Diversity for Body Area Networks

***A.A. Serra*[1], *P. Nepa*[1], *G. Manara*[1], *P.S. Hall*[2]**

[1]Dept. of Information Engineering, University of Pisa,Via G. Caruso 16, 56122, Pisa, Italy
andrea.serra, p.nepa, g.manara@iet.unipi.it

[2]Electronic, Electrical and Computer Engineering, University of Birmingham, Birmingham, B15 2TT, UK
P.S.Hall@bham.ac.uk

Abstract

In this paper a review of diversity for body-centric communications is presented. On-body communication channels are affected by fading whose effects need to be mitigated. Recently, diversity techniques for on-body systems have been experimentally analyzed. Results on space diversity at 2.4 GHz have been obtained, which proved the effectiveness of diversity scheme implementation. The diversity performances have been evaluated in terms of diversity gain, power imbalance and envelope correlation coefficients between the two receiving channels, and finally by the analysis of the cumulative distribution function of the normalized received power.

1. Introduction

On-body communication are often being applied in medical diagnostics and real time patient monitoring. Other important applications involve sports training, police and military agencies, and entertainment. Much work has been done to investigate the body channel at the ISM bands such as 2.45 GHz. At this frequency, electromagnetic propagation involves two main aspects. Firstly, propagation takes place over the surface of the body by creeping or surface waves. Such propagation may be significantly affected by the motion of the body. Secondly, multipath propagation around the body, which is due to reflections from the surrounding environment and the body parts, will also occur. Propagation through the body is negligible at this and higher frequencies. Fading will occur due to the large relative movement of the body parts, shadowing, polarization mismatch, and scattering due to the body and the surrounding environment. To improve the performance and overcome fading, diversity is a very powerful tool. The principle behind diversity is the use of more than one independent and hence uncorrelated received signals which will fade independently of each other. Diversity can be achieved in various ways such as frequency diversity, time diversity, and antenna diversity. Antenna diversity involves the use of multiple antennas, different radiation patterns, and/or polarizations [1]. Space diversity is by far the most popular technique, [1-3]. Space diversity is achieved by using more than one antenna at the transmitter or receiver side. This technique does not consume extra spectrum [1, 2] and the basic issue is that of antenna spacing. The diversity branches in the other antenna diversity techniques can be achieved by using different radiation patterns in the same or separate antennas and by using a single antenna with orthogonal polarizations or separate antennas with orthogonal polarizations[4]. When two antennas are placed close to each other, mutual coupling between the antennas must be low to prevent the effect of one antenna on the other. A spacing of $\lambda/2$ is sufficient for most of the applications [1]. The improvement due to the use of diversity is usually measured in terms of diversity gain (DG). DG is an improvement in the signal strength or signal to noise ratio or bit error rate over a single antenna with no diversity, at a certain level of outage probability [3,4]. DG depends upon the correlation and power imbalance between the two branch signals. If the power imbalance is more, the diversity combiner will favor the strongest signal for most of the time and hence a negligible diversity gain will result. For the on-body communication channels, pattern and polarization diversity antennas must be designed carefully to prevent one antenna being dominant compared to the other, for various positions and postures of the body, otherwise the high power imbalance can severely affect the diversity performance. Due to limited changes in the antenna orientations for most of the on-body channels, the power imbalance will be larger if either the pattern or polarization of the diversity antennas is different. Space diversity can be considered as a good choice for most of the on-body channels. The improvement offered by diversity for the on-body channels was reported in [5-9] using monopole antennas. A comparison of the space and pattern diversity for on-body channels is given in [10]. This paper presents a review of the diversity performance for on-body communication channels. Diversity gains and correlation coefficients have been reported for various spacing of space-diversity receiving monopole antennas and other realistic antennas mountable on the body, namely the printed-inverted F antenna, (IFA) and the planar inverted F antenna (PIFA). Measurement setup, environments and procedures are described and commented. On-body channels and the assumed human postures are defined on the basis of applications.

2. Diversity performance in on-body communication systems

In this section, the most recent results on diversity for on-body communication systems are described [5,6,9]. The measurement procedure and the data analysis is briefly described, and the effect of the environment is discussed. As in traditional mobile communication systems, where distinctions among indoor and outdoor, urban and rural propagation environments have been identified, a body posture classification can be developed for on-body communications, since the relative position of the transmitting and receiving antennas significantly influences the system performance. Postures with different levels of mobility have been taken into account and generally roughly classified in sitting and standing. Free movements are allowed for each part of the body: leaning down, turning the trunk, walking, kneeling, and moving arms. The transmitting antenna is usually mounted in the waist position thus forming five on-body channels named belt-chest, belt-back, belt-head, belt-wrist, and belt-ankle. They are intended to be used for devices like wireless earphone or visors in a helmet on the head, music and video players for the head, temperature sensors or step counters for the chest and the ankle, media players or mobile phone in a backpack. Measurements have first been taken in an anechoic chamber [5,6] to investigate the fading effect of the body itself in the absence of multipath due to environment and then in indoor environments [9] like a typical laboratory containing equipment, tables, chairs, and computers thus providing a rich multipath propagation environment. The transmitting antenna was connected to a signal generator. The two receiving antennas were connected to the two ports of a vector network analyzer operating in tuned dual channel receiver mode with an amplitude and phase sampling time selected to ensure that all the variations caused by the fast movement of the body were captured. Collected samples have been used to calculate the statistics of both channels as well as the diversity gain relevant to different combining techniques. A sample of measurement results is shown in Fig. 1 [5,6]. For each branch (Ant1 and Ant2), Fig. 1 shows the CDF of the relative power level (dashed lines with markers) for the waist/ankle and the waist/wrist radio links. The CDF traces have been constructed by normalizing the power samples measured at the two branches with respect to the mean power of the strongest channel (Ant.1 in Fig. 1). The continuous line represents the theoretical Rayleigh distribution, which has been proved to be useful in characterizing indoor and outdoor propagation channels. It has been added as a reference and calculated on the basis of the statistics of the strongest channel. It appears that the Rayleigh channel model is not the most appropriate for on-body communications. The two-branch normalized power samples have been combined through the selection combining (SC), equal gain combining (EGC) and maximum ratio combining (MRC) techniques, and the CDF traces relative to the combined signals are plotted in the same figure (continuous lines with markers). For a fixed value of the CDF and for each combining technique, the difference between the strongest channel trace and the curve relevant to the combined signal represents the diversity gain. From [5,6,9] it results that diversity gain can be much obtained for some postures and not for others. Moreover, it appears that the signal combining does not improve the performances of line-of-sight links, like the waist/chest one, for any posture or distance between antennas. In these cases, the diversity gain is close to zero for the SC scheme since one of the two channels is characterized by a stronger signal level. For the same link, the diversity gain for EGC and MRC techniques does not increase more than 2-3 dB. Similarly, almost static links, like the waist/centre back link, and shadowed links, like the waist/ankle link in the sitting posture, show relative small values of diversity gain: around 3-4dB for the SC and 6-7dB for EG and MRC techniques. Better performance is obtained for non-line-of-sight links like the waist/wrist and the waist/head links, and diversity gain is between 8-9dB and 11-12dB for SC and EGC/MRC, respectively.

In [9], measurements were also taken in a typical laboratory containing equipment, tables, chairs, and computers thus providing a rich multipath propagation environment The system performance in such an environment result to be comparable to those carried out in the anechoic chamber in terms of envelope correlation coefficients and they show larger values (of about 1-2dB) for the diversity gain due to the increased effect of the multipath of the external environment. It was observed that slow fading was similar and hence correlated for both diversity branches. This high correlation suggests that the slow fading has effectively no part in the diversity performance and should be removed. The data was properly demeaned and the slow and fast fading envelopes were extracted.

In [5,9], it has been demonstrated that DG tends to increase with increase in the antenna spacing. There are a few exceptions, however, in which either the power imbalance is large or the correlation is high and then the DG reduces. The same trend was observed for the measurement data in the anechoic chamber and the office environment. The relationship of envelope correlation coefficients with the antenna spacing was analyzed, showing a minimum at about $\lambda_0/4$ for all the cases analyzed.

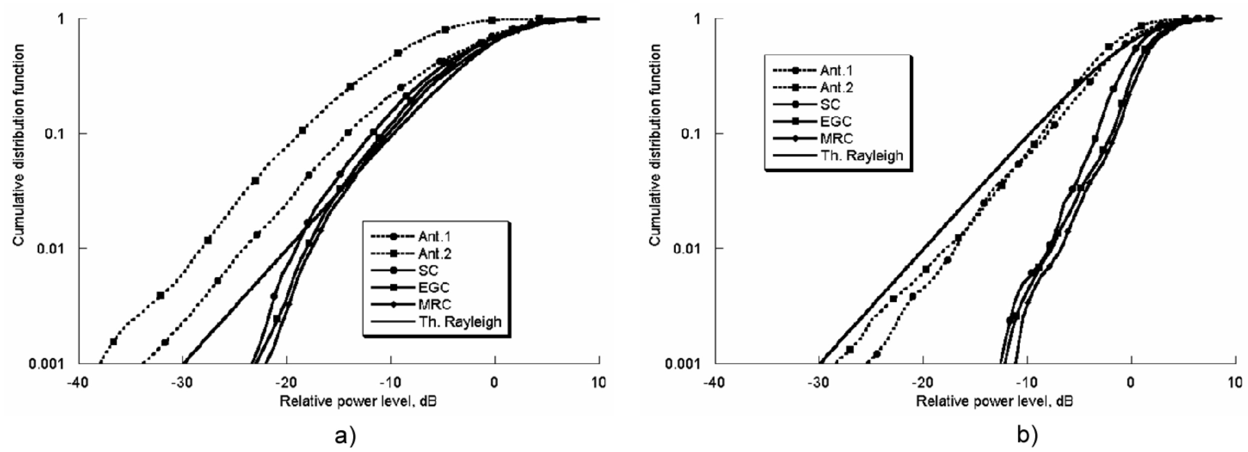

Fig. 1 Cumulative density function for the waist/wrist (a) and the waist/ankle (b) radio links, for a standing posture and different combining techniques: selection combining, SC, equal gain combining, EGC, and maximum ratio combining, MRC.

3. Antennas for on-body diversity

Some antennas, other than monopoles, like printed IFA and PIFA were used to evaluate the diversity gain performance in [9]. There, high diversity gains and low envelope correlations were achieved even for the belt-chest channel, which suggests that the multipath components were much stronger than the direct ray. For the printed-IFA the direct ray is polarized parallel to the surface of the body and is therefore attenuated much more than a perpendicularly polarized ray. Thus, as expected, the mean received power was lower compared to the monopoles [5-6]. The diversity gains are on average higher than the diversity gains for monopoles. It has been also shown that the antenna orientation is important. It is apparent that an orientation that gives high power imbalance is undesirable. Like the printed-IFA, high diversity gains and low envelope correlations were achieved with the PIFA for all the channels, except for the belt-chest link. The high power imbalance and low diversity gains suggest the presence of stronger direct link compared to printed-IFA. Also the mean received power levels are higher than the printed-IFA but lower than the monopoles. The average diversity gains are higher for PIFA than for printed-IFA.

The previously described antennas allow for pattern and polarization diversity. A novel dual-pattern/dual-polarization planar annular-ring slot antenna to be used in a receiving pattern/polarization diversity scheme for body-centric communication systems has been described in [11-12]. The annular-ring slot antenna design radiates through two concentric annular slots etched on a metallic layer. In the outer slot the second-order resonant mode is excited and the corresponding radiation pattern exhibits a null in the direction perpendicular to the antenna plane and a quasi-omnidirectional radiation pattern in the plane parallel to the antenna. The main beam direction of the inner slot is perpendicular to the antenna, producing a radiation pattern complementary to the outer slot’s one. To radiate two orthogonally polarized electric fields, two ±45° oriented strip lines feed the inner slot. A set of prototypes of the annular-ring slot antenna has been already fabricated and measurements have being carried out for diversity performance at 5.8GHz [12].

4. Conclusions

Relatively high diversity gains achieved for the on-body channels suggest that multipath due to the environment and the body plays an important role in the on-body propagation phenomena. The correlation of the diversity branches is low for most of the on-body radio links, which suggests that the diversity can provide a significant improvement of the communication system performance, if the power imbalance is carefully dealt with. Dynamic channels or channels with non-line-of-sight condition exhibit the highest diversity gain values.

5. References

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