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ULTRA-WIDEBAND SPATIAL CORRELATION STUDY FOR MULTI-SENSOR MULTI-ANTENNA BODY AREA NETWORKS

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Abstract

This paper is a first step towards the development of UWB multi-sensors MIMO Body Area Networks, where the sensors communicate with a multi-antenna central device. The spatial correlation in the frequency and delay domains has been extracted from channel measurements on the human torso. We highlight two behaviours depending on the propagation mechanisms: diffraction around the body and environment reflections.

1 Introduction

A new kind of wireless personal and body-centric network has emerged for a few years. It is composed of several sensors placed on the human body and measuring vital information. This information is then carried out towards a central body-worn device, such as a personal digital assistant (PDA). This wireless network is known as a Body Area Network (BAN). Radio signals may then reach the central device directly or via multi-hops using other sensors as relays. Several applications are foreseen, e.g. patient monitoring, where the user is no longer restricted to one specific place and can be taken care of remotely.

The gain of interest for BANs is confirmed by the IEEE 802.15.4a group activities where BANs are included as a relevant scenario. This group is mandated to develop a low complexity, low cost and low power consumption physical layer based on the promising Ultra-wideband (UWB) technologies. UWB systems are characterized by a bandwidth ranging from 3.1 to 10.6 GHz, leading to several advantages such as low interference to and from other systems, low sensibility to fading and accurate position locating due to the fine time resolution [8].

In this paper, multi-sensor MIMO (MS-MIMO) UWB systems are investigated. Each sensor consists of one antenna while the central device (where most of the computational complexity is located) uses an antenna array. Using MIMO techniques, it is possible to perform beamforming, multi-hops relays or to improve the capacity of the transmission.

Yet, the development of efficient space-time algorithms requires a full UWB MS-MIMO channel characterization, with a special attention to the spatial domain. In what follows, measurement results are presented, dealing with the correlation between body worn antennas. The particular body propagation mechanisms are emphasized.

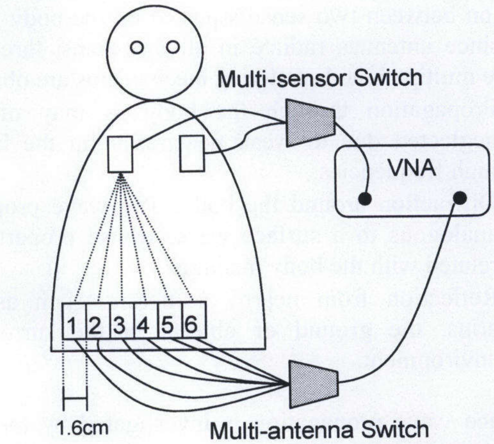

Fig 1. Schematic diagram for MS-MIMO measurements

2 Measurement campaign

2.1 Measurement setup

The schematic diagram in Fig 1 shows the experimental setup. Measurements have been performed on a single person whose body is in a standing position, arms hanging along the side in all cases. A Rohde&Schwarz ZVA-24 multi-port vector network analyser (VNA) has been used to measure the complex frequency response in the 3 GHz to 10 GHz range. Each of the two ports of the VNA is connected to an Agilent 87106C-SP6T coaxial switching unit that selects up to six antennas. The first switching system simulates the central device with antennas placed near the belt, configured as an uniform linear array (ULA), the simplest well-understood narrowband array configuration. The second switching system represents the various sensors located at different positions on the human torso. Low-loss coaxial cables are used to inter-connect all the components. Both the VNA and the switches are controlled by a MATLAB routine on an external computer. The same Skycross SMT-3TO10M UWB antennas have been selected for all MS-MIMO measurements since their small-size and low-profile characteristics precisely matched with body sensor requirements. Unfortunately, the radiation pattern and antenna impedance (S_{11}<-5dB) are modified when the Skycross antennas are placed close to the body. The antenna de-embedding is however quite complex and has not been realised at this early stage. Thus, the following results include both the channel and the antenna effects.

The complex time-domain response is obtained by means of an inverse fast Fourier transform (IFFT) on the complex baseband frequency signal. A Hamming window has been applied to reduce sidelobes.

2.2 Measurement environments

Many publications have highlighted an extremely complex propagation between two sensors placed on the body [2,6,7]. In fact, since antennas radiate in all directions, three main distinctive multipath and scattering mechanisms are observed:

- Propagation through the body. It may often be neglected due to weak penetration in the body at high frequencies.
- Diffraction around the body. The wave propagates analogous to a surface wave, whose properties are related with the body medium.
- Reflection from nearby scatterers, such as body arms, the ground or objects in the surrounding environment.

The surface wave propagation is investigated by means of two measurement scenarios. First, absorbing materials are placed around the body to simulate pseudo-anechoic conditions. They have an average attenuation of 20dB across the whole bandwidth. Unfortunately, ground and body reflections are still present. Afterwards, a measurement is performed in a very large open space environment avoiding reflections. A time gating on the impulse response is applied in order to only keep the surface wave. Eventually, environmental reflections are taken into account by performing measurements inside a classic room with many scattering objects whose effects can be investigated.

3 Spatial correlation analyses

Spatial correlation compares the channel variations in order to obtain the coherence distance between antennas corresponding to independent channel realizations. A high decorrelation maximizes diversity and thus improves the communication quality. Usually, a half-wavelength inter-antenna spacing is required in order to have a low correlation [9]. Nevertheless, this is less obvious in UWB since a wide range of wavelengths are involved. According to the target application (diversity, spatial multiplexing, beamforming, etc.), different solutions need to be applied [5]. However our current work is only to understand the inter-element spacing behaviour without fixing a specific solution. Complex spatial correlation have been calculated over 100 channel measurements, both in the frequency and delay domains, with the following formula:

$$\rho(X_{ij}, X_{kl}) = \frac{E\left[(X_{ij} - E[X_{ij}])\ (X_{kl} - E[X_{kl}])^*\right]}{\sqrt{E\left[|X_{ij} - E[X_{ij}]|^2\right]\ E\left[|X_{kl} - E[X_{kl}]|^2\right]}}$$

Where

- X_{ij} is the frequency or delay channel complex coefficient from the antenna i to the antenna j;
- X_{kl} is the frequency or delay channel complex coefficient from the antenna k to the antenna l;
- * denotes the complex conjugate operation.

4 Observations and Discussion

4.1 Frequency-domain spatial correlation

We compare the magnitude of the frequency-domain spatial correlations at the central device for BAN channels with and without external reflections. The first element in the antenna array is taken as reference. The sensors are placed on the human torso at about 35 cm from the belt. Elements of the antenna array are close to each others as seen in Fig 1.

4.1.1 Measurement results for the diffracted waves

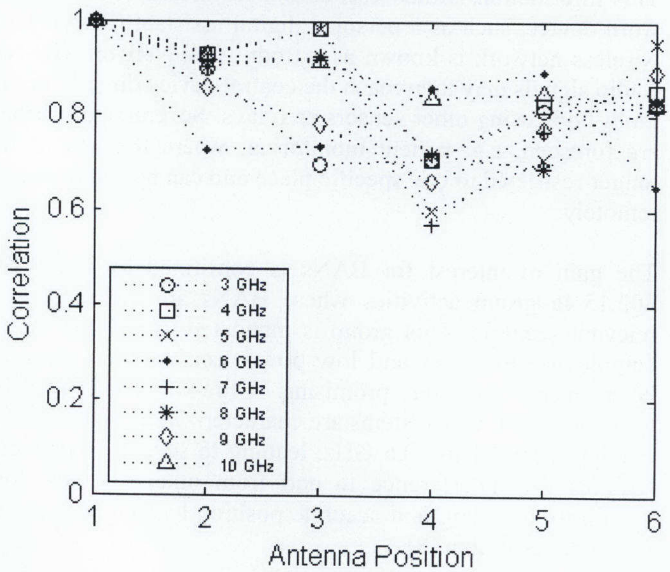

Fig 2. Frequency-domain spatial correlations for diffracted waves

From Fig 2, a significant correlation (above 0.6) between the antennas can be observed. This result is verified for all frequencies. Due to the absorbing panels, the environment reflections are suppressed. Channel temporal variations are caused by body movements essentially due to breathing (remember that the human body is in a standing position). The received signal is therefore almost constant over time leading to this very high correlation. The variance of the received power has been calculated at each frequency and a mean value of 0.50dB is obtained. This low variance confirms the quasi static behaviour of the signal.

4.1.2 Measurement results including the environment

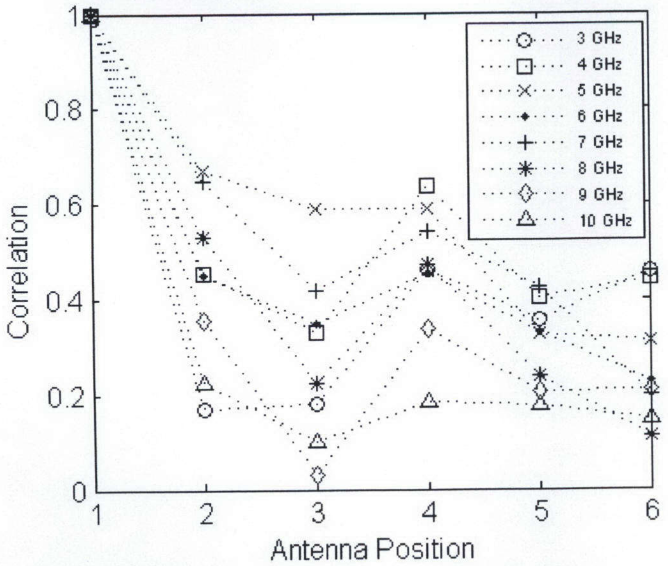

Fig 3. Frequency-domain spatial correlations including the environment

In order to quantify the effect of the environment, the same measurements have been performed in an office with people working all around. The channel impulse response is completed by additional multi-path components (MPCs) created by environment reflections.

Each MPC has a contribution to the total received power highly dependent on the spatial position and of time. Therefore, it acts as a decorrelation mechanism as can be seen in Fig 3.

4.2 Delay-domain spatial correlation

The following results are obtained in the time domain. Fig 4 presents a channel impulse response between a sensor and the first element of the central device antenna array. This measurement has been performed in the environment rejecting reflections from surrounding scatterers. Its structure is identifiable: A prevailing direct diffracted wave is directly followed by other diffracted waves and reflections from the body scatterers. Later, the ground effect appears.

Fig 5 shows the delay-domain spatial correlations for the values given by the markers described in Fig 4. As seen, the channel is static over time and high correlations are expected over the whole delay range. However, it is only confirmed for significant values of the impulse responses. In the other cases, the correlation behaviour is probably influenced by the measurement noise, thus lowering the correlation.

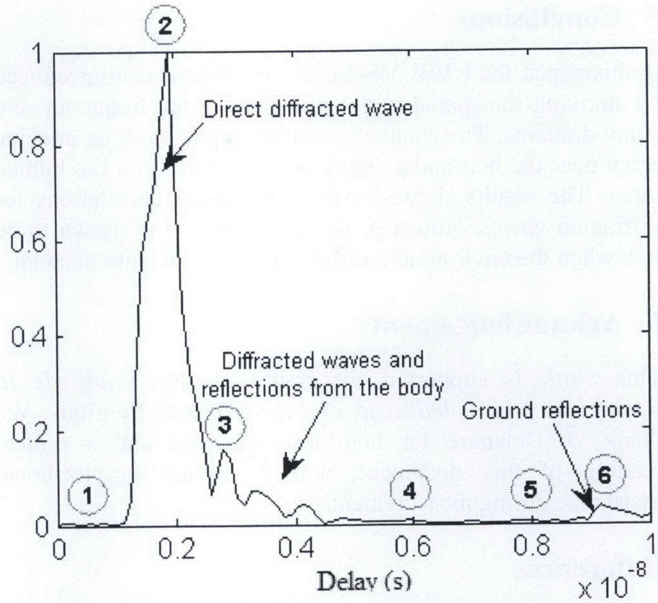

Fig 4. Example of a normalised impulse response

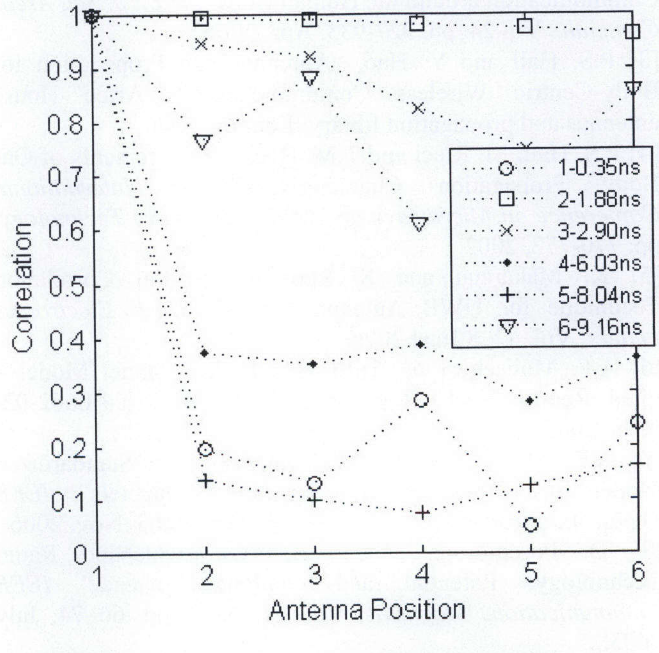

Fig 5. Delay-domain spatial correlations

4.3 Omni-directional antennas in question

The measurements are impaired by the directional behaviour of the antennas. In fact, previous studies advice that the Skycross antenna seems to be directional above 6 GHz [10]. Furthermore, close spacing of the ULA elements creates mutual coupling that alters the antenna radiation patterns and increases the directional dependence of the impulse response.

5 Conclusions

In this paper, the UWB MS-MIMO BAN has been introduced by studying the spatial correlation in both the frequency and delay domains. The channels were measured with an antenna array near the belt and a single antenna placed on the human torso. The results showed very high spatial correlations for diffracted waves. However, the correlation was shown to be low when the environment reflections are taken into account.

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