# Indoor Channel Measurements and Capacity Evaluation with Directional Antennas

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***Abstract*—Recently UWB beamforming attracts significant research attention to obtain spatial gain in the form of antenna array. It is commonly believed that directional antenna based communication could improve the system performance. In order to further make clear the relationship between system performance and the antenna radiation pattern, UWB indoor channels extracted from practical measurements with omnidirectional antenna are combined with circular horn antenna to evaluate the channel capacity. In the line of sight (LOS) environments, the channel capacity increases with the antenna beamwidth decreasing and is always larger than that of omnidirectional antenna. However in the non-line of sight (NLOS) environments, the capacity is not always better with directional antenna. And the change consistency between the capacity and the antenna beamwidth disappears. This reminds us that when antenna beamforming is used to obtain array gain, the beamwidth should be carefully designed to obtain optimal performance, especially in the NLOS environments.**

***Index Terms*—UWB, channel, measurement, beamforming, capacity, directional antenna.**

## I. INTRODUCTION

During the past years, the UWB performance researches were mostly based on omnidirectional UWB channels. In practice, directional communications with aperture antennas or antenna array are commonly implemented, especially for the recent beamforming systems. Because the system performances are greatly effected by the channel properties, a detailed characterization of UWB channels with directional antenna is essential to accurately evaluate the system performance.

There are not too many considerations about the antenna direction in the past channel modeling or system performance evaluation literatures. For UWB indoor channels, some early literatures [1], [2] showed that smaller channel delay and larger fading factor would arise with directional antennas. For recent beamforming systems [3], [4], it's necessary to further make clear the relationship between antenna pattern and the system performances.

In this paper, we will look into the double directional channels and give deep insight about the relationship between the channel capacity and the antenna radiation pattern.

## II. DOUBLE DIRECTIONAL UWB CHANNEL MODEL WITH DIRECTIONAL ANTENNA

In this paper, we consider the 2D channel model. Combining the directional spatial channel model (SCM), the IEEE 802.15.3a standard channel model and the directional antenna properties [5], the 2D UWB channel model with directional antenna can be described as

$$h(t) = \sum_l \sum_k G_T(\psi_{k,l,AOD}) a_{k,l} G_R(\psi_{k,l,AOA}) \delta(t - T_l - \tau_{k,l}), \quad (1)$$

where $a_{k,l}$ are the multipath gain coefficients, $G_T(\psi_{k,l,AOD})$ and $G_R(\psi_{k,l,AOA})$ are gains of antenna patterns for both the transmitter and the receiver, $\psi_{k,l,AOD} = (\theta_{l,AOD} + \phi_{k,l,AOD})$ and $\psi_{k,l,AOA} = (\theta_{l,AOA} + \phi_{k,l,AOA})$ are the angle of departure (AOD) and angle of arrival (AOA) for the corresponding path component, $\theta_{l,AOD}$ and $\theta_{l,AOA}$ are the AOD and AOA for the *lth* cluster, $\phi_{k,l,AOD}$ and $\phi_{k,l,AOA}$ are the offset angles for the *kth* component of the *lth* cluster, $T_l$ is the delay of the *lth* cluster, $\tau_{k,l}$ is the delay of the *kth* multipath component relative to the *lth* cluster arrival time $T_l$.

## III. MEASUREMENT SETUP AND RESULTS

An intuitive and efficient way of recording the channel impulse response (CIR) is to emit a very narrow pulse, and record the received signal by a digital sampling oscilloscope (DSO). Measurements were conducted in the Wireless and Networking Research Laboratory at the University of Victoria. We perform the measurements in two typical scenarios which are LOS and NLOS propagation environments. To perform double directional measurements, virtual arrays are used on a X-Y positioning $9 \times 9$ grid at both transmit and receive end.

With SAGE algorithm, AOD, AOA and the corresponding multipath amplitudes are derived from the collected data. The AOD and AOA here are the azimuth angles.

Fig.1 gives the scatter plot of AOD versus AOA in the LOS scenario. There exist four obvious angle clusters. The angle spread of AOA is smaller than that of AOD. Associating the AOD and AOA with the multipath amplitudes, we can get the 3D figure of multipath components with the directions in Fig.2. This property is helpful to evaluate system performance when we use directional antennas.

The scatter plot of AOD versus AOA in NLOS scenario is given in Fig.3. From the figure, the AODs and AOAs of multipath components are more disperse, which means that the angle spread in NLOS scenario is larger. We can also see that the multipath components are mostly come from the line direction between the transmitter and the receiver. Fig.4 gives the multipath amplitudes versus AOD and AOA in NLOS scenario. Compared with Fig.2, the amplitudes are less fluctuational but relatively smaller because there exist no LOS components.

## IV. EVALUATION OF CHANNEL CAPACITY

In the measurements, the omnidirectional antennas are used. In order to evaluate the channel capacity with directional antennas, the channel CIRs extracted from the measured data will be combined with directional antenna radiation pattern.

Circular horn antenna will be used in the simulations. Uniform circular horn is the simplest directional antenna form with its radiation pattern function as $f(\theta) = 2J_1(u)/u$. Here

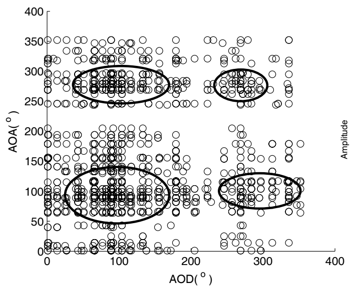


Fig. 1. Scatter plot of AOD versus AOA of LOS.

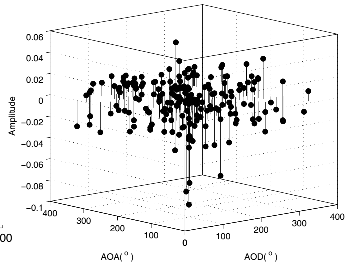


Fig. 2. Multipath amplitudes versus AOD and AOA of LOS.

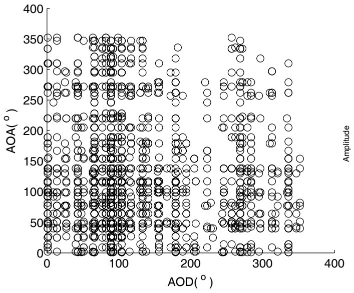


Fig. 3. Scatter plot of AOD versus AOA of NLOS.

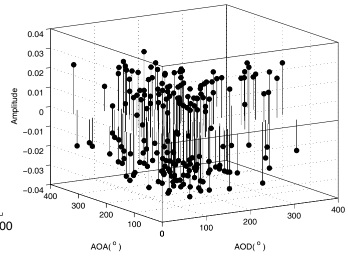


Fig. 4. Multipath amplitudes versus AOD and AOA of NLOS.

$u = 2r\pi\sin(\theta)/\lambda$, $r$ is circular horn radius and $\lambda$ is the wavelength. The half power beamwidth (HPBW) is $29.22\lambda/r$ in degree. And the maximum horn gain is $G = (2r\pi/\lambda)^2$.

Four different horn patterns will be adopted in our simulations. The HPBWs are separately 10, 20, 40 and 80 degrees. The transmitter and receiver are assumed to use the same pattern antennas. The maximum antenna gain aims at the strongest multipath component direction. It should be noted that with smaller beam width the horn gain is larger.

For UWB indoor slow fading channels, conditional on a realization of channel $h$, the channel could be regarded as an AWGN channel with received SNR of $|h|^2SNR$. Considering the circular horn gain $G$, then the capacity is given as

$$C = log_2(1 + G|h|^2SNR)bits/s/Hz. \quad (2)$$

From the above quantities, the capacity is a function of the random channel gain $h$ and is therefore random. Here we consider the average capacity of the practical measurement channels.

Fig.5 gives the capacity variety with the antenna radiation beamwidth in LOS scenario. As we all know, channel capacity increases with the multipath richness. However in the LOS scenario, the capacity increases with the beamwidth decreasing. This is mainly due to the antenna gain. The smaller beamwidth has larger antenna gain. Besides, the beam direction always aims at the strongest LOS multipath components. In the LOS environments, the capacity of channels with directional antenna is larger compared with capacity of channels with omnidirectional antenna.

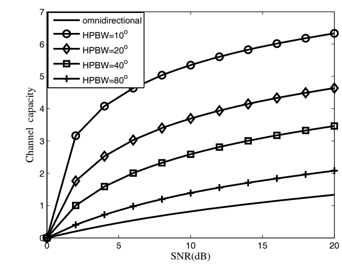


Fig. 5. Channel capacity with different HPBW of LOS.

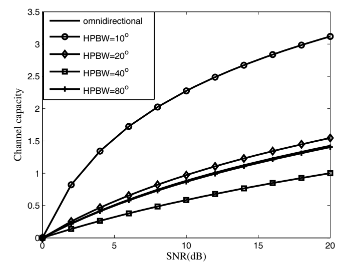


Fig. 6. Channel capacity with different HPBW of NLOS.

The capacity with different HPBWs in NLOS scenario is given in Fig.6. From the figure we can see that the capacity no longer increases accordingly with the HPBW decreasing. Obviously the capacity with 40 degree HPBW is smaller than the capacity with 80 degree HPBW. Above all, the capacity with directional antenna is not always larger than that with omnidirectional antenna. The capacity with 40 degree HPBW is smaller. In the NLOS scenario, there exist no dominant strong path components like in the LOS environment. So the capacity is more influenced by the antenna gain. In some conditions, the capacity with directional antenna becomes smaller than that with omnidirectional antenna.

## V. Conclusions

UWB indoor channels are measured and system performance with directional antenna under such channels are evaluated. In the LOS environments, the channel capacity increases with the beamwidth decreasing and is always larger than that of omnidirectional antenna. In the NLOS environments, the capacity is not always better with directional antenna. The capacity with 40 degree HPBW is even worse than those of omnidirectional antenna. And the change consistency between performance and antenna beamwidth disappears. The capacity with 80 degree HPBW is better than that with 40 degree HPBW. This is mainly because there exist no dominant strong path components in the NLOS environments. Only the best compromise between the amplitude energy and the antenna gain could results in the best performance. This reminds us that when antenna beamforming is used to obtain array gain, the beamwidth should be carefully designed to obtain optimal performance, especially in the NLOS environments.

## Acknowledgment

This work is supported by the Fundamental Research Funds for the Central Universities (3102014JCQ01053) and Natural Science Basic Research Plan in Shaanxi Province of China (Program No.2013JQ8019).

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