Indoor High-Resolution Channel Characterization

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Abstract - **Future communication systems will utilize multiple antennas and beamforming to a larger extent than what has been done before. Design and evaluation of systems with many antennas and large bandwidth requires channel models with good accuracy in angle and delay. An angular resolution down to one degree, and bandwidths of several GHz, are foreseen for the future 5G wireless systems. For this purpose, an indoor channel measurement campaign has been conducted at 58.7 GHz providing reliable and accurate direction information by massive spatial channel sampling and offline FFT processing.**

Index Terms — **Antennas, propagation, mm-wave, LSP**

1. Introduction

For proper design and evaluation of wireless systems utilizing large bandwidth and large array antennas, there is a need for channel models with high angle and delay accuracy. To parametrize such channel models, measurement methods providing reliable highly resolved angle and delay information are crucial. As pointed out in [1-2] super resolution methods for estimating the radio channel characteristics may provide biased results depending on corresponding model assumptions. In particular, the so-called diffuse component may not be reliably characterised. A commonly used method to directly measure the directional channel characteristics is to scan different ranges of spatial angles by means of directive antennas combined with rotation modules. This method does not suffer from bias due to model assumptions. However, the method is limited by antenna pattern side-lobe levels. The novel method, presented and validated in [3] and described shortly in Section 3, does not suffer from any of these problems as it is based on standard beamforming with extremely large antenna arrays (in terms of spatial samples) optimized to suppress side lobes over the full spatial angle. This paper presents a high resolution campaign at 58.7 GHz, together with analysis and conclusions.

2. Measurements

The measurements presented in this paper were performed in an indoor office environment covering both line of sight (LOS) and non-line of sight (NLOS) conditions. The frequency response of the radio propagation channel was measured by means of a vector network analyzer (VNA) using 2001 frequency samples, equally spaced, over a bandwidth of 2GHz, at a carrier frequency of 58.68 GHz. To provide high resolution directional measurement results, the channel was sampled massively in space (commonly referred to as the virtual antenna method). A high accuracy antenna positioning robot has been used to sample the channel at TX in a 2D plane. A total of 256x64=16384 samples (horizontal-vertical) per RX location were measured, which is an extreme number even for the virtual antenna method. The spatial sampling distance is 2 mm, resulting in a virtual array size of 51x13cm. This method has commonly been used at sub millimeter wavelengths [4]. It has also successfully been used at 60 GHz in an indoor MIMO measurement campaign [5] where a 3D virtual array was used. Using this method herein, a sidelobe suppression of up to about -32 dB was achieved. Using 3D sampling would provide full space angle direction information with uniform resolution. However, the resolution required for 5G channel models (better than 1 degree) would require unfeasible measurement time. For this reason, the 2D planar was chosen for this study. The drawback is that the measurements cover only part of the space angle (~120 degrees) and that there is an ambiguity in the forward/backward direction. This ambiguity is however mitigated as the open wave guide TX antenna suppresses the back lobe. A floorplan and photos of the measurement may be found in [7]. RX location 2 may be characterized as a LOS scenario, whereas RX locations 1, 3 and 4 are NLOS scenarios.

3. Analysis Method

The directional analysis herein is based on straight forward beam-forming. Due to the computational challenge to process the huge size of data (256x64x2001 = 32.8 mega-samples) for each measured channel, fast Fourier transformation (FFT) is used both for transformation from the space (2D) domain to the direction domain and from frequency to delay domain. In both cases Hanning windowing is used for suppression of the side-lobes.

The space samples of the channel are transformed using FFT forming a two dimensional rectangle in the wave vector domain. However, the physical possible values of the wave vector **k** reside on a sphere fulfilling

$$|\mathbf{k}| = \frac{2\pi}{\lambda}. \tag{1}$$

As the measurement data is only 2D, one component of the wave vector, k_x, is missing. This component may however be uniquely determined by

$$k_x = \pm\sqrt{\left(\frac{2\pi}{\lambda}\right)^2 - k_z^2 - k_y^2}\,.\,, \tag{2}$$

except for the sign. It should be noted that the angular resolution *res* is degraded for directions deviating by θ from the array main lobe direction as

$$res \propto \frac{1}{\cos\theta}\,. \tag{3}$$

For e.g. $|\theta| > 60^\circ$ the resolution is degraded by more than a factor of two.

4. Results and Discussion

Power delay profiles (PDP) from the four RX locations are shown in Figure 1. Note that the more NLOS the scenario is, the fewer clear spikes may be observed RX[2,4,3,1] (in order of most LOS to most NLOS). By overlaying propagation path lengths and direction of arrival to photographs and floorplans of the environment, it was observed that these spikes are specular reflections. In [7], angular power spectrums superimposed on measurement photos may be seen. Another observation, made by analysing the angular power spectra, is that the channel is much richer for the NLOS scenarios compared to the LOS scenario. One striking observation is that the most significant scatterer in the deepest NLOS measurement (RX1) actually is a curtain. Though the curtain is rather thick this effect was not expected. The corrugated shape makes it scatter waves in all directions. This result is of great value as it shows that standard ray tracing may be inadequate for channel modelling in many cases.

Propagation channels are typically modelled by a set of discrete multipath components (MPCs). Due to the high resolution of these measurements it is expected that it is possible to approximate the measured channels as the sum of a number of MPCs. The analysis focuses on the number of MPCs needed for proper characterization of the measurements. For each peak of the three dimensional measured channel responses (2D in space + 1D in delay) a corresponding multipath component is identified. By this method a large number of MPCs has been identified for each of the measurement sets. Figure 2 shows cumulative distribution functions of the total received power vs. number of Ms. Note that the MPCs are ordered in descending power. A key observation is that the more NLOS the scenario is, the more MPCs are needed for capturing the majority of the power. It was also noted that the MPCs are more spread out in angular domain in the NLOS scenarios than in the LOS scenario as shown in [7]. Another interesting observation is that the LOS and weakly obstructed scenarios indicates clustering in both angle and delay domain, whereas heavily obstructed NLOS scenario is only clustered in angle and spread out in delay.

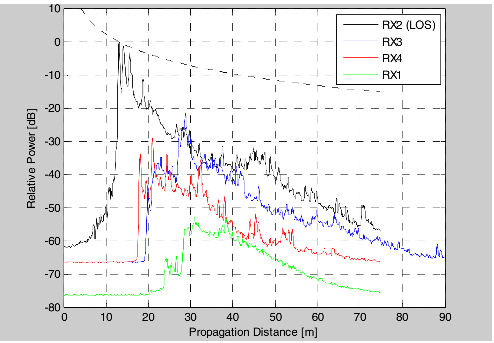

Figure 1. Power delay profile for the four measured locations.

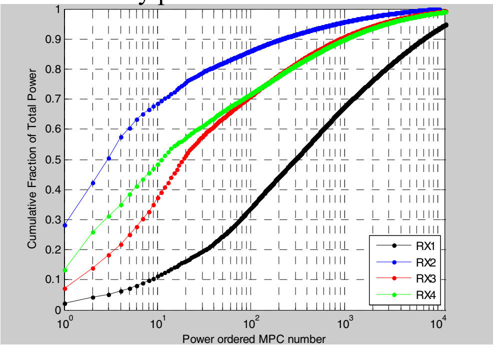

Figure 2. Cumulative distribution function of the received power as a function of the number of estimated MPCs used to

By analyzing Figure 2 it is found that for the more obstructed scenarios a substantially higher number of MPCs is needed. As quantification; it is observed that between 1000 and 10000 MPCs are needed for modelling 95% of total power (1000 needed for the measured LOS scenario, RX2). Further it is observed that the strongest MPC accounts for 2-30% of the total power, and the 100 strongest MPCs account for 10-70% of the total power. This may be related to the observations in [6], where about 100-400 MPCs are required to account for 95% of the received power. It should be noted that the measurements in [6], were made using a bandwidth of 150Mhz, compared to the 2GHz used herein, and the angular resolution was “only” 8 degrees, which is a factor 10 lower than herein. This is a key result of this study showing that the number of MPCs needed to represents the channel increases with the required channel bandwidth and angle resolution.

5. Conclusion

This paper provides input to high resolution channel models of future communications systems. It is observed that a substantial part of the total channel power is received from non-specular contribution, due to scattering caused by the many smaller objects and structures, particularly in the NLOS measurement (RX1). This indicates the importance of modelling not only the large scale flat structures of a propagation environment, but also the more complex shapes and small structures, in ray-tracing simulations. For this scenario, between 1000 and 10000 MPCs are needed for modelling 95% of total power. Further, a key observation is that the number of required MPCs is strongly dependent on the angular resolution and channel bandwidth.

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