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Millimeter-Wave Communication System Using Photonic-Based Remote Antennas for Configurable Network in Dense User Environment

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Abstract—Photonic-based millimeter-wave communication systems combined with conventional wireless systems have been proposed for the application in dense user environment like a big football stadium. By utilizing a narrow beam antenna for millimeter-wave asymmetric links, effective communication channels can be obtained.

Keywords—millimeter-wave; radio-over-fiber; heterogeneous network; dense user environment

I. INTRODUCTION

In the next generation (5G) wireless communication systems, the utilization of the millimeter-wave (MMW) band for wireless carriers seems to be promising to realize enhanced broad-band (> 5 Gb/s) telecommunication services and to secure many wireless network applications like M2M and IoT [1], [2]. MMW is also attractive for use in space-division-multiplexing (SDM) technique to prepare a lot of wireless communication channels and throughput. Our research and development work has focused on the study of 5G wireless communication systems in dense user environments utilizing advanced photonic devices and radio-over-fiber (RoF) technologies [3]. Especially, we have focused on a RoF-based heterogeneous wireless communication system, which includes 3G, LTE (4G) Wi-Fi and MMW wireless links for broadband, low latency, low-power consumption and low-cost.

In this paper, the experimental demonstration of photonic-based MMW wireless communication links using photonic-based remote antennas in a large football stadium are reported. This can be combined with an asymmetric MMW link configuration with terminal localization techniques. Some basic experimental results of Giga-bit Ethernet connections over the MMW wireless links in an actual football stadium are also shown.

II. SYSTEM ARCHITECTURE

Figure 2 shows the concept figure of the 5G network of the configurable MMW links combined with legacy (3G/LTE/Wi-Fi) networks. In a big football stadium, almost ideal free-space propagation characteristics are available for MMW links when a remote antenna is installed with a directive antenna at a catwalk or the underside of a roof of the stadium.

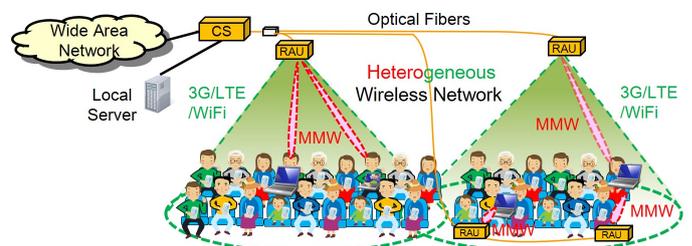


Fig. 1. Concept of the configurable network using remote antennas.

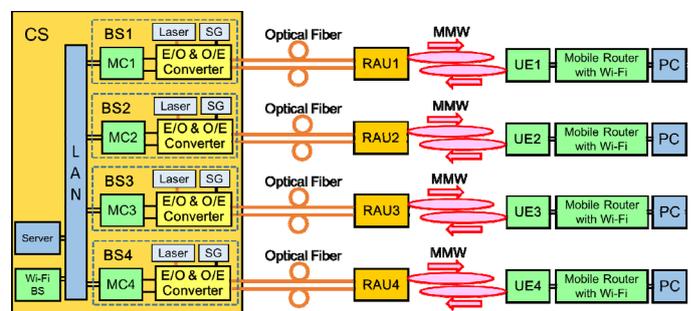


Fig. 2. Block diagram of the photonic-based wireless base stations and remote antenna units for MMW wireless links.

This research results were achieved in part by the research project of "Radio technologies for 5G using Advanced Photonic Infrastructure for Dense user environments" (RAPID), the Commissioned Research of National Institute of Information and Communications Technology (NICT), Japan.

The designed block diagram of MMW wireless base stations and remote antennas are shown in Fig. 2. By utilizing the photonic 2-tone generation technique with AKS modulation formats, MMW signal transmission over a standard silica fiber cable can be obtained for any fiber length.

III. EXPERIMENTS

The proposed MMW wireless communication links using photonic technologies were designed and fabricated to implement heterogeneous wireless communication systems with Wi-Fi links. The carrier frequencies of the MMW up- and down-links were set at 63 GHz and 60 GHz, respectively. The input and output interfaces of the fabricated communication systems were the Giga-bit Ethernet, and the data from the Giga-bit Ethernet line was converted to a stream of simple on-off keying signals by use of Giga-bit media converters (MCs).

A photograph of the fabricated base stations for 4-channel photonic-based MMW links is shown in Fig. 3. Photonic-based Wi-Fi links were also prepared and implemented in the heterogeneous communication system for the field trial in the football stadium.

Firstly, preliminary measurements of the fabricated photonic-based MMW links were done in a big anechoic chamber as shown in Fig. 4. Typical measurement results are shown in Figs. 5 and 6. Figure 5 shows the measured MMW field strengths emitted from the photonic-based remote antenna units by changing the distance to the user equipment when two types of antennas were installed in the MMW link. The characteristics corresponding the antenna patterns were obtained. Figure 6 shows the measured data throughput in the fabricated photonic-based MMW Ethernet link from the Internet server to the remote computer. The server was connected to the base station and the remote computer was installed in the user equipment shown in Fig. 2. The measured maximum data rate was matched with the performance of the Giga-bit media converter used in the experiment. Therefore, by use of higher bit rate converter and interfaces, much higher throughput (~10 Gb/s) can be obtained, we believe.

We also measured the multi-link communication characteristics by use of two pairs of the photonic-based MMW links for checking the performance for frequency re-use in dense user environment by using the experimental set-up shown in Fig. 7. A typical measurement result is shown in Fig. 8. This result indicates that by use of photonic-based MMW links with high-gain antennas to generate narrow beams, small-size wireless cells (cell radius ~2 m) are easily obtained. Therefore, multiple (>1,000) wireless communication channels with >1 Gb/s/channel can be implemented with the SDM technique in a large football stadium, since almost free space propagation characteristics are obtained in such a stadium for MMW signals [5]. Adopting this MMW link with an asymmetric link configuration, the terminal localization technique and array-antenna-electrode electro-optic modulators [6], scalable 5G wireless systems can be introduced in large stadia [4].

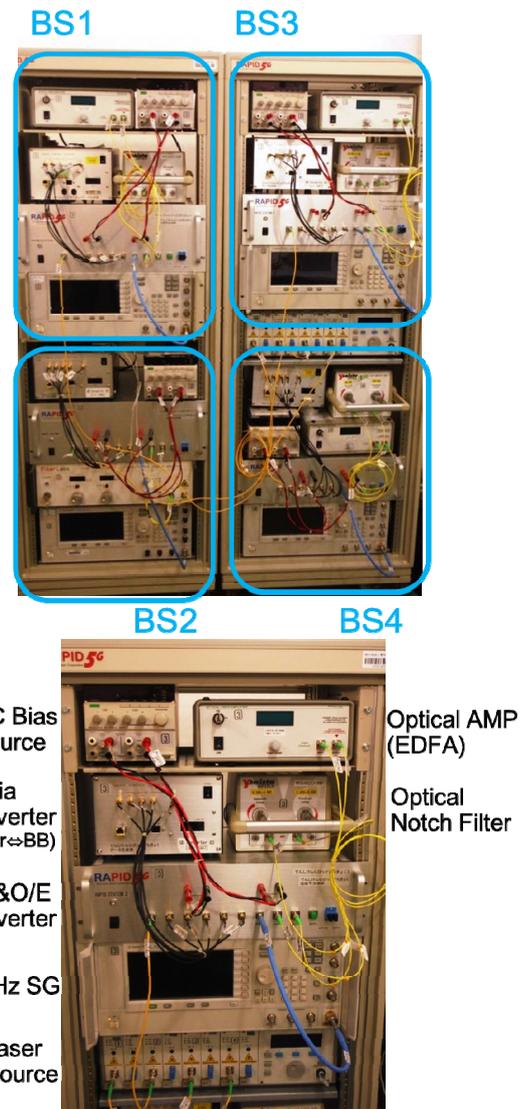


Fig. 3. Photographs of the 4-channel base stations (BS1-4) for MMW links (upper) and the magnified image of BS3 (lower).

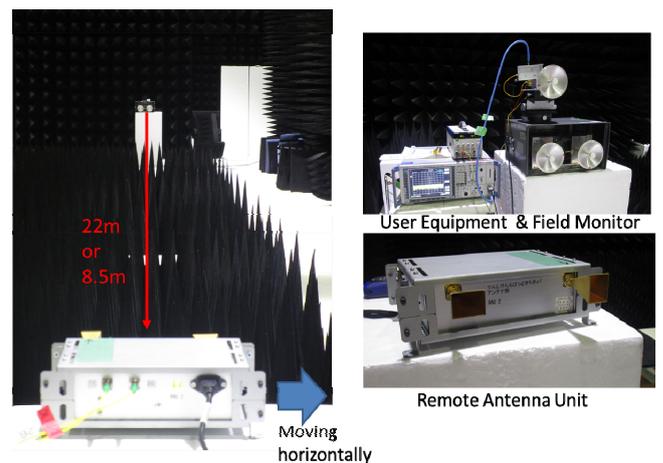


Fig. 4. Experimental setup in an anechoic chamber.

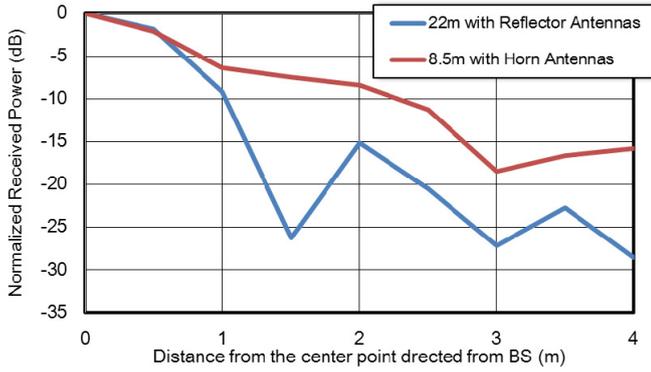


Fig. 5. Measured MMW field strength from the photonic-based remote antenna unit.

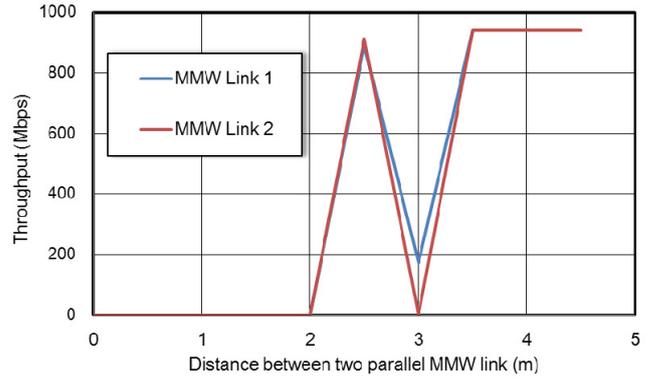


Fig. 8. Measured MMW data throughputs by using two pairs of the photonic-based MMW base stations, remote antennas, and user terminas.

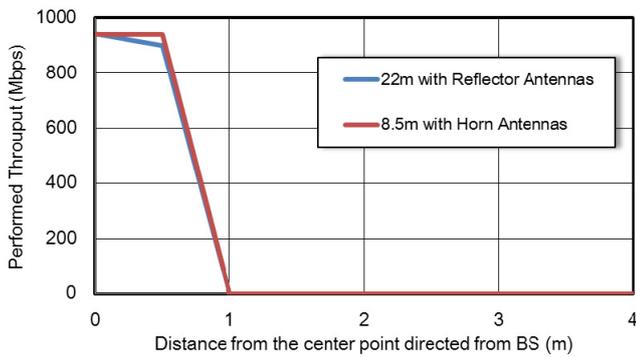


Fig. 6. Measured data throughput between the photonic-based MMW base stations and user equipments by using the remote antenna units.

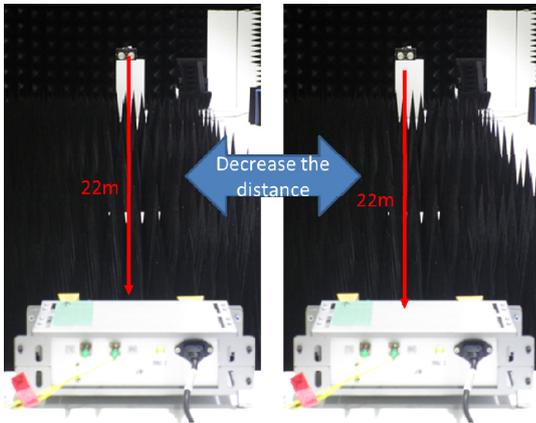


Fig. 7. Experimental setup using two MMW wireless links in an anechoic chamber.

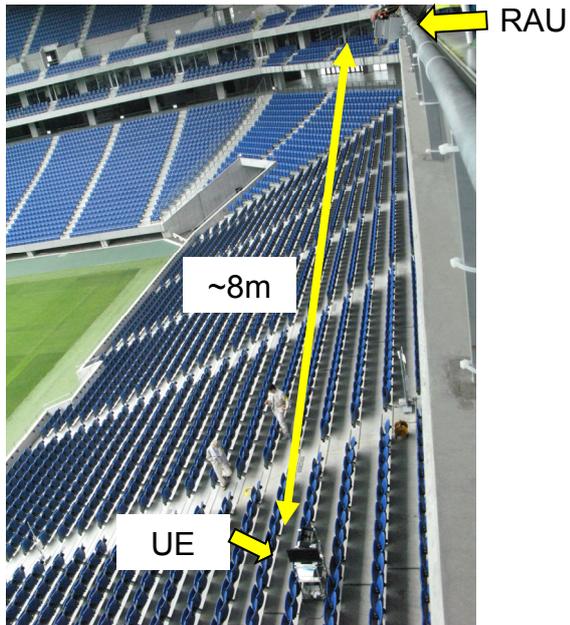
Finally, we tried to do field communication experiments by use of the fabricated photonic-based antennas and MMW links in the large football stadium located in Suita, Osaka, Japan. Figure 9 illustrates the photonic-based MMW remote antenna unit (RAU) installed at the handrail of the higher level floor of the Suita football stadium. The wireless receiver units for user equipment (UE) were also set at the main seat area of the stadium as indicated in Fig. 9. The separation between RAU and UE was about 8 m, and the horn antennas and reflector antennas were also used in the stadium experiment.

The base stations (BSs) for the MMW links and Wi-Fi links were also installed in the central station located inside the stadium. Standard single-mode silica optical fiber cables were used to connect the multiple BSs in the central stations and RAUs in the main stand of the stadium. The length of the optical fiber cables to connect the BSs and RAUs was about 600 m.

In the experiment over four days in the football stadium, TCP/IP data transmission over 900 Mb/s was successfully demonstrated using the fabricated photonic-based MMW link. The download of the high-resolution 4K videos also succeeded using the fabricated remote antennas and user terminals in the real football stadium.

IV. CONCLUSION

The basic performance of the fabricated photonic-based remote antennas for heterogeneous 5G communication systems were verified by the measurements in the anechoic chamber and the big football stadium. The switching between a MMW Giga-bit channel and Wi-Fi channel with a short switching time (\sim ms) as a heterogeneous wireless system was also demonstrated successfully using the Mobile IP technology.



ACKNOWLEDGMENT

The authors thank Dr. Hidehisa Shiomi, Dr. Toshiyuki Inoue, Prof. Atsushi Sanada and Prof. Yasuyuki Okamura of Osaka University, Japan for their valuable comments and supports.

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Fig. 9. Experimental set-up in a large football stadium and three UEs in the main stand area.