Human effect on on-body selective combining at 2.4 GHz

Article · December 2014

DOI: 10.1109/LAPC.2014.6996402

Dina Al-Saffar
Loughborough University

Robert Edwards
Loughborough University

Oluwaseun Adeniyi Ojerinde
Federal University of Technology Minna

Haider M. Alsabbagh
University of Basrah

Human effect on On-body Selective Combining at 2.4 GHz

D. Al-Saffar[1], E. Habeeb[2], R. M. Edwards[1], O. Ojerinde[1], H. M. Alsabbagh[2], C.J.Panagamuwa[1]
[1]The Centre for Mobile Communications Research, Loughborough University [2] Dept. of Electrical Engineering Basra University, Iraq,

Abstract— **Use of the body as a platform for wearable electronics is a topical subject. Omnidirectional antennas are thought to be useful for antennas in body area networks. However, the desirable properties of omnidirectional radiation patterns close to humans are severely diminished due to the lossy load nature of biological matter and high levels of scattering due to mismatch. To alleviate these problems two or more antennas can be used on the body. In this paper, two on body antennas are used with selective combining and then compared with their free space equivalents. The frequency of operation is 2.4GHz.**

Index Terms— **on-body channels, SIMO, Body Area Networks, Radio Frequency Measurements. CDF , SC**

I. Introduction

OMNIDIRECTIONAL patterns are a desirable feature for on-body antennas. However, antennas close to the body suffer severe perturbations to their characteristics exhibiting lower quality factors, radiation resistances and pulling of resonant frequency when compared to their free space counterparts. These perturbations are caused by reflections from skin, absorption of energy in matter and reactive coupling of the antenna and the body via the electromagnetic fields generated by radiating elements. On the body radio frequency energy in the field is absorbed by matter[1]. This absorption generally destroys any pattern symmetry. A partial solution is to have multiple antennas on the body allowing better omnidirectional field strength due to the superposition of element patterns. Nevertheless, as humans move the propagation paths from all or any antennas can still be blocked by limbs [2]. Therefore deep fades due to obstruction are more likely for antennas worn close to the body. It is less likely though that two or more antennas will be blocked at the same time. The use of two or more antennas allows the diversity techniques to be implemented. This paper considers on and off-body Selection Combining (SC) [3] and concludes to whether or not selection combining is useful for inter-body communications by comparison. Three common environments were measured, an office, a laboratory and a corridor. Two pairs of positions for on-body receivers antennas were considered, the shoulder pair and the waist pair.

SC is a simple diversity technique. In this technique, the strongest signal from the diversity branch is selected at the receiver. The more branches the lower the probability of a fade and thus the higher the probability of a better signal at the receiver. In this work, a two-branch diversity system will be considered.

To allow the comparison of our results against a bench mark an analytical form of selection combining will now be discussed. The model used is N=2 version of the general treatment given in [4]. This model assumes that each sample is an independent sample of the fading process and that the fading process is slow, flat and Rayleigh in nature. The intention of using the analytical form is to provide a reasonable benchmark to allow our results to be set in context. This method has been used to illustrate both a single Rayleigh channel and the baseline expectation for a two antenna single input multiple output (SIMO) system. Note that although the results for maximal ratio combining [5] are presented the analysis is not used in this paper and is future work.

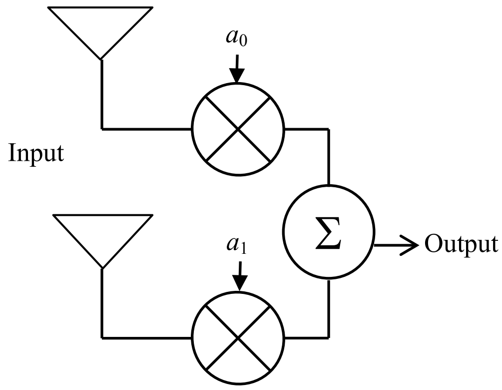

Figure 1. Two-antenna receiver model for selection combining.

Over one period T_s the power in the signal for any single path is given by:

$$p = \frac{1}{T_s}\int_0^{T_s}|h_n(t)|^2\,|u(t)|^2 dt$$
$$= |h_n(t)|^2\frac{1}{T_s}\int_0^{T_s}|h(t)|^2\,dt = |h_n|^2 \quad (1)$$

The simplification of Equn. 1 is achieved by assuming $|h_n(t)|$ to be constant over the period T_s and $u(t)$ to have unit power.

Letting $E\{|n_n(t)|^2\} = \sigma^2$ the instantaneous SNR for any path can be written as:

$$\gamma_n = \frac{|h_n|^2}{\sigma^2} \qquad (2)$$

For Rayleigh fading $h_n = |h_n| e^{j\angle h_n}$ in which $\angle h_n$ has a uniform distribution over 0 to 2π and $|h_n|$ has a Raleigh fading probability density function.

$$|h_n| \approx \frac{2|h_n|}{P_0} e^{-|h_n|^2/P_0} \qquad (3)$$

$$\gamma_n \approx \frac{1}{\Gamma} e^{-\gamma_n/\Gamma} \qquad (4)$$

$$\Gamma = E\{\gamma_n\} = \frac{P_0}{\sigma^2} \qquad (5)$$

Where Γ is the average SNR of a single element and P_0 is the statistical average of $|g(n)|^2/2$ [4].

To study the effect of the body on the channel we have used selection combining. In selection combining the path with the greatest SNR is chosen. Therefore with reference to Figure 1 and if we choose $\gamma = max_n\{\gamma_n\}$ as the output then

$$a_k = \begin{cases} 1, & \gamma_k = max_n\{\gamma_n\} \\ 0, & otherwise \end{cases} \qquad (6)$$

and again from [3]

$$P_{out}(\gamma_s) = \left[1 - e^{-\gamma_s/\Gamma}\right]^N \qquad (7)$$

For conciseness the results of [4] are not repeated here, however for a reliability of 99% we use those results as a benchmark concluding to SC gain of 15dB as being typically achievable.

II. PROCEDURE FOR MEASUREMENTS

The antenna sets constructed for the on-body measurement consisted of two identical quarter-wavelength monopole antennas on an isolated circular ground plane. The circular ground plane minimized unwanted surface corner reflections due to less than infinite ground plane size. Isolation was achieved using a polystyrene disk that lifted the antenna a repeatable distance off the skin above the clothing by a distance of approximately 1cm. The antennas were designed and built to resonate at 2.4GHz. Comparisons on and off the body showed little variation in S_{11}. An antenna without its ROHACELL foam radome is shown in Fig. 1.

An adjustable rig was constructed to allow antennas to be positioned at shoulder and waist height in a repeatable fashion. The experiment was carried out at 2.4GHz. An HP 8350 signal generator set to 10.5dBm was used to transmit power to the horn antenna. The received power at the antennas was measured using a LeCroy SDA 18000. The serial data analyser (SDA) is set to measure the received power in the two-monopole antennas attached to channel 1 and channel 2 simultaneously. Note that the horn antenna main beam is approximately in the null of the patterns for the received monopoles which is the worst case for the LOS measurements.

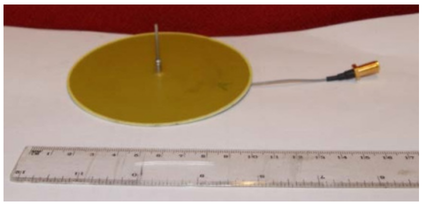

Figure 2. Quarter wave monopole on a circular groundplane. For isolation a polystyrene disk was used under the antenna and for added rigidity a ROHACELL radome were added.

The antennas were connected to the LeCroy SDA 18000 using 3m long RG316 cables. Channels 1 and 2 were set to respond to a maximum frequency of 6GHz. The sampling rate was as 500kS/s. To select the narrowband of the signal, the transmitted power was measured with the receiving antenna attached to the Advantest R3182 spectrum analyzer. The narrowband was set at 134kHz based on the signal strength.

The measured data was then post processed in Matlab. Figure 3 shows a volunteer with 2 antennas in place. The photo shows the waist configuration. The range between the transmitter and receivers was approximately 4.6m for all experiments. Only amplitude measurements were taken with transmitter and

The communication system in this experiment is a multiple antenna system. The system is built with one transmitting antenna and two receiving antennas. The measurements took place in three locations. The communications laboratory (LAB), the corridor and the centre for mobile communications research (CMCR) width of the lab is 7.16 m while the length was 8.31 m, the distance between floor and ceiling is approximately 3m. Contents are assorted office furniture. Open ended corridor length and width 30.8m and 2.2m respectively and the same distance between floor and ceiling in lab environment. The corridor was empty. The office width was 5.1m has a length was 15.2m ceiling with a height of 3m approximately. Contents of assorted tables and desks four side desks.

The system diagram is shown in Figure 5. In our research we first looked at 300 seconds worth of data for self similarity and found that subsets of 6 seconds were adequate to reproduce the mean and variance. Measurements were therefore taken for two scenarios, one with the antennas on a human and one without.

Each measurement was taken for 300 seconds giving 15,000 power points in each channel. All other elements with the experiment were unchanged and therefore it is reasonable to assume that any improvement or worsening of SC in terms of average received power is due to human effect. The two receive antennas were 50cm apart, which were approximately 4 wavelengths at 2.4GHz. Figure 3 shows the experimental rig and the connections to the data analyzer. Care was taken to ensure the polarity of the antennas and antenna cabling was consistent on and off the body and that symmetry was maintained.

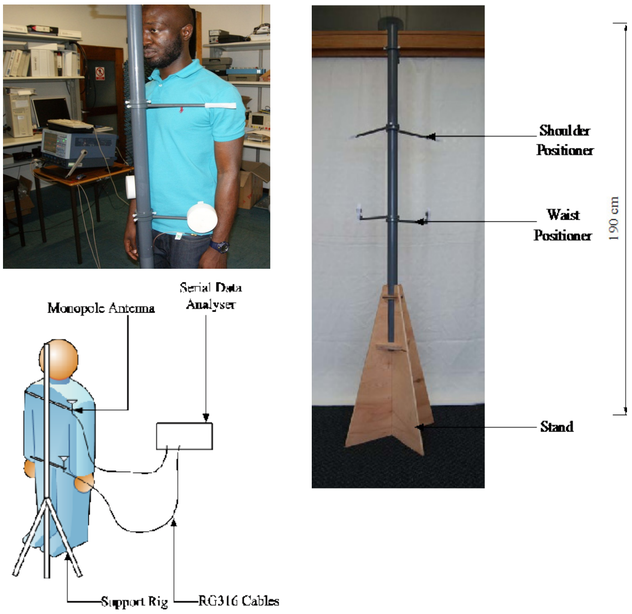

Figure 3 Top left: Procedure for an on-body measurement; Bottom Left: Cable arrangements; Right,: Plastic Experimental rig.

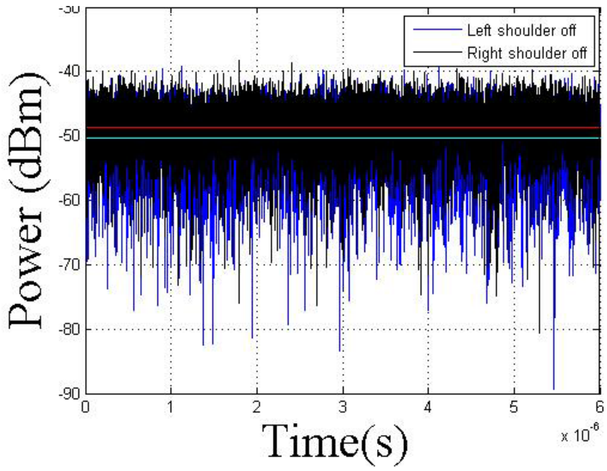

Figure 4 Received power in dBm for the left and right shoulder off-body channel and means.

Cable chokes were not used in our experiments, however the match for our antennas both on and off the body was very similar and we therefore feel it reasonable to assume that the effects of cable on the received signal were minimal. An example 6-second data set is shown in Figure 4.

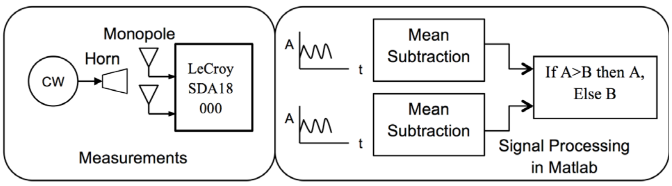

Figure 5. System diagram for selective combining measurements and analysis.

III. RESULTS

The paths and scenarios measured are shown in Table 1. All on-body measurements were duplicated off body. The three environments were a laboratory, an office and a corridor. The combination antenna positions were shoulders and waist.

TABLE 1 RESULTS FOR ON AND OFF BODY CHANNELS AND SELECTIVE COMBINING DIVERSITY GAIN. RESULTS IN TABLE 1 ARE IN DB ROUNDED TO 1 DECIMAL PLACE. SC = SELECTIVE COMBINING. THE 10^{-3} POINT ON THE CUMULATIVE DENSITY FUNCTION CURVES WAS USED TO MARK THE CHANNEL VALUES.

Set		Right On	Right Off	Left On	Left Off	SC On	SC Off	SC Gain On	SC Gain Off
	Waist								
1	Lab	-51.3	-55.9	-51.4	-61.6	-48.3	-52.8	3.0	3.1
2	Office	-57.2	-64.8	-61.5	-68.3	-51.8	-55.1	5.4	9.7
3	Corridor	-59.0	-72.3	-42.7	-41.6	-42.7	-41.3	0	0.3
	Shoulder								
4	Lab	-49.0	-60.8	-58.5	-64.4	-48.4	-55.1	0.6	5.7
5	Office	-66.9	-66.9	-58.5	-67.2	-54.9	-55.7	3.6	11.2
6	Corridor	-62.0	-47.9	-62.0	-46.5	-51.3	-44.2	10.7	2.3

Three representative sets of results are shown in figures 7, 8 and 9. The figures show the selective combined gains for on-body SC plotted with off-body SC. To obtain the gain values results of the received signal strength samples were post processed using Matlab.

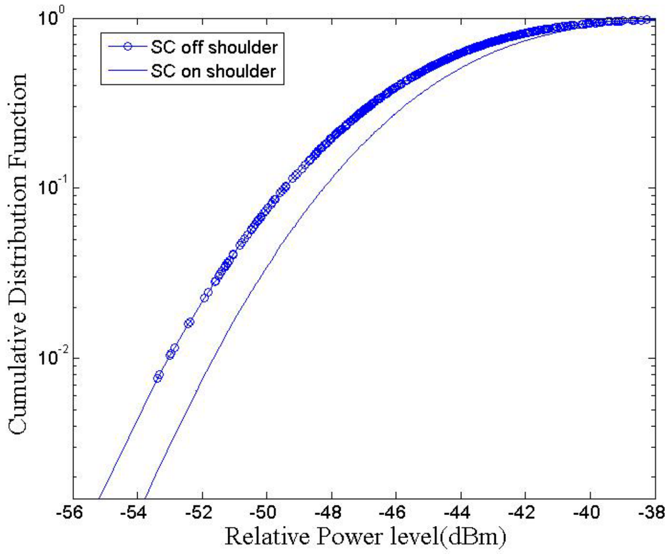

Figure 6. Selection combining results for on and off the shoulder antennas in an office.

With reference Figure 6., the results show that on-body SC is better than off-body SC by approximately 1dB. Referring to Table 1, set 5 we see that when referenced to the best channel mean at CDF 99% reliability with SC improved off-body by 11.2dB and on-body by 3.6dB. This compares to the 15dB possible predicted by the Rayleigh fading analysis shown in Figure 1 and discussed in [3], [4]. This measurement set took place in an office. Using the rig shown in Figure 3 an antenna was positioned on each shoulder of a volunteer and the left and right branches were measured. The volunteer then moved away leaving the antennas in place. The left and right off-body branches were then measured again. The office is a rich scattering environment. The Rx power is similar for three channels and approximately 8dB better for the left on body channel. The antennas are relatively high off the ground.

In Figure 7 the results for waist placed antennas in a Lab are presented. The data for these channels is in Table 1, set 1. The antennas are at the midpoint of the body. The Lab should be considered as a rich scattering environment. The channels have relatively similar means for on-body but asymmetrical by approximately 5dBs for off-body. The SC gains are quite similar. Overall the on-body SC provides the best branch combination.

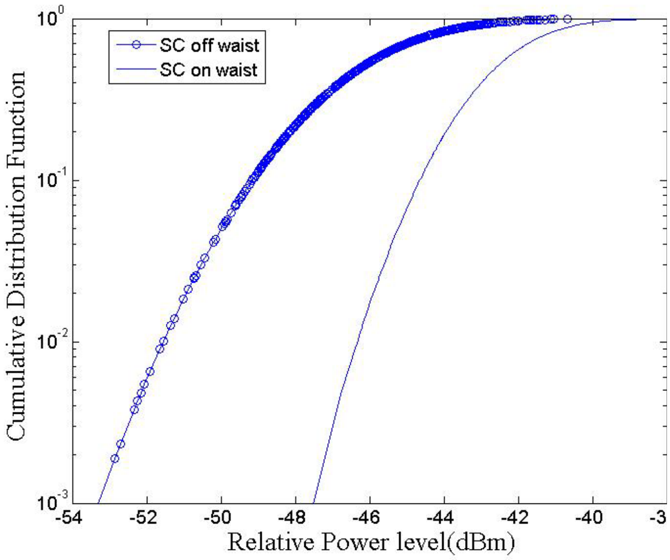

Figure 7. Selection combining results for on and off the waist in a laboratory.

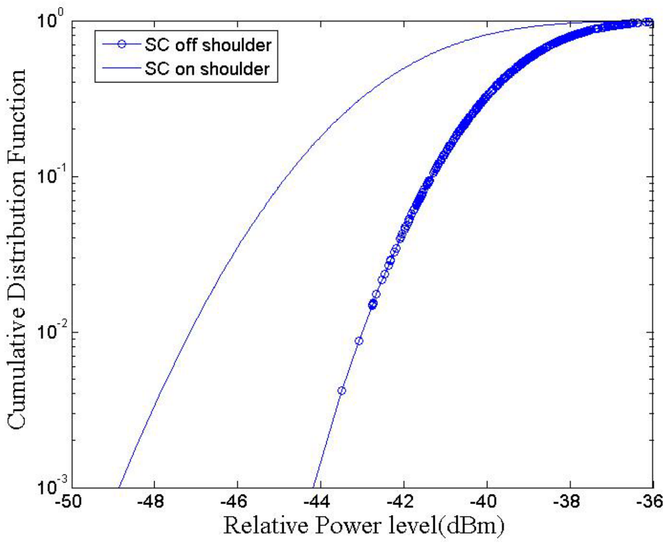

Figure 8. Selection combining results for on and off the shoulder in a corridor.

Lastly in Figure 8 the results for SC on and off the body, for antennas on the shoulders are shown for a corridor environment. The antennas are high off the ground. The corridor should be considered a poor scattering environment. Please refer to Table 1, set 6 for the channel data. In this environment the two sets of branches are roughly similar to one another but approximately 18dBs worse for the on-body system. The best set of branches was seen to be the off-body combination. For sets 1 through 5 the general channel conditions for the on-body branches were better. Only set 6 had a better off body figure in terms of overall performance. For SC gain the off branch combination was generally either equal or better than the on branch combination.

IV. Conclusions

In this paper we have developed a technique for isolating the effects of the human on selective combining. It has been seen despite the complex fading environments studied general trends can be identified. Overall SC was always beneficial and at 2.4GHz in these common environments can provide significant gains. Further work involves developing the transmission matrix to include the body in the transmission path thereby allowing the extension of the analytical forms for SC and maximal-ratio combining. In this work since the SC relies mainly of scattering for its performance and the main beam of the Tx was in the null of Rx antennas, the gain of the antennas was not considered. However, high gain planar body worn antennas are now a possibility. Therefore a further paper to study this aspect combined with other diversity techniques is proposed.

References

[1] [1] R. M. Edwards, "Wireless Body Area Network Channels," in *LTE-Advanced and Next Generation Wireless Networks: Channel Modelling and Propagation*, vol. 2012, John Wiley & Sons, 2012, p. 568.

[2] [2] S. L. Cotton and W. G. Scanlon, "Channel Characterization for Single- and Multiple-Antenna Wearable Systems Used for Indoor Body-to-Body Communications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 4, pp. 980–990, Apr. 2009.

[3] [3] M.-S. Alouini and M. K. Simon, "Performance analysis of generalized selective combining over Rayleigh fading channels," in *1999 IEEE Communications Theory Mini-Conference (Cat. No.99EX352)*, 1999, pp. 110–114.

[4] [4] R. Janaswamy, *Radiowave Propagation and Smart Antennas for Wireless Communications*, vol. 599. Boston: Kluwer Academic Publishers, 2002.

[5] [5] R. K. Mallik, M. Z. Win, J. W. Shao, M. S. Alouini, and A. J. Goldsmith, "Channel capacity of adaptive transmission with maximal ratio combining in correlated Rayleigh fading," *IEEE Trans. Wirel. Commun.*, vol. 3, pp. 1124–1133, 2004.