

A 28 GHz Beamforming Technique for 5G Advanced Communication Systems

Yoshimi Fujii*, Tetsuya Iye*, Kensuke Tsuda*, Akihiro Tanibayashi*

*Communication Engineering Dept., Kozo Keikaku Engineering, Inc., Tokyo Japan

yfujii@kke.co.jp, tetsuya-iy@kke.co.jp, kensuke.tsuda@kke.co.jp, a_taniba@kke.co.jp

Abstract— This paper describes a new approach of enabling nano-area, which is realized with advancing 5G NR radio access technologies [1] and digital/hybrid beamforming in 5G NR FR2, here we call ‘mmWave’ band, including 28 GHz band. 5G has adopted mmWave in earnest to handle rapidly increasing telecommunication traffic, however, due to its extreme distance attenuation characteristics, mmWave is mainly for a relatively small area that has a large amount of traffic or a large number of terminals (high density). We call such an area as “nano-area”. Beamforming technique is indispensable to compensate for the distance attenuation even in the nano-area. This research advances the beamforming and beam management methods for 5G to accommodate as many UEs as possible while keeping latency low. We devise underlying technologies for realizing the advanced beamforming and evaluate them by performing experiments and simulations for their implementation.

Keywords— 5G NR, mmWave, digital beamforming, hybrid beamforming, SDR, nano-area

I. INTRODUCTION

We are attempting to construct mmWave nano-area base stations with software-defined virtualizable DU (vDU) and its underlying RUs [2], [3]. Currently, only one vDU is placed in the nano-area, and multiple RUs are connected to that (Figure 1). There are a large number of UEs in the nano-area, which are intended for IoT devices, and the RUs with array antennas forming elaborate beams to ensure communication quality for the individual UEs. To ensure service continuity, multiple RUs are deployed to mitigate the shielding effects of obstacles by operating in a coordinated manner.

II. TECHNICAL ISSUES AND SOLUTIONS

A. 28 GHz Analog and Advanced Digital Beamforming Experiments

A single RU is designed to cover an area of about a dozen meters square, with an antenna unit often at a height of a few meters to less than 10 meters, and the RUs are designed to look down on the UE from a slightly higher vantage point, with the beam controlled not only in the azimuthal direction, but also in the elevation direction to cover the entire area. In our research, we are realizing a hybrid beamforming system consisting of 28 GHz two-dimensional planar patch antennas arranged in an evenly spaced 8x4 array. The elevation beam directivity is controlled by analog beamforming (ABF) while the horizontal directivity is controlled by digital beamforming

(DBF). We are planning to evaluate the performance of the beamforming system by using a prototype of the beamformer. We have completed the evaluation of analog beamforming and prototyping of the digital beamformer and are preparing for its performance evaluation.

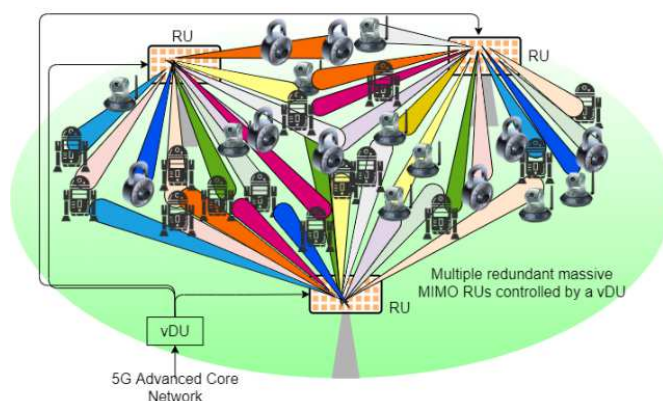


Figure 1. MmWave ‘nano-area’ composed of multiple RUs with hybrid beamforming capability under a vDU.

In this study, an experimental evaluation of the analog beamforming system was performed using an 8-element linear array antenna with CW signal at 28 GHz. It was found that the phase of the RF signal supplied to the antenna element has a large phase error of up to 20 degrees due to the wiring length error and the initial phase error of the analog beamformer chip. It was found that the beam formation with this initial phase error resulted in a distorted shape of the beam and the side-lobe shape could be greatly improved by using the existing antenna directivity correction techniques [4], [5], since the 5G Advanced system requires precise beam formation. (Figure 2).

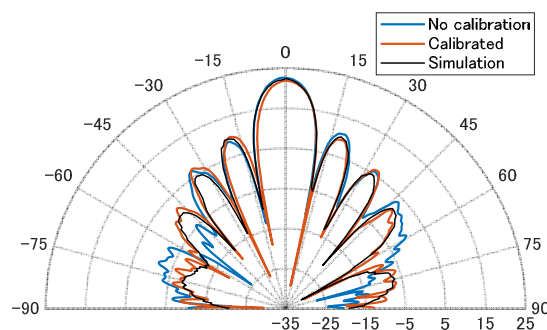


Figure 2. Effect of calibration on analog beamforming.

Currently, preparations for similar evaluation experiment for digital beamforming are underway. Digital beamforming enables beamforming for each 5G NR SSB (Synchronization Signal Blocks). Our advanced digital beamformer enables multiple SSBs in the frequency domain at the same time and transmit them as separated beams (Figure 3). This feature is implemented on a Xilinx FPGA [6] (Figure 4). In this digital beamforming experiment, it is planned to evaluate the performance of the capability.

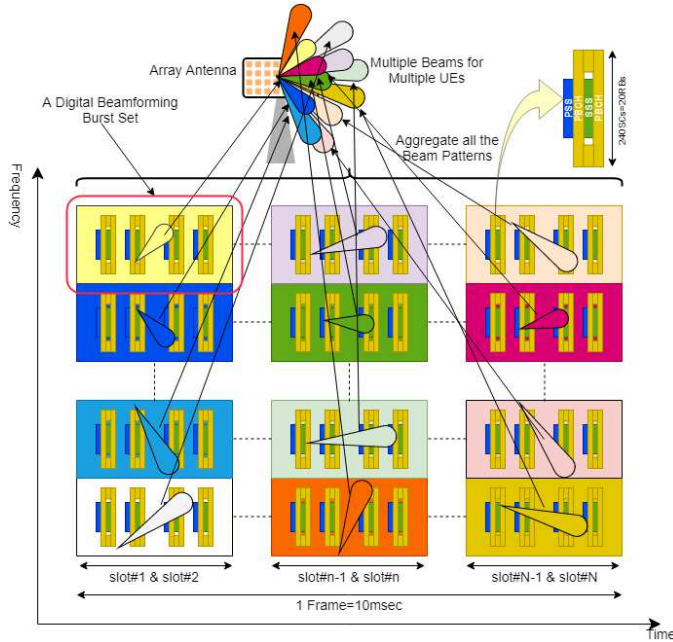


Figure 3. Advanced digital beamforming scheme.

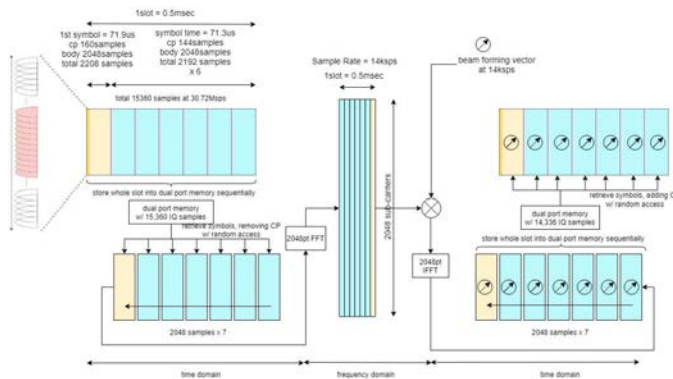


Figure 4. Abstract blockdiagram of advanced digital beamformer realized on an FPGA.

Our next challenge is to realize a way of constructing effective beams, which are optimised for each UEs with minimum latency, even under massive number of UEs. We are planning a series of simulations to evaluate the control overhead of the advanced beam management [7], [8]. Compared with the study of distributed Massive MIMO (DM-MIMO) in the Low SHF band [9] and the study of beam management assuming Massive MIMO in the 28 GHz band

[10], our study adopted a digital method for beam formation. As a result, a large number of beams can be generated at the same time, and many terminals can be supported at one time to shorten the beam sweep time. Therefore, beam management becomes more complicated. The 28GHz band hybrid MIMO (beamformer) and its control method have already entered the design stage, and we plan to evaluate them using actual equipment.

B. Cooperative Beam Forming among RUs

In order to avoid communication interruption due to millimeter wave shielding characteristics, it is necessary to arrange RUs redundantly and operate them cooperatively [11]. In this study, we first conducted an experiment in which multiple RUs sharing LO in the 28 GHz band were placed 1.5 m apart, and the same 5G NR OFDM signal was transmitted from both RUs and received by the UE (Figure 5). Both RU and UE used an omni-antenna to transmit and receive, and the EVM at the time of reception was measured.

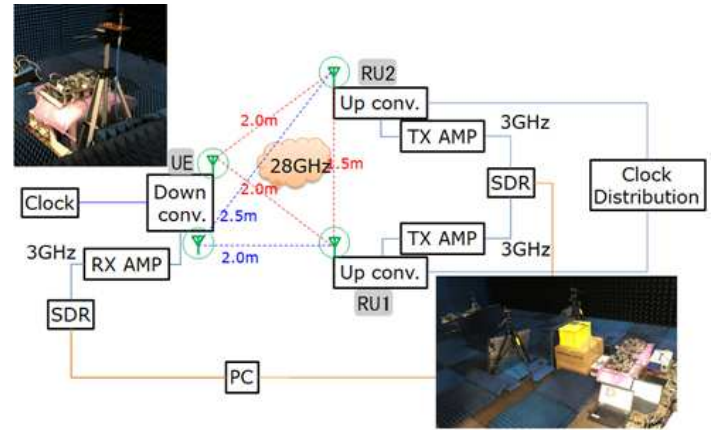


Figure 5. An experiment setup of cooperating multiple RUs to mitigate shadowing at 28GHz wireless communication.

The findings of the series of experiments are listed below.

- Making RU redundant, good EVM characteristics can be maintained even if the radio waves shielding happens for one of the RUs.
- When radio waves from two RUs can be received without the influence of shielding, increase of EVM is observed due to a slight movement of the UE in several millimetres (Fig. 6).
- EVM deteriorates to a level where communication is not possible if both RUs are blocked.

Although these were results that were almost in agreement with the preliminary predictions and simulation results, the behaviour could be confirmed by experiments.

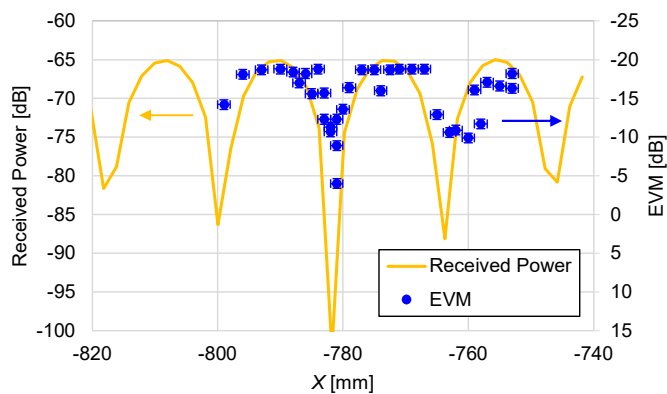


Figure 6. Fading effect with multiple RUs cooperation at 28GHz.

Also, when a similar experiment was performed using a common 10 MHz reference clock instead of sharing the LO, it was found that the EVM value was not stable. As expected, we realized that a mechanism / procedure for synchronizing RUs is indispensable when multiple RUs are operated cooperatively. Currently, we are studying the procedure for synchronizing RUs based on the 5G NR signalling sequence, as well as the signalling sequences to establish connection among a UE and multiple RUs, with system-level network simulations [12].

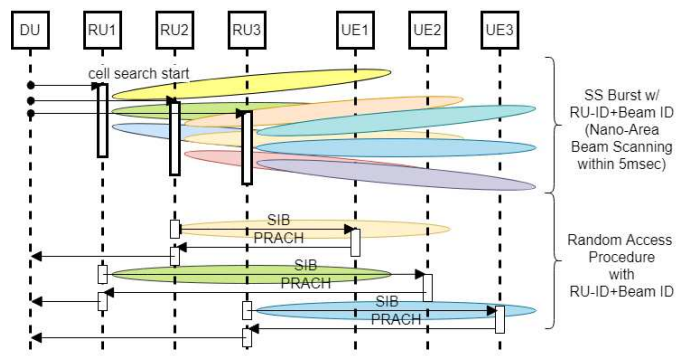


Figure 7. Consideration of cooperating multiple RUs capable of digital/hybrid beamforming and synchronization procedure in nano-area.

III. CONCLUSIONS

We have verified the performance of an proposed advanced wireless communication technology, at implementationside, which is a further development of 5G by using mmWaves through individual fundamental experiments and identified the technical issues to address each of them. We have also proposed and evaluated solutions to some of them. Toward the next stage, we are integrating these elemental technologies on a prototype of 5G NR air interface using an open source "OpenAirInterface" [13] to create a platform that actually operates as a wireless communication system.

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Yoshimi Fujii (M'19) received B.S. and M.S. degrees in computer science and communication engineering from Kyushu University, Fukuoka, Japan, in 1989 and 1991, respectively. Since 1991, he has been working as a Software Engineer in the telecommunication field with Kozo Keikaku Engineering, Inc., Tokyo, Japan. His research interests include various layers of wireless communication technology, especially lower layers such as the physical layer and media access layer. Currently, he is involved in a series of projects related to the implementation of wireless communication PHY layer using a software-defined radio (SDR) approach. In addition to telecommunication, he is interested in the implementation of GNSS signal generators and receivers with an SDR.



Tetsuya Iye (M'19) was born in Tokyo, Japan, in 1986. He received a B.S. degree in physics from Waseda University, Tokyo, Japan, in 2009 and M.S. and Ph.D. degrees in physics from Kyoto University, Kyoto, Japan, in 2011 and 2014, respectively. From 2013 to 2014, he was a Research Fellow of the Japan Society for the Promotion of Science. He joined Kozo Keikaku Engineering, Inc., Tokyo, Japan, as a System Engineer in 2014. His current research interests include

millimeter-wave communications, antennas and propagation, beamforming, and the software-defined radio (SDR).



Kensuke Tsuda received B.S. and M.S. degrees in theoretical physics from Osaka University, Osaka, Japan, in 2000 and 2002, respectively. He joined Kozo Keikaku Engineering, Inc., Tokyo, Japan, as a Computational Electromagnetics Application Engineer. His research interests include the development of a real-time multi-GNSS signal generator and virtualized 5G/6G radio access networks, based on the software-defined radio (SDR) technology.



AKIHIRO TANIBAYASHI was born in Hyogo, Japan, in 1963. He received the B.S. degree in industrial engineering from Osaka Prefecture University, Osaka, Japan, in 1988. He joined Kozo Keikaku Engineering, Inc., Tokyo, Japan, as a System Engineer in 2008. His current research and development interests are system- and network-level simulations.