Ultrawideband 3D mmWave Channel Sounding for 5G

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Abstract

Increasing data rates in mobile networks require new technologies for the next generation of mobile communication systems such as massive MIMO, device-centric architectures, smarter devices, machine-2-machine communication etc. However, one important step to reach the goal of 100 GBit/s will be use of higher bandwidth. Owing to the limitation in bandwidth of currently used frequency bands, future fifth generation (5G) mobile networks will need to operate at higher frequencies. Analysis of the multipath propagation in dynamic single and multi-user scenarios under time-variant shadowing environments with high bandwidth requires a millimetre-wave (mm-wave) channel sounder (CS). It must provide ultra-wideband (UWB) real-time operation with multiple antennas and a high dynamic range. In addition, polarimetric information is needed to fully characterise the wireless channel, e.g. for cases of polarisation misalignment at the mobile device. This paper presents a novel UWB dual-polarised (DP) mm-wave channel sounder architecture for real time measurements in 5G mobile networks to overcome these requirements. We also show measurement data to motivate the need for polarimetric double-directional measurements.

1. Introduction

In the last years, many developments in electronics and software provided the capabilities for a new generation of mobile communication networks. The vision of 100 GBit/s requires new concepts such as device-centric architectures, massive MIMO, smarter devices, native support for machine-2-machine links [1], etc. These technologies help to develop a reliable and fast mobile infrastructure, but one important step to reach the 100 GBit/s goal is the extension of useable bandwidth [1]. Here, the advances in semiconductor technology open an opportunity for low-cost manufacturing and low power consumption of mm-wave components [3]. The availability of such mm-wave systems allow much higher frequency bands and more bandwidth than available in 4G networks. Associated gains are already discussed in literature [1], [2]. The current steps in search of suitable frequency bands with a high data transmission capacity for 5G mobile networks call for UWB analysis of different frequency ranges.

Some activities for the characterisation of propagation effects in new bands have already been performed, e.g. investigating whether aspects [5], multipath delay spread[6] [7], direction of arrival (DoA) [7] [8], reflection coefficients of materials [8] [9], coverage/outage probability with steering beam antennas at mm-wave frequencies [9] [10], etc. Previous work in [2] demonstrates the usability of the 28 GHz and 38 GHz range for future high data rate cellular networks - but these measurements analyse only a bandwidth less than 1 GHz. Detection of the optimum band for high data rate links and to investigate propagation characteristics within the available spectrum, an UWB measurement system can deliver the necessary information. The large bandwidth also helps to better separate and investigate close multiple paths. Other open questions in the research of mm-wave propagation are shadow fading caused by moving people, polarisation aspects, power elevation spectrum, K-factor, large and small scale fading statistics, and multi-link analysis which all call for real-time multiple input multiple output (MIMO) sounding. In the past, we presented CS devices that were used to measure multipath propagation in UWB real-time single input multiple output (SIMO) configurations with 7 to 9 GHz bandwidth in the FCC-band or from 59-66 GHz [10]-[12]. Although this CS design already included dual-polarisation for some of our measurements and could investigate multi-user access and time-variant shadowing, it could not address all aspects important for 5G sounding.

In this paper we propose a novel MIMO CS system that considers all above mentioned challenges by its architecture in different bands from 3.5 GHz up to 66 GHz - the dual polarised ultrawideband multichannel sounder (DP-UMCS) for mm-waves. It allows real time measurements over an instantaneous bandwidth of more than 3.5 GHz. One important innovation for this new device generation is the ability to coherently measure outdoor scenarios with large (> 100 m) transmitter (Tx) and receiver (Rx) separation.

The rest of the paper is organised as follows. Section II describes the necessity of polarimetric double-directional (DoD/DoA) propagation measurements for mm-wave networks showing example data. Section III present the novel DP-UMCS architecture for distributed coherent measurements based on an M-sequence UWB system. Section IV draws some conclusions.

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2. Challenges in mm-wave channel measurements for 5G networks

For novel wireless communication systems at mm-waves, the measurement of the radio channel is a crucial step on the way to understanding propagation characteristics. A different channel performance compared to wireless networks at lower frequencies such as 0.9 or 1.8 GHz has been observed at 60 GHz in our previous experimental work [10]-[12]. The impact of relevant physical effects on the mm-wave radio channel has to be studied experimentally for the entire range of spectral and spatial resources. Any propagation measurements must therefore be conducted with huge bandwidths of several GHz and must provide the capability of polarimetric double-directional DoD/DoA investigation. Attention should also be focused on dynamic channel effects which will become of importance for 5G mobile networks due to increased Doppler influence at mm-waves. Different use cases of moved mobile devices as well as shadowing caused by moving persons impact will need to be assessed. These effects introduce a significant time variance to the mm-wave channel [12]. Additionally, it has already been understood that innovative antenna concepts such as MIMO, beamsteering, beamforming, opportunistic antenna selection, or distributed antenna systems will be needed to reduce the high path loss and minimize ray shadowing at the same time [4].

To find the best strategies for a robust and efficient mobile infrastructure, CS hardware must cover all aspects simultaneously - not only spatial but also polarimetric propagations effects must be observed in real time as already simple measurement examples indicate. To show the need of fully polarimetric channel characterisation, we performed very basic 3D polarimetric propagation measurements at 60 GHz in an indoor office scenario. Since we were only interested in a static scenario for this experiment, we used a slow (i.e. non-real-time) measurement approach with a high-directivity horn antenna (35 dBi gain, aperture 5°) mounted on a 3D positioner at Tx and a fixed omni-directional antenna (1.5 dBi gain) at Rx. To get the complete co- and cross-polarised information, the polarisation at Tx and Rx was successively changed from 0° to 90° rotation in their phase centres. The full measurement setup and the results are discussed in [5]. Here, we only want to show one result that highlights the importance of polarimetric awareness in 60 GHz channels.

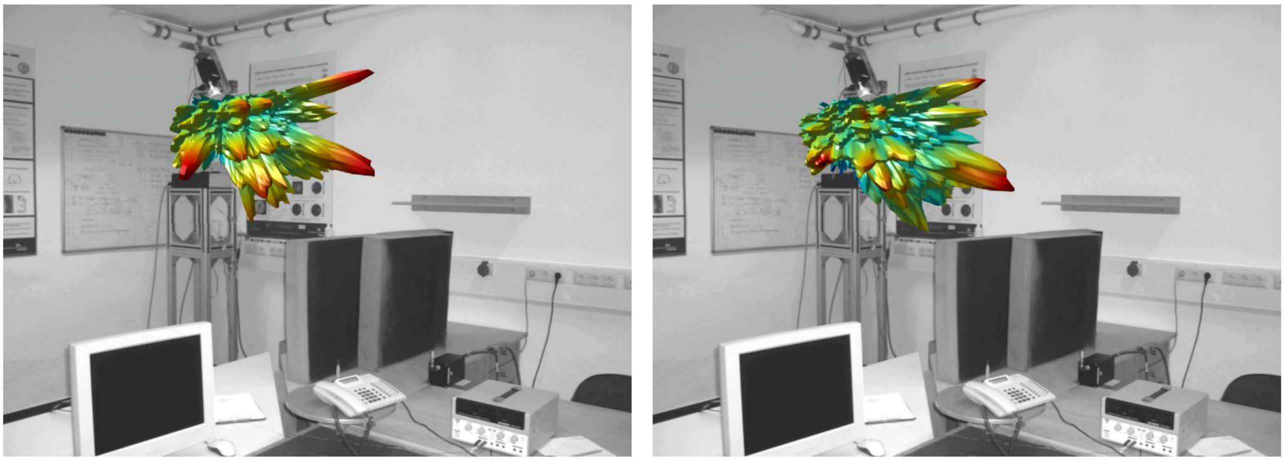

Fig.1: Received power at Rx1 for scanned azimuth and elevation of departure. Left side Tx horizontal and Rx horizontal, right side Tx vertical and Rx vertical

Fig. 1 shows the spatially resolved polarimetric characteristics of the links between the different polarisation combinations (HH, VV) in the office scenario. To illustrate the influence of the polarization for the different multipath components, we use a 3D power spectrum (PS) plot, which shows the received power for different elevation and azimuth angles at the Tx. Depending on Tx direction, there are LOS and NLOS paths seen by the Rx. The results differ significantly among the polarizations especially for the NLOS components. One example is highlighted in Fig. 1 where a strong path appears in HH but not in VV. Therefore, polarization plays an important role in multipath propagation at mm-wave. Hence by exploiting the polarization effect e.g. due to combining independent paths MIMO or beamforming concepts can significantly gain which leads to an increase the data rate or more robust links. For outdoor environments with more diffuse reflections and vegetation, the polarimertic mismatching is likely to increase over indoor scenarios making polarimetric equipment essential.

3. Dual –Polarized Ultrawideband Multichannel-Sounder

To gain knowledge of the channel dynamics and polarimertic effects of multi-access cellular networks, the traditional slow and single access measurement concepts with high dynamic range such as Vector Network Analysers will not suffice. Measurement equipment that is capable of recording dynamic effects while providing multi antenna systems with parallel fully-polarimetric measurements at mm-wave frequencies needs to combine fast acquisition speed with high dynamic range on many parallel recording channels. In the framework of 5G research work, we develop a high-performance measurement system that will address these challenges and will finally allow investigations of novel multi-access and polarimetric technologies.

The key features of our novel dual polarized ultra-wideband multichannel sounder (DP-UMCS) architecture are wideband operation with up to 7 GHz instantaneous bandwidth and easy scalability of the number of receivers. Furthermore, extreme stability of stimulus and timebase lead to a high dynamic range even when doing fast measurements. The DP-UMCS covers measurements in baseband (0 to 3.5 GHz) or can be used with an intermediate frequency (IF) conversion stage from/to the FCC band (3.5 to 10.5 GHz). This flexibility allows finding the best intermediate frequency configuration to match different mm-wave frontends and scenarios to reduce coupling and increasing the immunity to noise/interference. Depending on the IF choice, the used filters, and mm-frontend, many bands can be assessed with a bandwidth of 3.5 GHz or 7 GHz, e.g. 24-27.5 GHz, 28.5-31.5 GHz, 31.5-38.5 GHz, 17.5-24.5 GHz, 59-66 GHz, or 49-56 GHz. By using a 7 GHz clock as a single source for the timebase and stimulus generator, the DP-UMCS currently provides a maximum delay window of 585 ns, which translates into an unambiguous range of about 175 m. The DP-UMCS architecture is presented in Fig.2.

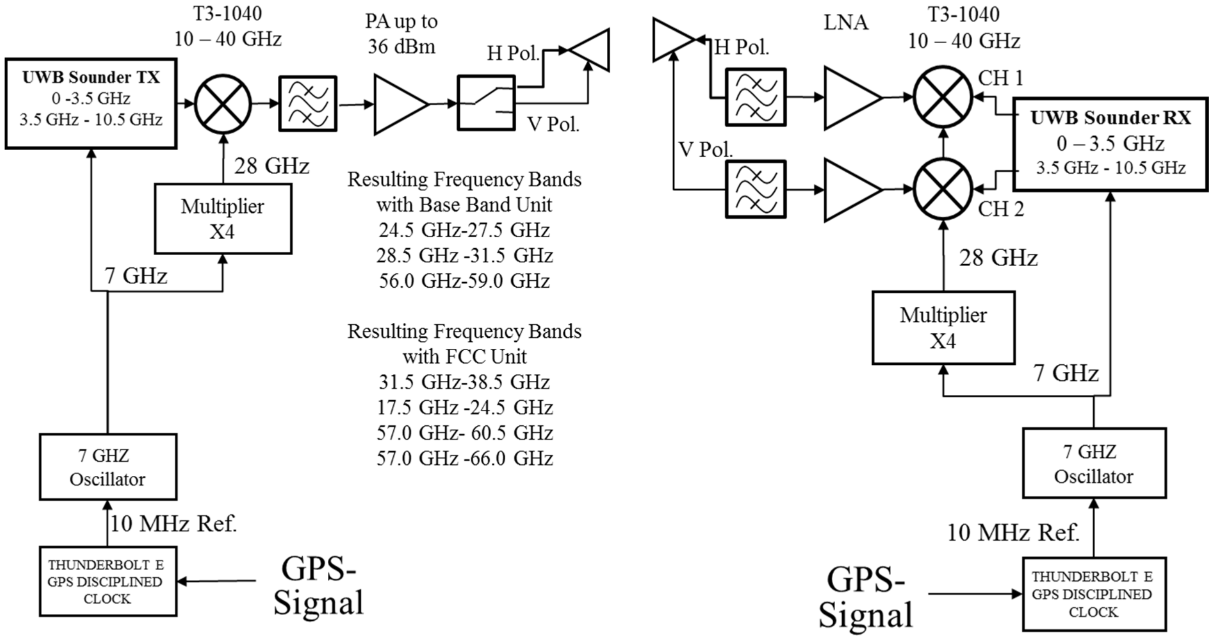

Fig.2: Architecture of the DP-UMCS for different mm-wave bands: Tx (left), Rx (right)

The DP-UMCS is based on M-Sequence UWB sensor chip-sets [13] and the functionality of the core components is described in [11]. The M-sequence principle is an optimal choice for the DP-UMCS since it combines high bandwidth with extreme signal and timebase stability while allowing fast measurements to accommodate dynamic scenarios. Due to the stability of the M-Sequence principle, the basic calibration can be done at the lab and the correction coefficients can be stored to be included later in data processing with real measured data.

Nerveless, to indoor measurements, a single clock source cannot be used for distributed Tx-Rx measurements. Therefore, a novel concept for stable synchronization and new calibration algorithms become necessary to enable coherent measurements over several 100 m for outdoor cases. In our solution, the 7 GHz system clock will be generated using an extremely stable 10 MHz GPS reference signal with a phase noise lower than 115 dBc at 10 Hz. Every Tx and Rx module is connected to a separate GPS synchronization unit.

The modular concept of Fig. 2 allows different mm-wave stages on distributed locations with different antennas. Furthermore using dual polarimetric antennas, the vertical and horizontal characteristics can be measured in parallel on the Rx side. Here we exploit one more advantage of the M-sequence concept - many Rx channels can easily be operated in parallel. To support DP and I/Q down-conversion, the DP-UMCS architecture usually has at least four Rx channels at each Rx module. For the Tx a fast switch is used to subsequently stimulate the channel in H and V polarization. The current system internally measures at 3300 complex impulse responses (CIR) per second, which are coherently averaged in the digital backend down to 200 IR/s in order to increase SNR and to decrease the data stream to the computer. This allows a theoretical maximum Doppler of 100 Hz or about 1.5 km/h at 30 GHz considering the sampling theorem. Although the Doppler effect of moving people is usually higher than that and a certain amount of oversampling is needed to correctly acquire the Doppler influence, the current speed is already sufficient for characterization of time-variant shadowing statistics [11]. However, the next generation of the DP-UMCS with an ultra-fast digital backend will allow a higher transfer rate of more than 500 IR/s, which accommodates a theoretical Doppler of 250 Hz. At 30 GHz the maximum delectable speed is increased to around 4 km/h, which is enough to measure the effects of human shadowing.

For most applications, a statistical analysis of the shadowing and time variant channel is already useful and this can be done even without the faster digital backend. Furthermore, there is always a compromise between fast measurement speed and high dynamic range. The longer the averaging window, the better measurement noise can be suppressed but on the other side dynamic channel effects are suppressed as well. The DP-UMCS provides the flexibility to choose this compromise according to the experiment and scenario that shall be investigated, e.g. SNR improvement via long averaging times in static channel measurements is only limited by drift effects induced by the environment.

4. Conclusion

The mm-wave frequency bands will be indispensable for the aim of 100 Gbit/s wireless communication networks due to their large available bandwidth. However, this brings also new propagation effects which should be reflected in the characterization and measurements of channels at the new frequency bands. A 3D and fully polarimetric wireless channel characterization for accurate channel modelling and system evaluation is necessary. Measurement campaigns comprising all the parameters for different deployment scenarios such as urban, dense urban, feeder links, as well as indoor scenarios are currently missing.

We introduced the dual polarized ultra-wideband multichannel sounder consisting of available RF components as well as of a customized M-sequence UWB sounding device. The concept allows fully polarimetric real time sounding for indoor and distributed outdoor scenarios. Furthermore, it is also applicable on positioning units and for antenna arrays to perform double-directional (DoD/DoA) measurements. Preliminary measurement results from an indoor scenario at 60 GHz show several strong multipath contributions with considerable polarimetric power differences. This supports earlier findings that especially in mm-wave communication systems a reduction of the performance may appear when utilising only a single polarisation. On the contrary, polarisation diversity (MIMO in mm-wave networks based on cross-polarised streams) gives a possibility to increase the capacities of wireless networks. We would like to highlight the necessity of polarimetric channel characterization for 5G and the advantage of fully polarimertic communication systems. Our new DP-UMCS concept allows measuring wave propagation in real time and coherently with distributed Tx and Rx over an instantaneous bandwidth of more than 7 GHz thus spanning multiple wideband mobile channels. Using different up and down converters, it will be possible to detect and investigate useful mm-wave bands for future 5G mobile networks.

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