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Space Time Channel Sounding Method using SAR Approach

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Abstract— This paper explores the feasibility of direction of arrival (DoA) measurements with high angular resolution using a hybrid antenna array. The original concept is based on the design of a virtual planar antenna array synthesized by utilizing a real antenna array on the top of a moving vehicle. In order to validate this concept, a wideband channel sounder is developed using Software Defined Radio (SDR) module. The designed sounder is cost-effective, portable, compact and built with mainly off-the-shelf hardware. Preliminary measurements collected in suburban environments are used to validate the concept. Results demonstrate that the measured DoA's are coherent with the measurement configuration. This new approach makes it possible to carry out a large number of DoA measurements at the mobile in various environments.

Index Terms— Beamforming, channel sounding, direction of arrival, virtual antenna array.

I. INTRODUCTION

Massive MIMO is a promising technology for upcoming fifth generation (5G) mobile networks. The idea of massive MIMO is to use large number of antennas (ranging from few tens to hundreds) to reduce the radiated power by directing the energy towards targeted mobile users. It ensures improved data rates to provide services to more users with higher network reliability and latency. Hence, it requires development of advanced propagation models that make it possible to simulate the spatial and temporal properties of the electromagnetic field.

The 3D propagation model will require computation of many DoA's in a mobile configuration, in azimuth and elevation. Currently, existing devices are complex (e.g., several RF chains) or comprise discrete measurement points (e.g., XY positioner) as they require to be interrupted to collect data. Thus, they limit measurement campaigns both geographically and in mobility. A solution with 2×16 spherical array has been proposed in [1]. Results based on a vehicle-to-vehicle (V2V) measurement campaign were presented in various environments in the 5-GHz band. However, its implementation seems quite complex. Moreover, the angular resolution is limited with only 16 elements to cover 2π steradians. Planar and cubic solutions have also been explained in [2]–[4].

To address this issue, an original mobile characterization solution is proposed here. Measurements are made with a planar antenna array mounted on the roof of a moving vehicle to obtain the second dimension of the array. The result is a planar array with a flexible size. This is similar to the well-known synthetic aperture radar (SAR) principle. To

validate the concept, a robust and cost effective wideband spatial-temporal channel sounder is developed.

This paper is organized as follows. Section II presents a SDR channel sounder used for DoA estimation. In Section III, a novel concept of virtual antenna array design is explained. Preliminary results are presented in section IV to show the proof of concept. Finally conclusions and perspectives are drawn in Section V.

II. SDR BASED MIMO CHANNEL SOUNDER

A. Motivation and challenges

Commercial solutions are usually expensive and not always suitable, which leads several research centers to develop their own sounder. Such projects require multiple skills, whether in computer science, signal processing, hardware or microwave. The aim is to develop a cost-effective channel sounder with mainly off-the-shelf hardware, especially SDR receiver to avoid development of active RF systems.

In order to investigate massive MIMO from a channel modeling point of view, it is crucial to support at least 256 antennas on transceiver side. The bandwidth must be at least 100 MHz to be compatible to 5G communications. Moreover, the equipment must be pragmatic enough (e.g., portable, easy to use etc.) to perform extensive measurement campaigns necessary for statistical studies in different environments. The antenna is also an important determinant for spatial-temporal characterization of radio channel. Furthermore, 2D beam scanning is of ultimate importance along with polarization diversity for channel modelling. The array should be easily changeable to evaluate the performance of different array solutions.

B. Adopted Hardware Solution

The use of SDR products has significantly grown since last few years. A number of such products are available in the market. Such product has started to be used in channel sounding equipment [2], [5]–[6]. EttusTM products offer great flexibility in terms of performance: various models and daughter boards are available. These products are also open source and compatible with different operating system environments. The Ettus X310 device offers a wide bandwidth (up to 160 MHz) and includes an external general purpose input/output (GPIO) interface to control antennas.

MIMO channel sounding is comprised of using periodic signals to characterize radio channel. This involves switching

of the antennas at Tx and Rx terminals. Thanks to this well-known principle, a single receiver suffices along with a single RF cable and switching is performed using the GPIO interface. This also simplifies the calibration process as the active parts are shared by each antenna.

To ensure real-time operation, the Xilinx Kintex-7 FPGA platform of USRP X310 device was reprogrammed to generate real-time switching signals on the GPIO. This change allows to control an array with up to 4096 antennas. To achieve remote synchronization between the Tx and Rx in case of MIMO measurement, GPS modules have been used which provide the time and frequency references. In this case, the switching signal of the Tx antenna is regenerated locally by the SDR module which is also used to generate the Tx signal waveform.

The antenna array is a crucial point. To investigate, space time properties at the base station, a 64-element antenna array was already developed and used with this channel sounder [7]. This array integrates the switching system to avoid external switching unit and extra cables. It also simplifies the implementation and calibration process. The uniform linear array (ULA) as used at the roof of the car will use the same approach: single RF access and switching unit included in the antenna. The whole system, controlled by a PC, was integrated in a 19 inches rack for portability purpose as shown in Fig. 1.

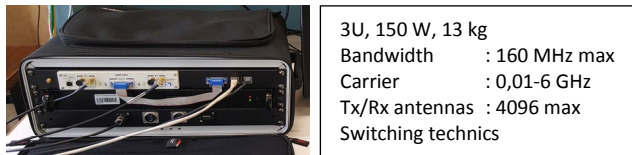


Fig. 1. Portable SDR MIMO wideband channel sounder.

C. Adopted Software Solution

The objective of the sounder was to achieve continuous acquisition, control and real-time visualization of the measured data. For software development, mostly free tools such as Python, QT, Numpy, C++ were used. The overall software architecture of the channel sounder is presented in Fig 2.

A program has been developed in C++ for controlling the SDR receiver while switching the antennas on transceiver side to record real-time data files on a computer. An interactive graphical user interface (GUI) has also been developed in Python language to monitor in real time the data recorded by C++ daemon. The GUI has been developed in combination with QT designer and various open source libraries such as NumPy and Matplotlib. Moreover, in order to support real-time high data rate from the USRP (800 Mbits/sec), the computer RAM was used for exchange of data between the C++ daemon and GUI instead of using the hard disk drive.

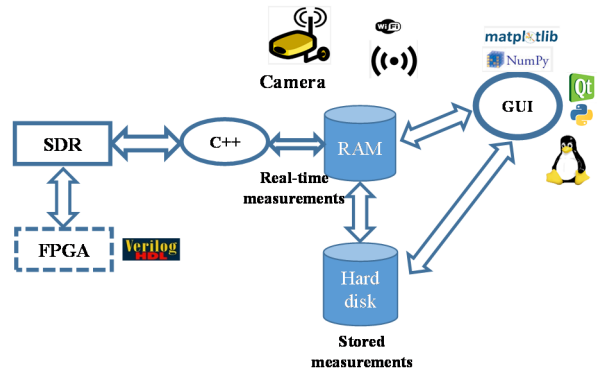


Fig. 2. Software architecture of the proposed channel sounder.

III. DIRECTION OF ARRIVAL ASSESSMENT IN MOVING CONDITIONS

A. Virtual antenna array concept

It is possible to characterize the direction of arrival in street conditions using an antenna array mounted on a vehicle roof [1]. The array must be able to steer the beam unambiguously in both azimuth and elevation. We propose an original approach using a cost-effective measurement setup, to enable continuous measurements with significant angular resolution, while reducing the implementation complexity. We consider an eight element ULA placed on the roof of a car; we synthesize a virtual planar array of antennas from the vehicle's movement as shown in Fig. 3.

On one hand, each antenna is measured successively (conventional approach). Each channel is selected successively by means of a numerical control. Frequency synchronization, provided here by GPS, is very important in order to exploit the switching principle. On the other hand, the displacement of the vehicle will be used to obtain the second dimension of the array. The use of a virtual array of antennas is perfectly applicable in channel sounding because of the periodicity of the transmitted signals and in particular the synchronization between the Tx and the Rx.

We note that the inter-antenna distance is crucial for the ability to steer the beam. It should not exceed $\lambda/2$ to avoid side-lobes, where λ is the operating wavelength (5 cm). The resulting planar array will be much larger than the arrays typically used on a vehicle. Thus, it can be constituted by several hundred antennas, and offer excellent angular resolution, both in azimuth and elevation. This principle of synthetic array by displacement is widely used in remote sensing (synthetic aperture radar).

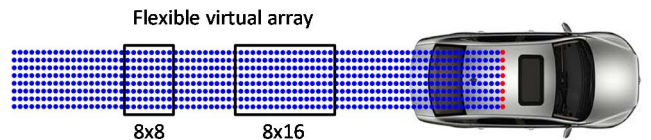


Fig. 3. Principle of mobile virtual array.

The virtual array configuration overcomes the problem of interference and inter-element mutual coupling which is inherent in physical arrays. However, it relies on the assumption of being stationary during measurement time which is true according to the short measurement duration.

B. Direction of arrival algorithm

The difficulty in DoA estimation lies on the unknown number of simultaneous radio signals impinging on an antenna array, each from unknown directions and with unknown amplitudes. In addition, the received signals are usually affected by noise. This problem has been widely studied and numerous methods to perform the DoA estimation are proposed [8].

A traditional beamforming method (Bartlett algorithm) [4], [8] has been implemented to compute the DoA. Signals impinging on the antenna array originate from various directions with different delays. This approach steers the beam and identifies the power in the different directions. This approach is limited in angular resolution by the physical size of the array aperture but provides linear and robust behavior. Moreover, it is less time consuming than the high-resolution techniques as it neither involves searching values nor it is an iterative process. To improve side-lobe levels, a 2D weighting window could be applied, but it will also increase the beamwidth. Once the concept is validated, more advanced high resolution algorithms could also be implemented to increase the DoA estimation accuracy.

IV. MEASUREMENT RESULTS

A. Measurement campaign

The measurement campaign was carried out in outdoor conditions, on ten different routes near a campus (suburban environment). The complex impulse responses were collected with the wideband channel sounder at a carrier frequency of 2.4 GHz, a measurement bandwidth of 8 MHz (reduced bandwidth to meet the authorized frequency) and a sampling frequency of 10 MHz. The Tx antenna was placed on the rooftop of a building at about 2 meters above floor level. The Tx comprised of a quarter wavelength antenna with a 2 dBi gain. At the receiver side, a classical ULA of eight isotropic monopole antennas were used on the roof of a car (Fig. 4).



Fig. 4. a) Monopole antennas used in the setup, mounted on the aluminium sheet, on a vehicle roof, b) DoA measurement bench.

Due to their simplicity and applicability to many DoA algorithms, ULA's are extensively used in array designs. As any approach by a virtual array, stationarity and phase stability are a major concern. A synchronized clock via GPS was used on transmission and reception. Each characterization starts and ends with 10 seconds of measurement at a static position in order to validate the phase coherence in emission and reception. To further simplify this approach and apply it to real signals, we are currently exploring asynchronous solutions. A good knowledge of the trajectory and the velocity of the vehicle provided here with the GPS, is also decisive for dynamically calculating the beamforming weightings.

B. Validation in LoS configuration

An example in Line of Sight (LoS) condition is given in Fig. 5, where the Tx antenna is facing the Rx array, hence simulating a dominant LoS propagation. The resulting radio signature as estimated by the DoA algorithm is shown in Fig. 6. It corresponds to the analysis of the strongest path of the impulse response as the vehicle crosses in front of the transmitter. The behavior of the direction of arrival is well observed. It is worth mentioning that the car speed is not constant over the entire trajectory. Thus, this is taken into account when estimating the beamforming by loading a database of virtual arrays implemented at various speeds.

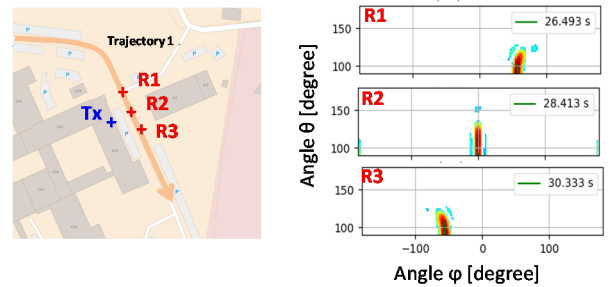


Fig. 5. Example at short distance in LoS condition.

C. Validation in NLoS configuration

This second example is performed in Non-Line-of-Sight (NLoS) condition. The main path is attenuated by a set of trees which reduces the amplitude of the main path. As a matter of fact, the relative amplitude of multipath is increased and the power delay profile (Fig. 6) is a little more spread in time

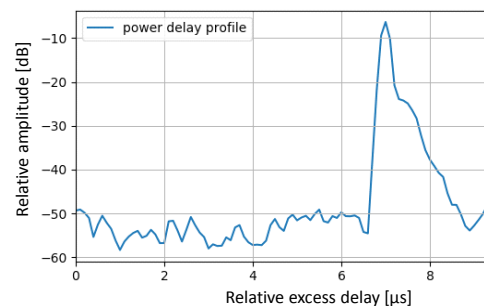


Fig. 6. Power delay profile.

Several excess delays are analyzed in terms of DoA in Fig. 7a. The main path ($7 \mu\text{s}$) highlights a single DoA with an angle corresponding to LoS direction. Another analysis is performed $0.5 \mu\text{s}$ later. In this case, several paths are found with two significant, coming from 0° and -55° . According to the path characteristics and supposing a single bound propagation mechanism, the potential propagation paths were built in Fig. 7b. It is interesting to notice that potential scatterers are located on buildings.

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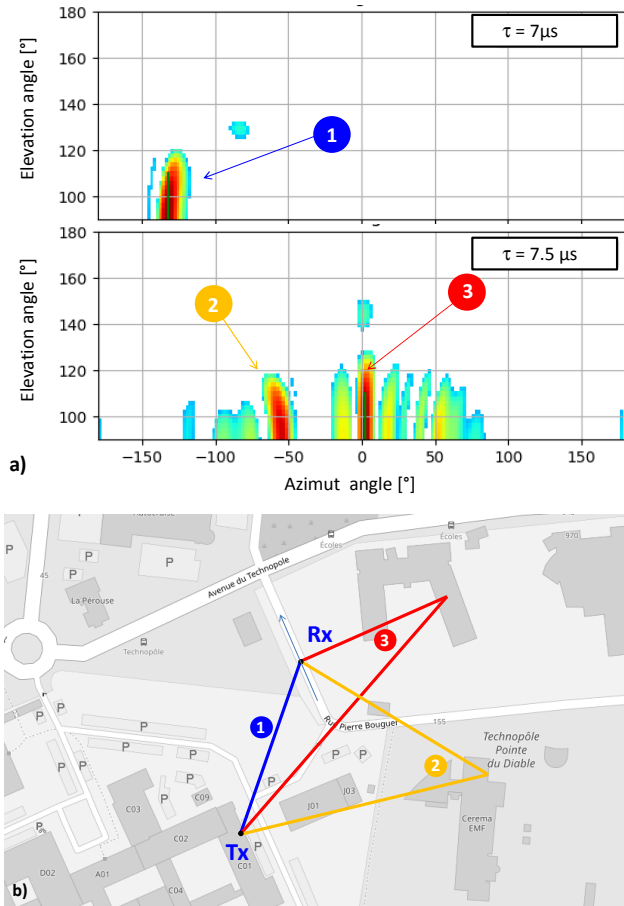


Fig. 7. a) Doa analysis of strongest paths, b) map of the area.

V. CONCLUSION

A wideband channel sounder, based on SDR equipment, has been developed for space time channel measurements. A new approach, allowing space-time characterization at a lower cost at the mobile, was proposed. It combines virtual array implementation with mobile move and real ULA. Measurements were performed to show the proof of concept.

Future work will involve the development of a wider array with dual polarization. It will be used in various scenarios to provide statistical analysis of space time characteristic at the mobile.