Demonstration of Real-time Photonics-assisted mm-Wave Communication based on Ka-band Large-scale Phased-array Antenna and Automatic Beam Tracking Technique

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Abstract: Based on 256-element phased-array antenna and photonics-assisted mm-Wave communication, we successfully demonstrate real-time bi-directional 1.5Gbps uncompressed high-definition video transmissions at 26.5~29.5GHz. The FPGA-based self-steering beamforming has been implemented using the proposed automatic beam tracking technique.

1. Overview

With the explosive growth of numerous bandwidth-consuming applications, such as high-definition (HD) video live, virtual reality and digital twin, etc., mm-Wave (MMW) communication has been attracted extensive attentions from both academia and industry. For example, the n257 band (26.5~29.5GHz, located at Ka-band) is already specified as an important frequency window for 5G new radio (NR) systems in frequency range two (FR2) by 3GPP [1]. However, such MMW frequency is susceptible to atmospheric attenuation, suffering from higher wireless propagation loss as compared with conventional sub 6G band. In order to expand the coverage of MMW, photon-assisted MMW communication utilizing optical heterodyne beating to generate MMW signals and then transmit them remotely through optical fibers is an effective solution. Actually, this is also an important means to overcome the wall loss for 5G MMW and thus achieve indoor coverage [2]. Another method to substantially increase the transmission distance of MMW is to use large-scale integrated phased-array antenna (PAA) [3], which benefits from enough antenna gain via its unique beamforming property. However, it is challenging for a PAA to implement self-steering beamforming to support user equipment (UE) mobile communication in the dynamic scenario without using extensive phase control signals.

In recent studies, the beamforming-enabled photonics-assisted MMW communication based on the PAAs have been demonstrated [2, 4-6]. These systems are either limited to static beamforming in several fixed directions [2], or only implement one-way [5] and offline communication [6]. More importantly, all of above are conducted with the small-scale (no more than 4-element) PAAs, which does not accord with the development trend of highly integrated and large-scale PAA for future 5G MMW fiber wireless access networks.

2. Innovation

In this demonstration, we implement the real-time bi-directional HD video transmissions for 5G MMW fiber wireless access over 5km fiber and 1.5m wireless link. Firstly, this demonstration is based on the large-scale (256-element) PAA, which designed by Purple Mountain Laboratories. To the best of our knowledge, this is the first demo using such large-scale PAA in 5G FR2 n257 band. Secondly, we propose and implement the automatic beam tracking technique based on field-programmable gate array (FPGA), and thus self-steering beamforming of the PAA has been achieved for dynamic scenario, without using any extra phase control signals. Finally, we package a photonics MMW terminal and build the bi-directional MMW transmission links, and then successfully demonstrate the real-time video display in the terminal mobile scene within a max angle range of ±50°.

3. OFC relevance

This demonstration involves automatic beam tracking control of large-scale PAAs in the dynamic scenario and photonics-assisted MMW real-time bi-directional HD video transmissions for 5G MMW indoor/outdoor coverage. The above two topics are both the hot trending in OFC. This demo may be of great interest for telecom operators and communication service providers who engaged in 5G MMW indoor/outdoor coverage. Additionally, this work may also arouse the attention of part of industry insiders, who are interested in real-time uncompressed HD video transmission in optical fiber wireless access networks.

4. Demonstration description

Figure 1 shows the demonstration setup of real-time bi-directional HD video transmissions based on 5G MMW PAAs. The demonstration system mainly contains four types of key components: photonics MMW terminal, arc-shaped slideway, automatic beam tracking subsystem and the remaining transceiver modules. To facilitate the movement of MMW terminal, two laser diodes (LDs) with 27GHz frequency interval, one intensity modulator (IM), one optical tunable attenuator (VOA), one photodiode (PD), one MMW envelope detector (ED), three electrical amplifiers (EAs) and a pair of horn antennas (HAs) are packaged into a standard 3U chassis, this is what we call the photonics MMW terminal, as shown in Fig.1 (a). Meanwhile, an 120° arc-shaped slideway shown as Fig.1 (b) is used to ensure the alignment of HAs and PAAs during the movement of the chassis. Since we desire to demonstrate the bi-directional HD video transmissions, the entire transmission paths include uplink and downlink in this system. Due to the limitation of the laboratory space, the wireless transmission distance is set to 1.5 meters. At the downlink MMW transmitter, the real-time 1.4875Gbps video from a HD camera (camera1) is converted from HDMI to SDI interface through uncompressed encoding, then amplified and sent to the IM for electro-optic modulation. Two LDs (LD1 and LD2) with a frequency difference of 28.7GHz are used as the downlink continuous light sources. Note that there is a 1.7GHz interval between the frequencies of uplink and downlink shown as Fig.1 (c), aiming to reduce mutual crosstalk. A 5km standard single-mode fiber (SSMF) is sufficient to provide the signal access from outside to indoor. Subsequently, the 28.7GHz MMW signal can be obtained through optical heterodyne beating via a PD. After 1.5m wireless transmission, the MMW signal is down-converted to baseband by the ED of photonics MMW terminal. Then the video can be played in real-time after corresponding decoding at the downlink video receiver. The uplink is substantially similar to downlink, except that the MMW signal generated in the chassis without fiber transmission, as well as the MMW reception involving branch processing, which will be described in detail next.

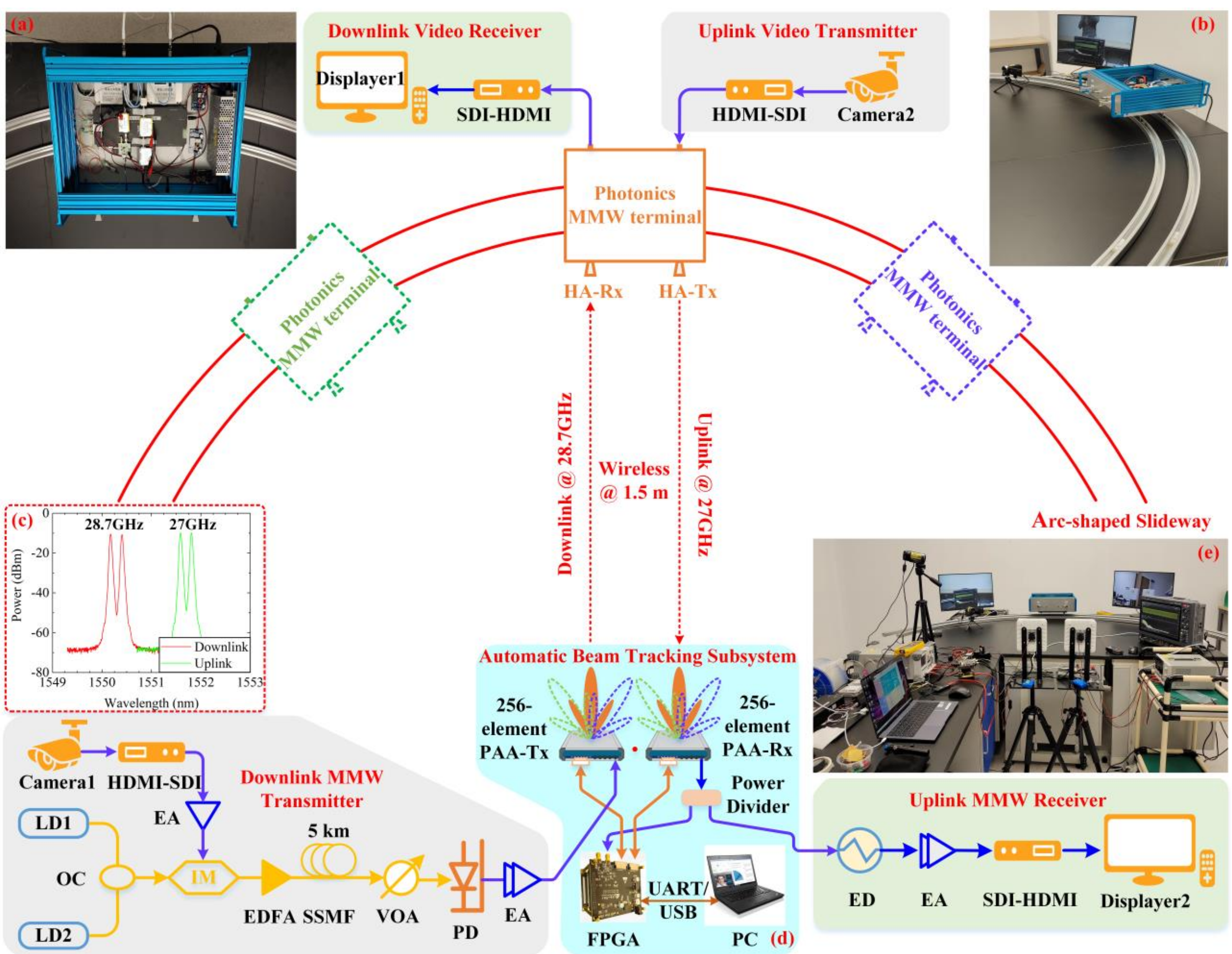

Fig. 1. Demonstration setup of real-time bi-directional HD video transmissions based on 5G MMW PAAs. (a) Packaged chassis of the photonics MMW terminal. (b) Arc-shaped slideway. (c) Optical spectra of the uplink and downlink. (d) Automatic beam tracking subsystem; (e) Testbed.

In order to support the capability of PAAs' self-steering beamforming, the automatic beam tracking subsystem has been proposed and successfully implemented, as shown in Fig.1 (d). This subsystem consists of two PAAs (Tx and Rx), one MMW power divider and one FPGA as well as one control PC. Table 1 shows the key parameters of the large-scale PAA. Note that the PAA supports time division duplex mode, however, for simplifying control purpose in this demo, we use two PAAs for continuous transmitting and receiving, respectively. The FPGA board is the core of the automatic beam tracking subsystem, and its functional interface is shown in Table 2. Two rectangular connectors (J30JZ with 25 pins) are used for power supply and command (CMD) interaction with the PAA-Tx and PAA-Rx, respectively. The 27GHz MMW signal received from PAA-Rx is divided into two branches via a 40GHz power divider, one is sent to the uplink MMW receiver for normal video decoding, and the other is fed to the FPGA via a K-connector for power monitoring regarding as a feedback signal. At this case, when the terminal changes position, FPGA can always find the direction of the maximum receiving power by beam scanning. Then both the beams of the PAA-Tx and PAA-Rx are adjusted to the above direction by FPGA, so as to accurately point to HAs.

Table 1. Key parameters of PAA

Parameter	Value
Antenna type	Active phased array
Working mode	Time division duplex
Working frequency	26.5~29.5 GHz
Num. of elements	256
Polarization mode	Linear polarization
Beam sweep range	E/H side, $\pm 25°/\pm 50°$

Table 2. Functional interface of FPGA

Interface	Description
DC power	12V/3A power supply for FPGA
Rect. connector1	Power supply, CMD for PAA-Rx
Rect. connector2	Power supply, CMD for PAA-Tx
K-connector1	Receiving RF signal from PAA-Rx
K-connector2	Reserve
USB UART	CMD interaction with control PC

An automatic beam tracking algorithm is designed to improve the performance of real-time video transmission. The workflow is shown in Fig. 2. Firstly, set the scan mode and scan parameters, including the lower threshold (LT) α and upper threshold (UT) β, then measure the peak power $P0$ at the initial position (such as 0°). As the terminal moves, the current power $P1$ gradually reduces. As long as the current power is found to be lower than the LT power ($P1 < \alpha * P0$, meaning the video cannot display as before), the FPGA immediately starts to scan the beam according to the angles range setting by PC and meanwhile updates the current power $P1$ in real time. FPGA continues to scan until it reaches UT power ($P1 \geqslant \beta * P0$), which means the video can be displayed well. With the help of this automatic tracking algorithm, we successfully demonstration the real-time bi-directional video transmissions when the terminal moves within an angle range of ±25°/±50° at the E/H side of the PAAs, the testbed is shown in Fig. 1(e).

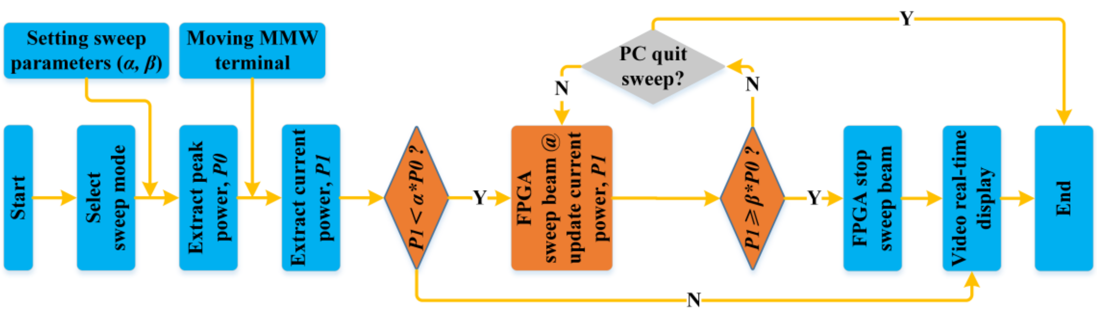

Fig. 2. Automatic beam tracking workflow.

5. Conclusion

In summary, this demo showcases the real-time bi-directional HD video transmissions based on 256-element PAAs and photonics-assisted MMW communication at 5G FR2 band for the first time. The FPGA-based automatic beam tacking technique is proposed and implemented. Finally, we successfully demonstrate an example of bi-directional video display with automatic beam tracking in the dynamic scenario, where the terminal can move freely within a max range of ±50°. *This work was partially supported by the National Natural Science Foundation of China (62101126 and 62101121).*

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