on the human body [5], was proposed to overcome shadowing for wearables. Due to the simultaneous existence of multipath fading and shadowing, the use of either micro-diversity or macro-diversity alone may not be sufficient to overcome the combined channel impairments. Motivated by this, we examine the potential improvement in signal reliability for wearable communications channels operating at 5.8 GHz using both micro- and macro-diversity based combining. To this end, we consider the use of a maximal ratio combining (MRC) scheme at base station (i.e. micro-diversity) and pure selection combining (PSC) for switching between the best performing base stations (i.e. macro-diversity).

II. Measurement System and Experiments

The purposely developed wireless node used for the wearable transmitter consisted of an ML 5805 transceiver manufactured by RFMD. It was configured to transmit a continuous wave signal with an output power of +17.6 dBm at 5.8 GHz. The transmitter was alternated between the front central-chest region and right wrist region of an adult male of height 1.83 m and weight 73 kg using a small strip of Velcro. The virtual micro- and macro-diversity system consisted of four spatially separated base stations while each base station composed of two micro-diversity receiver branches (separated distance 0.28 m). The diversity receivers featured an identical ML 5805 transceiver whose analog received signal strength output was sampled with a 10-bit quantization depth at a rate of 1 kHz using a PIC32MX microcontroller. The antennas used by both transmitter and receivers were +2.3 dBi omnidirectional sleeve dipole antennas (Mobile Mark model PSKN3-24/55S).

The measurements were conducted in the indoor hallway and open office environments described in [6]. As shown in Fig. 1, the virtual base stations were positioned in a rectangular configuration with a length of 10.0 m and a width of 10.4 m in the office environment while a rectangular configuration with a length of 14.0 m and a width of 1.0 m in the hallway environment. Please note that the virtual base stations were directly attached to the wall at a height of 2.0 m from ground level. During the measurements, the test subject walked along in a straight line, covering a total distance of 10 m and 14 andm for an open office and hallway environments respectively. To improve the robustness of our analysis, all measurements were repeated three times.

III. Results

Prior to the diversity analysis, the cross-correlation and power imbalance were calculated following the approach detailed in [7]. Before determining the correlation due to shadowing in the macro-diversity setup, we abstracted the shadowed fading from the received signal by averaging over a distance of 10 wavelengths. Following from this, the correlation due to multipath fading observed in the micro-diversity set up, was calculated after removing the estimated shadowed fading. It should be noted that two different groupings of virtual base

TABLE I
AVERAGE DIVERSITY GAINS FOR MRC MICRO-DIVERSITY, PSC MACRO-DIVERSITY AND MRC-PSC MICRO- AND MACRO-DIVERSITY SYSTEMS

Environments	Wearable Positions	Diversity gain (dB) Micro-diversity				Macro-diversity		Micro- and Macro-diversity	
		(1, 2)	(3, 4)	(5, 6)	(7, 8)	(1, 3, 5, 7)	(2, 4, 6, 8)	Target 7	Target 8
Hallway	Chest	6.4	6.5	5.0	4.8	8.9	6.9	12.6	10.9
	Wrist	6.4	5.3	5.0	5.5	11.2	9.0	14.6	13.0
Office	Chest	6.4	4.9	6.7	6.4	9.1	8.4	12.8	13.0
	Wrist	7.0	6.0	7.1	6.4	9.0	8.4	12.5	12.6

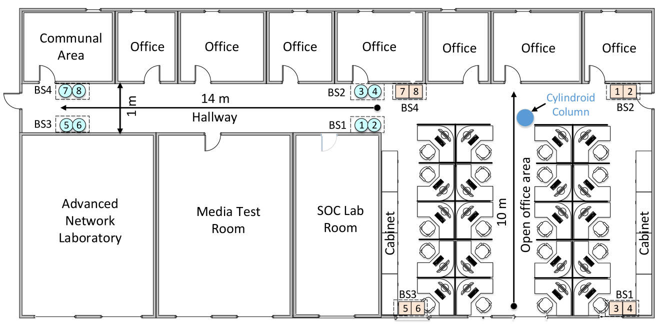

Fig. 1. Measurement environments and the allocations of the micro- and macro-diversity receivers.

stations were considered for the implementation of macro-diversity, these were *group* 1 (1, 3, 5, 7) and *group* 2 (2, 4, 6, 8). For brevity, we do not exhaustively list our results but note that the power imbalance for micro-diversity (maximum value of 2.8 dB) were much smaller than those for macro-diversity (maximum value of 13.0 dB). For the considered micro-diversity configurations the estimated correlation coefficients ranged from 0.01 to 0.21 while for the macro-diversity setups this was 0.01 to 0.94.

The performance of MRC-PSC diversity system was evaluated in terms of its diversity gain (DG). For a micro-diversity configuration, this is typically defined as the improvement between the signal level at the output of the diversity combiner and that of the branch with the highest mean for a given probability or signal reliability. On the other hand, for a macro-diversity system, this is generally defined as the difference in signal level at the output of the diversity combiner and that of the target base station. For the combined MRC-PSC system, the same approach. It is worth noting that receivers 7 and 8 was selected as the target receiver for *groups* 1 and 2 respectively to calculate DG achieved by macro-diversity. Accordingly, for a direct comparison, the DG obtained by micro-and macro-diversity is also calculated with target receivers 7 and 8.[1]

Table I shows the average DG statistics averaged over the three trials. As shown in Table I, the average DG obtained for micro-diversity ranged between 4.8 dB and 7.1 dB while the macro-diversity this was 8.4 dB to 11.2 dB. For all of the considered cases, the combined micro- and macro-diversity system provided a greater DG compared to macro-diversity system. More specifically, it was found that the micro-and macro-diversity system provided additional gains of between 3.4 dB and 4.6 dB compared to when macro-diversity was

[1]It should be noted that all diversity calculations were performed considering a cumulative probability of 10% (or equivalently a signal reliability of 90%) with the aid of [8, Eq. (9)].

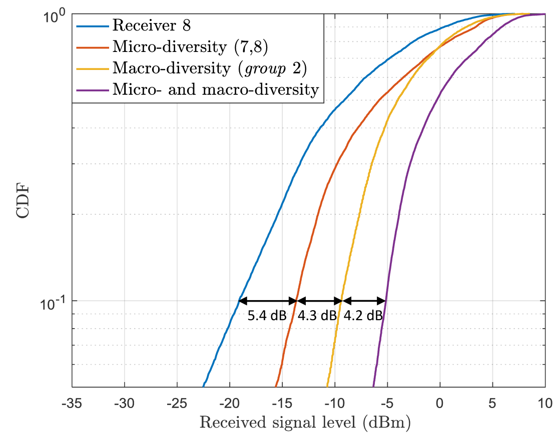

Fig. 2. CDFs of the output of micro-diversity (7,8), macro-diversity (*group* 2) and micro- and macro-diversity systems alongside that that of the receiver 8 for the wrist position in the hallway environment during the 2^{nd} trial.

utilized in isolation. For a visual inspection, Fig. 2 provides some example plots which illustrate the DGs achieved by each of the three setups for the wrist position in the hallway environment during the 2^{nd} trial.

IV. CONCLUSION

In this paper we have conducted an empirical evaluation of the performance of micro- and macro-diversity combining for wearable communications. MRC based micro-diversity, PSC based macro-diversity and a combined MRC-PSC system have been considered to counteract the negative effects of multipath fading and shadowing. It was found that both the micro-diversity and macro-diversity configurations provided a worthwhile DG for all of the considered wearable positions and environments. However, it has been shown that if an even greater improvement in signal reliability is required, this can be achieved by cascading MRC micro-diversity and PSC macro-diversity combining stages.

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