Ellipticity Statistics of Ultra Wideband MIMO Channels for Body Centric Wireless Communication

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***Abstract*—In this paper, ellipticity statistics of 2×2 ultra wideband multiple-input-multiple-output (MIMO) channel for body-centric wireless communication is evaluated by quantifying four different on body links namely; waist-back, waist-chest, waist-ankle and waist-wrist. Results show that at lower values of signal to noise (SNR), spatial multiplexing dependent capacity degrades as the eigen value dispersion decreases (*i.e.*, lower ellipticity statistic), whereas it increases at higher values of SNR.**

***Index Terms*—Body-centric, statistical analysis, MIMO, on-body, capacity**

I. Introduction

With the growing role of technologies in healthcare diagnostics and treatment, the demand for advance health monitoring and remote health care technologies continues to increase day by day. Body centric wireless communication plays a vital role in current wireless and patient specific communication due to its advantage of user friendly comfort, patient safety and care, in addition to its remote access to doctors for monitoring and treating patients.

Ultra-wideband (UWB) technology is a an ideal high rate, short range communications technology for body-centric communication because of its features including, low-power, high bandwidth and low probability of intercept [1]. Due to growing demand of high throughput, researchers are investigating new techniques and technologies to meet this requirement. One of the most popular technique to fulfill these prerequisite is the combination of multiple-input-multiple-output (MIMO) systems with ultra wideband technology [2], which not only increases the signal-to-noise/interference ratio but also provides additional diversity to combat fading.

In past, several studies are performed on MIMO systems for mobile and personal communication [3], narrow band body-centric communication [4, 5] and some on ultra wideband (UWB) body-centric communication [6–9]. Frequency space polarization is used in [8] to investigate on body UWB-MIMO, whereas Roy et. al [9] used space-time spatial model for multi sensor UWB body area networks (BAN). Recently, author's investigated [10], the capacity of UWB on-body MIMO networks using different power allocation techniques (*i.e.*, water filling and equal power allocation [11]). Results show that the waterfilling scheme outperforms the equal power in terms of capacit with an average improvement of 1.2 bps/Hz. To the best of the authors' knowledge, ellipticity statistics of UWB MIMO for body centric communication still needs investigation. In this paper, the ellipticity statistics of four different 2×2 UWB (3 - 10 GHz) MIMO on-body channels are presented and relationship between water filling capacity values and eigen value dispersion is studied.

The rest of the paper is organized as follows. Section II presents the measurement setup used in this paper for UWB MIMO BAN studies. Section III presents the statistic of MIMO channel and finally, conclusions are drawn in section IV.

II. Measurement Setup

In this study a 2×2 CPW fed UWB antenna [7] was used for MIMO measurements over the whole UWB band(*i.e.,* 3 -10 GHz). MIMO antennas used in this study were place on single substrate and exhibits excellent radiation properties and gain over the entire operational band. The antenna's used in this study were compact in size with overall dimensions of 27 mm $\times$ 47 mm [10] with a spacing of 0.34λ (15 mm). In order to observe the indoor effect on MIMO channel, measurements were first performed in the anechoic chamber and later on in an indoor environment at Queen Mary, University of London [7]. In this study transmitting antenna (TX) was fixed at waist (placed parallel to the body), whereas the receiving antennas (RX) were placed at different places *i.e.,* center of back, right chest, right ankle and right wrist as shown in Figure 1.

For the measurement of 2×2 UWB MIMO channels, an Agilent PNA-N5244 was used, which was calibrated and remotely controlled by Lab view program. Tx and Rx antennas were connected to 4 ports of PNA to record the channel responses (magnitude and phase) simultaneously over the UWB band, while subject was performing various daily life activities (details about performed activities are mentioned in [7]. Total 16005 samples were recorded for each channel with a carefully chosen sampling time (*i.e.,* 6.6 ms in this case to overcome doppler effect). A spacing of few millmeters is kept between the subject and antenna for optimal performance.

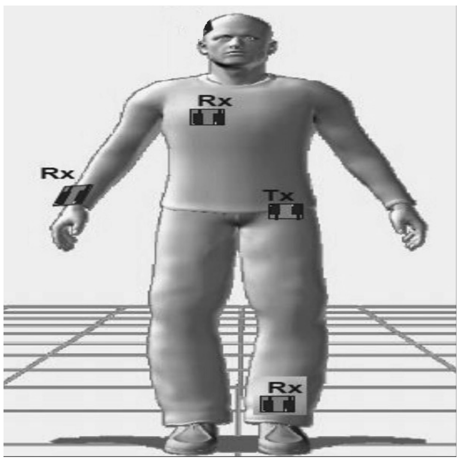

Fig. 1. MIMO transmitter and receiver locations used in this study

III. ELLIPTICITY STATISTIC OF MIMO CHANNELS

For an m-transmit and n-receive antennas for on body case, the input-output relationship is given by:

$$\mathbf{Y} = \mathbf{HX} + \mathbf{W} \tag{1}$$

whereas **X** and **Y** are transmit and receive vector, **H** is the $[n \text{ x } m]$ channel matrix and **W** is AWGN vector. **H** can be expressed as:

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1m} \\ h_{21} & h_{22} & \cdots & h_{2m} \\ \vdots & \vdots & & \vdots \\ h_{n1} & h_{n2} & \cdots & h_{nm} \end{bmatrix}, \tag{2}$$

whereas h_{ij} is a complex random variable representing the channel fading coefficient between the j^{th} transmit antenna and the i^{th} receive antenna.

For MIMO radio the major impact comes from richness of multipath and their correlation properties. Mutual information of MIMO channel between its input and its output defines channel capacity in terms of maximum achievable transmission rate. In this paper, it is assumed that the channel state information is known at the transmitter side (*i.e.,* water filling power allocation is considered) and can be expressed as [12]:

$$C = \sum_{i=1}^{K} \log_2 (1 + \lambda_i P_i), \tag{3}$$

where P_i is the power allocated to the i^{th} MIMO eigen-channel and λ_i is the corresponding eigenvalue [12]. This capacity can futher be broken up into three main parts: a) average SNR, b) channel fading, and c) eigen value dispersion. Eigen value dispersion has direct impact on spatial multiplexing efficiency of the radio channel. It is the richness nature of multipath components in MIMO radio channels that allow spatial multiplexing for MIMO systems, when the SNR is high enough. This contribution comes from channel eigen values that are above receiver noise level. Hence, multipath richness can be measured with a measure related to eigen values. Dispersion in power of eigen values is correlated with the spatial multiplexing efficiency of the wireless system. Ellipticity statistic is defined as a measure of multipath richness in MIMO channels [13] as a measure to eigen value dispersion. It is defined as the ratio of the geometric mean ($m_g^{(i)}$) and arithmetic mean ($m_a^{(i)}$) of eigenvalues $\{\lambda_k^{(i)}\}_{k=1}^{K}$, of $H^{(i)}H^{(i)H}$ and can be written as [14]:

$$\mathbf{ES_{mux}^{(i)}} = \frac{m_g^{(i)}}{m_a^{(i)}} = \frac{\prod_{k=1}^{K} \lambda_k^{(i)\frac{1}{K}}}{\frac{1}{K}\Sigma_{k=1}^{K}\lambda_k^{(i)}} \tag{4}$$

This measure provides some information about the relative differences between eigenvalues differences. In terms of MIMO channel metrics, it provides knowledge about the degradation of channel capacity from the perfect channel conditions, when all eigen values are equal, *e.g.,* $ES_{mux}^{(i)} = 0$, where there is no capacity degradation and channel may support high efficient spatial multiplexing. As the value of ES gets smaller, it indicates the amount of possible degradation in spatial multiplexing capabilities. This metric is different from condition number, which is the ratio of largest to smallest eigenvalues. This difference is clear when more than 2×2 MIMO system is involved, since the ES takes into account all eigen values in its calculations.

Fig. 2 shows that chest-to-waist MIMO channel has lowest ranges of ES that shows highest degradation in spatial multiplexing efficiency as compared to other MIMO channels. The chest MIMO channel is dominated with line of sight (LOS) component and multipath components are not dense enough to support high efficient spatial multiplexing capability. Fig 3, shows the capacity with respect to dispersion of eigen values and it can be seen from the results that at lower SNR values capacity degrades (*i.e.,* spatial multiplexing dependent capacity) as the dispersion move towards ideal case, when ES=1 (*i.e.,*

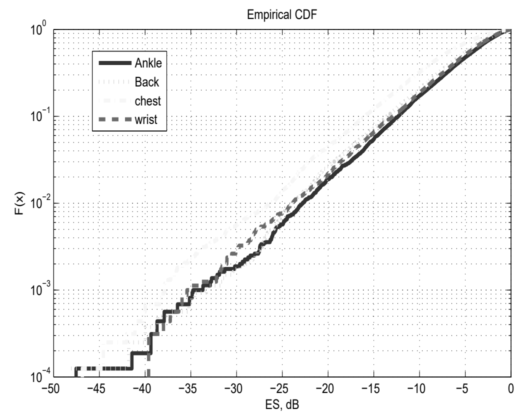

Fig. 2. Empirical CDF of ES for four different links for UWB MIMO channel

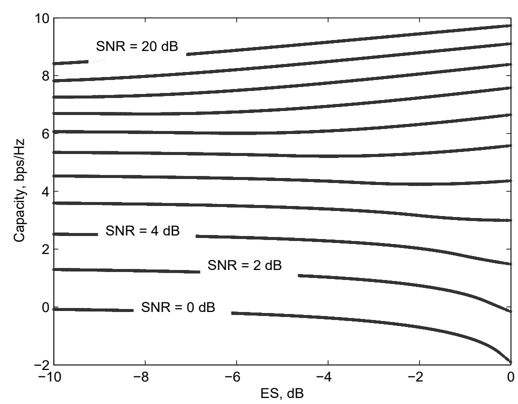

Fig. 3. Achievable channel capacities with respect to ES at certain SNR for chest-to-waist MIMO channel

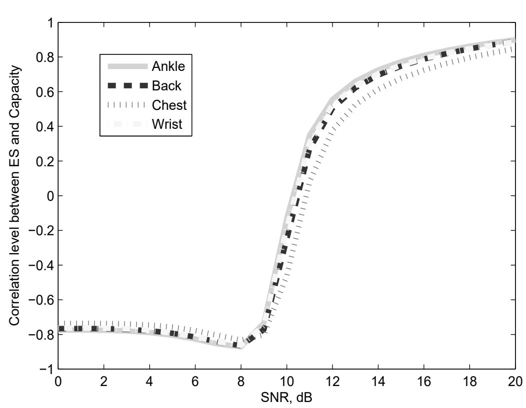

Fig. 4. Correlation between capacity and ES for four different links with respect to SNR

0 dB). Whereas, at higher SNR, there is a direct relation between the capacity and ES. Results also show that in the case, when SNR values are high, the desired value of capacity can be obtained at even lower value, if the dispersion of eigen values is low. Fig 4, shows that there is trade-off between the spatial multiplexing capacity and SNR. At lower SNR (below 8 dB), there is not an expected increase in capacity trend due to spatial multiplexing, while above 8 dB, there is a linear relationship between the gain of spatial multiplexing capability of channel and SNR. It can be concluded that, if there is any capacity enhancement at lower SNR values, it will be due to the diversity, while at higher SNR values this increase can be either due to spatial multiplexing with decrease in ES or because of diversity and spatial multiplexing both.

IV. Conclusion

In this paper, ellipticity statistics of four different on body UWB MIMO channel are presented. Water filling power allocation capacity values are studied with respect to eigen value dispersion *i.e.,* $ES_{mux}^{(i)}$ and results indicate that below certain cut off value of SNR the capacity values are independent of dispersion in eigen values, while after that cut off of SNR, there is a direct relationship between the SNR and capacity.

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