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Fan, Wei; Lyu, Yejian; Olesen, Kim

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Massive MIMO Channel Sounder for Sub-THz Based on Virtual Array Concept

Wei Fan
School of Information Science and Engineering,
Southeast University, China
weifan@seu.edu.cn

Yejian Lyu
Department of electronic systems
Aalborg University
Denmark
yely@es.aau.dk

Kim Olesen
Department of electronic systems
Aalborg University
Denmark
ko@es.aau.dk

***Abstract*—The sub-THz frequency spectrum ranging from 90 GHz to 300 GHz offers huge untapped frequency band, up to several tens of GHz, which is highly promising for achieving extremely high data rate transmission. Therefore, sub-THz technology is considered as one of the key technology candidates for beyond 5G communication systems. However, sub-THz communication relies on dominant propagation path in the environments. It is essential to identify and track the dominant paths in the channel to maintain the communication link. Understanding the spatial profiles of the channel is therefore essential. In this work, we present a long range sub-THz channel sounder we developed at Aalborg University Denmark, which is capable of capturing the spatial profile of the channel with high spatial resolution based on the virtual array concept. The channel sounder is experimentally validated in field measurements.**

***Index Terms*—sub-THz communication, channel sounder, multipath profile, virtual array, radio-over-fiber concept**

I. Introduction

Sub-THz technology is one of the candidate solutions for 6G communication, since it can offer huge data-rate transmission. However, there are also lots of challenges to achieve high daterate reliable communication for mobile users in deployment scenario scenarios for this frequency bands. Moreover, the propagation channel will be sparse and specular, composed of a few dominant multipaths originated from line of sight (LOS) or reflections, whereas diffraction and penetration loss will be more much significant. To ensure good SNR for the sub-THz communication, we can in principle boost power the transmitted power at the transmitter (Tx) or improve the receiver sensitivity at the receiver (Rx). However, those are limited due to current technology bottleneck. Therefore, it is required to employ high-gain and beam-steerable antennas both at the Tx and Rx to track the dominant propagation paths. Therefore, from propagation aspects, it is important to know the spatial profile of the propagation channel.

There are a few known strategies to obtain the channel spatial profiles in the state-of-art, namely, mechanical steering (also called directional scanning scheme, DSS), virtual antenna array (VAA), switched antenna array, electrical beam-steering (based on analog beamformer structure) and real antenna array (based on digital beamformer structure). The basic idea of the DSS scheme is that we can mount a highly directive antennas in the center of a mechanical turntable, which can be automated and rotated to directly record the channel spatial profile. It is the most popular one for the mmWave and sub-THz frequency bands, due to its low cost, simplicity and high SNR offered by the employed high gain antenna. However, it suffers from the long measurement time, and the limited spatial resolution. For the VAA scheme, a single antenna is mechanically moved to different spatial locations by a positioner, which can be automated and controlled to form arbitrary virtual array configurations. Compared to the DSS scheme, we can achieve much better spatial resolution, without increasing the cost and measurement time. However, it required phase coherent measurements among different spatial locations.

VAA has been widely adopted by the industry and different research groups, covering different frequency bands and measurement ranges [1-5]. There are several challenges to achieve long-range VAA channel sounding at sub-THz:

- Frequency limitation. We need to generate and analyze sub-THz radio signals in the channel sounder. This can be done via employing external frequency extenders.
- Measurement range limitation. Vector network analyzer (VNA) is widely used for channel sounding purpose at sub-THz bands. However, the Tx and Rx are collocated and housed in the VNA. For measurements in typically deployment scenario, we need to use cables to remote the antennas. Radio frequency (RF) cables are very lossy at sub-THz and expensive. RoF scheme can be employed to address this challenge, which however are not commercially available at sub-THz bands.
- Phase coherent measurements. It was highlighted in [6] that “a decent phase accuracy of virtual arrays is mechanically and RF technically non-achievable.”

In [7], a long-range VAA channel sounder was reported, where several schemes are introduced to address the above-discussed challenges, i.e. frequency extension scheme, RoF scheme and phase compensation scheme.

II. Long range VAA sub-THz channel sounder

A diagram of the developed channel sounder for the W band (i.e. 75 GHz to 110 GHz) is illustrated in Fig. 1. External Tx and Rx frequency extenders are employed for the sub-THz signal generation and analysis. The RoF scheme

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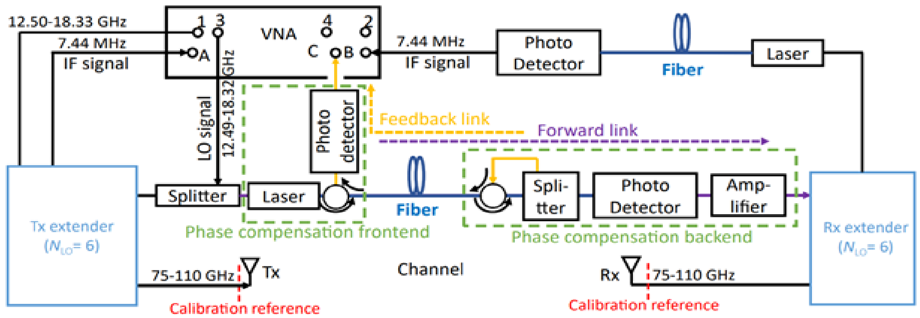
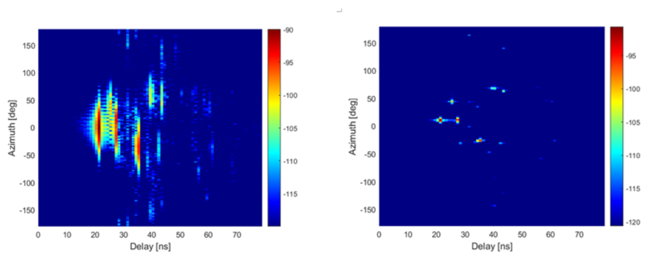


Fig. 1. system diagram of the long range VAA sub-THz channel sounder



(a) (b)

Fig. 2. system diagram of the long range VAA sub-THz channel sounder

was implemented in the local oscillator (LO) chain before the frequency multiplier. The RoF units, i.e. laser and photo detector, are commercially available in this frequency range. By doing so, we effectively avoid using RoF units at sub-THz frequency bands directly. A phase compensation scheme was implemented in the LO path to remove the random phase in the optical cable.

The developed channel sounder is very powerful, covering the frequency range offered by the VNA and the frequency extender and extremely good system dynamic range. The measurement range is mainly limited by the over-the-air signal transmission loss in the propagation channel. Arbitrary VAA can be implemented as well to record channel spatial profiles. The main limitation is the measurement speed, which limits its application for static scenarios only.

III. Measurement validations

The developed channel sounder was utilized for channel measurement in an indoor scenario. The frequency range is set to 99 to 101 GHz, with a bandwidth of 2 GHz. The number of frequency points is set to 1001. The VNA IF bandwidth and transmitted power are set to 500 Hz and 10 dBm, respectively. The Tx-Rx heights are set to the same height. An omni-directional antenna is used at the Tx side, while a directional antenna with half power bandwidth of 45^{o} is utilized at the Rx side. Both the DSS and VAA are implemented at the Rx side with the help of a turntable with 1^{o} rotation step. The measurement system is used for the DSS and VAA, with a difference that the directive antenna is centered at the turntable for the DSS and offset with 50cm radius for the VAA.

The measured power-angle-delay profiles (PADP) for the DSS and VAA schemes are shown in figure 2 (a) and (b), respectively. The measured channels are highly sparse and specular, with a few multipath components identified. Same multipaths are obtained in the DSS and VAA scheme. How-ever, it is shown that the VAA scheme offers much better spatial resolution and SNR, thanks to the array factor and array gain offered by the VAA scheme.

IV. Conclusion

A channel sounder based on VNA is presented, which covers up to sub-THz frequency range enabled by the frequency extender scheme, long measurement range offered by the RoF scheme, and virtual large scale array capability, enabled by the phase compensation scheme. The channel sounder capability is illustrated by the channel mea-surements in the field, where the VAA scheme is demonstrated to offer a much better SNR and spatial resolution compared the DSS scheme.

Acknowledgment

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