Influence of Polarization Direction on Static On-Body Propagation Channels

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***Abstract*—On-body propagation channels show significant polarization selectivity in static and dynamic scenarios. In this work, we measured polarized on-body channels on static body at 2.4 GHz by monopole antennas, where standing and sitting postures are considered. The polarization direction of the antenna (Z-polarization, H-polarization, V-polarization) depends on the the direction of the antenna in the body position. In the statistical characteristics of the channels, the V-polarization direction of the receiving antenna is more conducive to receiving signal and reducing the path losses. Cross-polar discrimination (XPD) are calculated from measurement data, the strongly depolarization of on-body channels is more easily caused by the human sitting posture due to legs scattering. No matter how the polarization direction of the transmission antenna , the receiving antenna can generally obtain a decent field component in the V-polarization direction.**

I. Introduction

On-body communications in wireless body area networks (WBANs) are short distance communications defined on or above the body of limited height [1]. An essential feature of on-body propagation channels is that they do not follow conventional far-field propagation principles and exhibits complex near-field characteristics including the body scattering effects [2], [3] and surface wave propagation [5]. Studies as [6] have shown the high sensitivity of on-body channels to the orientation of the transmit and receiving antennas, implying a possible polarization diversity for ultra-low powered sensor communication in e.g. medical and wearable applications.

Earlier studies on the finite-difference-time-domain (FDTD) simulations of the electromagnetic fields on the body surface [] have shown that due to the near-field body scattering effects, the surface wave propagation assumption may not fully consistent with the actual wave propagation in on-body channels, resulting the channel polarization dispersion both along and normal to the propagation path defined. The postures and body dynamics will further lead to the variation of the on-body polarization distribution over time and space domains. One limitation of previous measurements as reported in [6], [7] is that most of the measurements cover partial polarization configurations of on-body channels. Consequently, the polarization matrix of the channels are not fully characterized and modeled. Full-space description of the channel polarization distribution under specific scenarios is necessary to correctly capture the field components of the on-body channels.

In this work, measurements of polarized narrowband on-body channels at 2.4 GHz on static human body are conducted in indoor environment. Full polarization configuration are investigated for channels covering the key parts of the body. Two static postures of the body, i.e. the standing and sitting postures, were investigated, and the channel polarization distribution under the two postures were compared. The polarization matrix and the cross polarization descrimination (XPD) matrix for each scenario are summarized. The polarization gain and the depolarization ratio of the investigated on-body channels are investigated.

This paper is organised as follows. Section II describe the configuration of the measurements. Section III present the statistical analysis of the channel polarization distribution and depolarization characteristics. Finally, section **??** summarize the analysis.

II. Measurement Settings

The measurements were carried out in an indoor environment of an empty laboratory in dimension of 6 by 7 meters, no large obstacles around. We thereby assume the environment as reflection neglegible, and the channels is primarily affected by their geometry distribution and body scattering.

A male volunteer of height 160 cm and weight 50 kg was chosen. Two postures, standing and sitting with arms naturally posed, are investigated as shown in Fig. **??**. On-body channels were selected based on 5 key parts of the upper-body as presented in Fig. **??**, which are head-left-shoulder (T-LS), head-left-wrist (T-LW), chest-left-abdomen (C-LA), left-shoulder-chest (LS-C), and left-elbow-left-wrist (LE-LW) channels. The ground reflection is also treated as minimized for these channels. Narrowband on-body channels at 2.4 GHz frequency band over time domain were measured on the body. To avoid heavy interference from the Wi-Fi signals, the actual frequency was selected at 2.484 GHz, i.e. an extra Wi-Fi channel not used in the China region.

A vector network analyzer (VNA) of type R&S ZNB 20 was applied to measurement the channel S-parameters over time domain. The environment was quiet with no significant fading effects observed from the measurement. The analysis is then focused on the average channel loss. Monopole antennas of size 5 cm were used, mounted on the body 2 cm above the skin to alleviate the body coupling effects to the antenna efficiency. Setting details of the VNA and the antenna are presented in table I.

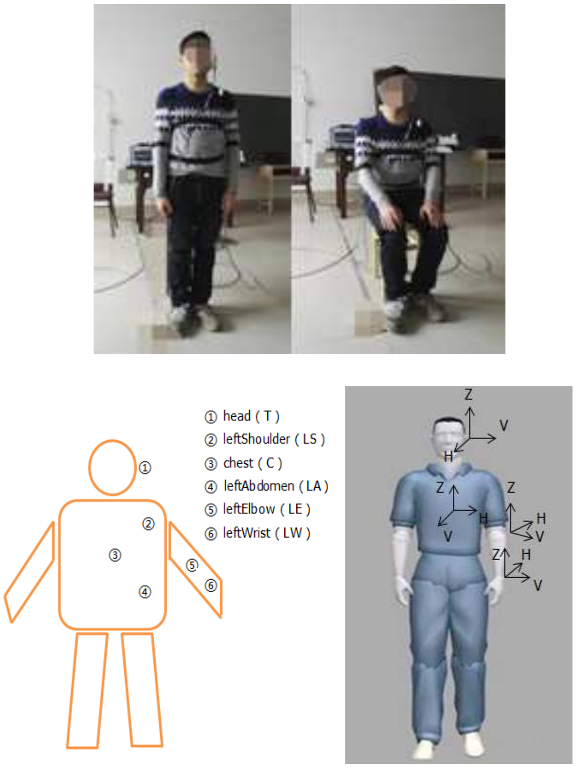


Fig. 1: Measurement context at 2.4 GHz. (a) Indoor scenario and human body postures. (b) Node placement on the body. (c) The definition of Polarization direction in different parts of the body.

TABLE I
RADIO SETTINGS

Parameter	Value
VNA	ROHDE SCHWAR ZNB 20
Sampling points	1000
Transmit power	10 dBm
IF bandwidth	10 KHz
Sweep time	10 s
Antenna model	Monopole
Antenna size	5 cm

FDTD simulations as reported in [] have shown that the field around the human body does not fully follow far-field propagation principles. The propagation path, as commonly defined by the surface wave presumption for on-body channels, may not be strictly perpendicular to the direction of the field polarization due to the body scattering effect and the near-field features of the radio waves. Consequently this will cause the polarization dispersion onto all directions. To effectively describe such inconsistency between the channel polarization and the propagation path, we suggest to define an on-body antenna's polarization in full-space dimension with respect to its relative positioning to the skin, which are vertical tangential, denoted as Z direction, horizontal tangential, denoted as H direction, and horizontal normal, denoted as V direction, as denoted in Fig. **??**. Note that because of the irregularity of the shapes of different parts of the body, the directions may be defined in different global orientations as well. By the extended definition of on-body antenna polarization, an on-body channel's polarization can be decomposed into 9 combinations, denoted as XY, $X, Y \in \{Z, V, H\}$, where X is the polarization of the transmit antenna and Y is the polarization of the receiving antenna.

TABLE II
Path loss summary of measurements [dB]

Standing Scenario	ZZ	ZV	ZH	VZ	VV	VH	HZ	HV	HH
T-LS	37.18	25.39	27.81	29.74	23.60	28.83	41.04	28.98	26.72
T-LW	58.11	37.21	47.69	59.12	42.78	61.49	61.84	48.39	62.10
C-LA	65.36	36.70	48.95	49.86	29.90	39.78	63.44	36.34	54.88
LS-C	50.38	30.32	43.70	49.68	30.69	54.65	54.81	35.68	45.71
LE-LW	47.66	23.92	31.12	42.14	29.99	29.93	50.10	30.33	27.97
Sitting Scenario	ZZ	ZV	ZH	VZ	VV	VH	HZ	HV	HH
T-LS	35.58	26.75	27.67	23.84	23.65	34.50	29.66	27.75	24.80
T-LW	53.47	39.17	39.60	58.62	47.17	46.49	58.22	39.24	43.51
C-LA	43.84	40.94	50.46	46.75	25.34	38.79	38.53	33.60	41.84
LS-C	47.02	30.60	48.15	50.81	31.09	50.89	45.27	36.66	46.30
LE-LW	39.05	35.77	32.07	44.11	28.52	32.32	56.16	33.52	25.91

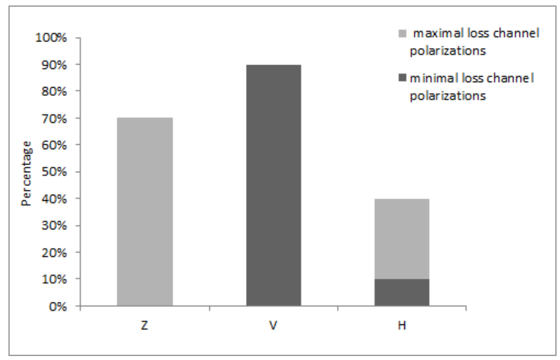


Fig. 2: The percentage of 3 polarizations of the receiving side in minimal loss channel polarizations and maximal loss channel polarizations respectively.

III. Measurement Statistical Analysis

The average path loss of on-body channels in different polarization combinations are summarized in Table II and categoried by the postures respectively.

A. V-polarization convergence

The first observation of the channel loss in both postures is that most channels shows V-polarization convergence at the receiving side. Under standing posture for instance, the minimal channel loss of scenarios T-LS and C-LA are achieved in VV channel polarization, and ZV channel polarization for T-LW, LS-C and LE-LW scenarios. Similar properties are also observed in these scenarios under the sitting posture. One exception under sitting postures is the LE-LW scenarios, whose minimal channel loss is achieved in HH channel polarization, a possible consequence of the body coupling effect variation to the antennas during posture changes.

On the contrary, in all scenarios investigated in two postures, the maximal channel loss does not occur in channel

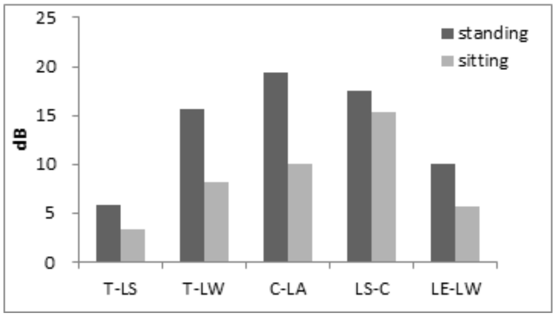


Fig. 3: The gain of receiving V-polarization of each channel in different postures.

polarizations with V-polarization at the receiving side for all polarizations at the transmit side. In some scenarios, e.g. the T-LW and LS-C under sitting posture, the maximal channel loss is observed in channel polarization with V-polarization at the transmitting side instead of at the receiving side. As shown in Fig.2, the percentage of V-polarization of the receiving side can up to 90 percent in minimal loss channel polarizations, Z-polarization at the receiving side should be avoided due to the proportion of up to 70 percent in maximal loss channel polarizations. This indicates that having the receiving antenna in V-polarization helps to capture the majority of the on-body channel field components.

The above observations show that on-body channels tend to have their field distributed along directions normal to the body. As consistent with previous FDTD simulations, the body coupling effect causes the absorbing of the on-body fields tangential to the skin, while the fields normal to the skin are less affected. As a result, the field will left the majority part along the normal direction. This may suggest therefore an optimal antenna emplacement for the communication aspects.

B. Polarization gain

To quantize the receiving advantage of receiving V-polarization, we define its polarization gain in **??**.

$$G_V = \frac{\sum_I \sum_J \text{Pl}_{IJ}}{6} - \frac{\sum_I \text{Pl}_{IV}}{3}, \tag{1}$$

where $I \in \{Z, H, V\}$ is the transmit polarization, $J \in \{Z, H\}$ is the receiving polarization other than V. Pl_{IJ} is the path loss of IJ channel polarization, Pl_{IV} is the path loss of IV channel polarization.

The V-polarization gain of each channel is summarized in Fig.3. In general, the V-polarization gain of scenarios under standing posture is better than that under sitting posture. The V-polarization gain of scenarios under standing posture is in average greater than 5 dB. Meanwhile, V-polarization gain of scenarios under sitting posture is in average greater than 3 dB.

C. Channel depolarization

The results presented in table II show as well heavy cross polarization in different scenarios. If the on-body communication systems are designed following regular antenna emplacement, i.e. the orientation of the antennas are either in Z, H, or V directions, such cross polarization may cause the actual field polarization of the on-body channel be apart from these regular directions. We denote this as the channel depolarization effect.

The channel depolarization can be described via the cross-polarization discrimination (XPD), calculated by Eq. 2.

$$\begin{aligned} \text{XPD}_{i,j} &= \frac{P_{ii}}{P_{ij}} \quad [dB] \\ &= \text{Pl}_{ij}[dB] - \text{Pl}_{ij}[dB], \end{aligned} \tag{2}$$

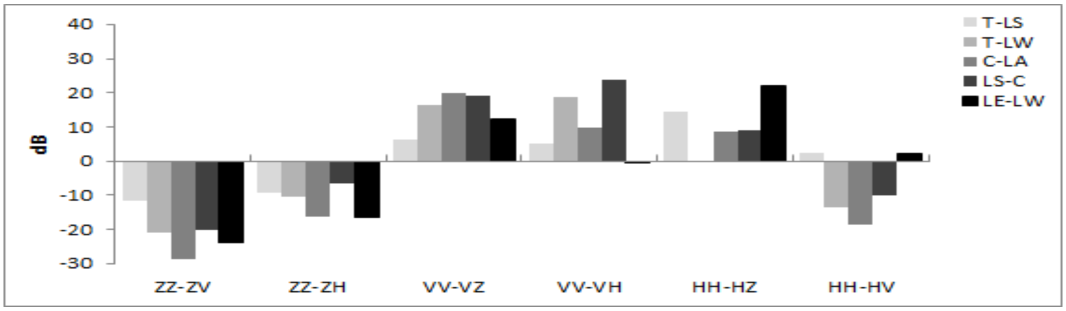
where $i, j \in \{V, H, Z\}$, P_{ii} is the power of the co-polarized channel component and P_{ij} is the cross-polarized channel component.

The XPD in Eq. 2 may describe three situations of the channel cross-polarization. First, if XPD is positive, the higher of the value indicates that the channel tends to concentrate on its co-polarization component. Second, if XPD is negative, the smaller of the value indicates that the channel is transmitting its fields to the cross-polarization component. Third, if the X-PD gets close to 0, the channel is considered to be depolarized, and the field will be projected both onto the co-polarized and cross-polarized components of the channel.

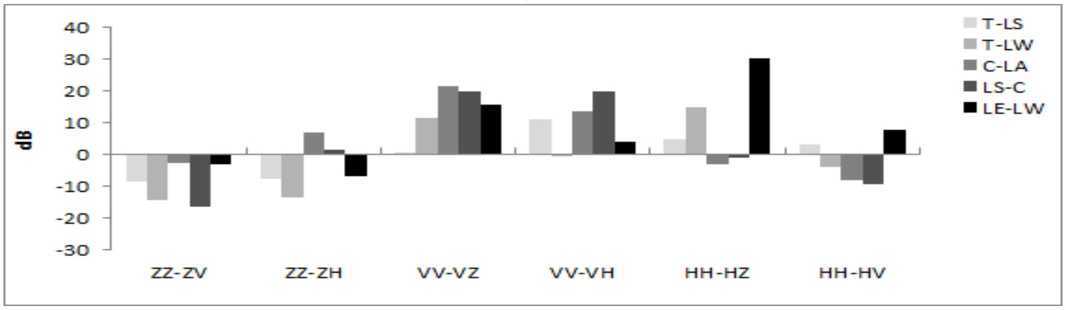
We studied the de-polarization in 6 channel cross-polarizations, which are $XPD_{ZZ,ZV}$, $XPD_{ZZ,ZH}$, ..., as presented in Fig. 4, categoried in two postures.

The negative XPD of ZZ-ZV and ZZ-ZH scenarios shows the cross-polarized configurations remain dominant in all channels, and ZV combination is better suited to on-body channels than ZH combination because of the greater absolute XPD of ZZ-ZV scenario. The positive XPD of VV-VZ scenario shows VV combination remains dominate in each channel. On the other hand, the LE-LW channel is strongly depolarized in VV-VH and HH-HV scenarios, with the XPD nearly equal to 0dB. The strong depolarization also occurred in T-LW channel of HH-HZ scenario and T-LS channel of HH-HV scenario. Besides, since the absolute XPD of each scenario is close to 10 dB or more for most on-body channels, most channels of all kinds of scenario can keep a stable polarization characteristic in the standing posture. The XPD of the sitting posture is shown in Fig.4(b). Unlike the case of the standing posture , we can find that there is the strongly depolarized channel in each scenario, for example, C-LA channel in ZZ-ZV scenario, LS-C channel in ZZ-ZH scenario and T-LS channel in VV-VH scenario. These show human sitting posture is more likely to cause depolarization of on-body channels due to the influence of the legs scattering.

In addition, we find that the XPD of the on-body propagation channels under the scenarios ZZ-ZV and HH-HV is generally negative and the XPD of the scenarios VV-VZ and VV-VH are generally positive values, regardless of the standing and sitting postures. These indicate that the receiving antenna can generally obtain the decent component of the field in the V-polarization direction, regardless of the polarization



(a)



(b)

Fig. 4: XPD of on-body channels in six scenarios. (a) XPD in the standing posture. (b) XPD in the sitting posture.

direction polarization of the transmission antenna. At the same time, this is also the reason why the receiving antenna with V- polarization can effectively receive signal and reduce the path loss.

IV. Conclusion

In this paper, measurement results of narrowband polarized static on-body channels at 2.4 GHz are presented under complete polarization combination in space. Analysis of the measurements demonstrate that V-polarization of the receiving antenna can effectively reduce the path loss and capture signal waves. The gain of receiving V-polarization of each channel can up to at least 3dB in the sitting posture, and the V-polarization gain of each on-body channel can up to at last 5dB in the standing posture. Depolarization of on-body channels is more serious in the sitting posture due to the effect of leg scattering. The receiving antenna with V-polarization is more beneficial to obtain the decent field component compared with the Z and H polarization of the receiving antenna by analyzing the depolarization characteristics of static on-body channels, regardless of the polarization direction of the transmission antenna. This once again proved that the receiving antenna with V-polarization can effectively reduce the path loss.

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