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# Real-time 2.5 Gbit/s spatial circuit switching on W-band wireless links

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**Abstract.** A spatial circuit switching system based on a beam steering application for W-band wireless links is proposed and experimentally demonstrated. The system enables two simultaneous transmissions of a 2.5 Gbit/s data signal over a carrier of 81 GHz, while allowing the receiver to dynamically switch between them. The performance of the system is tested with the real-time measurements of the BER, achieving values below the FEC limit for 7% of overhead and serving to prove the viability of wireless spatial circuit switching in the next generation of wireless access networks. © 2017 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: [10.1117/1.OE.56.2.026104](https://doi.org/10.1117/1.OE.56.2.026104)]

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## 1 Introduction

As we move toward the next generation of mobile networks, higher frequency bands have become more attractive due to higher bandwidth availability. The current focus of the 5G systems is to use the millimeter wave bands (30 to 300 GHz) for the wireless link between the network and the user equipment (UE).<sup>1</sup> To generate and transport the millimeter wave signals to the radio units, radio-over-fiber (RoF) techniques have been proposed and studied to serve as the backbone technology in the back- and fronthaul networks.<sup>2-4</sup> The implementation of RoF has allowed the network to add extra capacity, control, and flexibility with for example optical switches and labels on RoF<sup>4-6</sup> or multi-core fibers.<sup>7</sup>

Nevertheless, there are still some challenges in the wireless transmission of the signals in the W-band (75 to 110 GHz), one being the high attenuation at high frequencies. As an example, the attenuation for a distance of 2 m is 76.63 dB. To compensate for the attenuation, the W-band systems must use both high amplification stages and high gain antennas.<sup>3</sup> Therefore, the selection of antennas for W-band systems is constrained to antennas with high directivity, which will impact the total coverage of the base transceiver stations (BTS). Up until now, the total coverage has been increased with cell sectorization,<sup>8</sup> meaning that the total coverage area of the station is divided between two or more transceivers in the same BTS. However, the same implementation in W-band will require a large number of simultaneous transceivers in the BTS. In response, the use of beam steering techniques has been previously presented to enhance coverage and communication links in both uplink and downlink.<sup>1,8,9</sup>

In this paper, we propose and perform the real-time measurements of a circuit switching application for W-band (75 to 110 GHz) wireless links, by combining the generation of millimeter-wave wireless signals based on RoF techniques

with a beam steering application. This switching application allows the radio access unit (RAU) to dynamically select an area to transmit the wireless signal, increasing its total coverage adding flexibility and reliability to the next generation of radio access networks. The remainder of the paper is structured as follows: Sec. 2 describes the proposed system architecture. Section 3 describes the experimental setup and Sec. 4 discusses the experimental results. Finally, Sec. 5 summarizes the results and discusses the advantages of the proposed system.

## 2 Spatial Switching by Antenna Steering

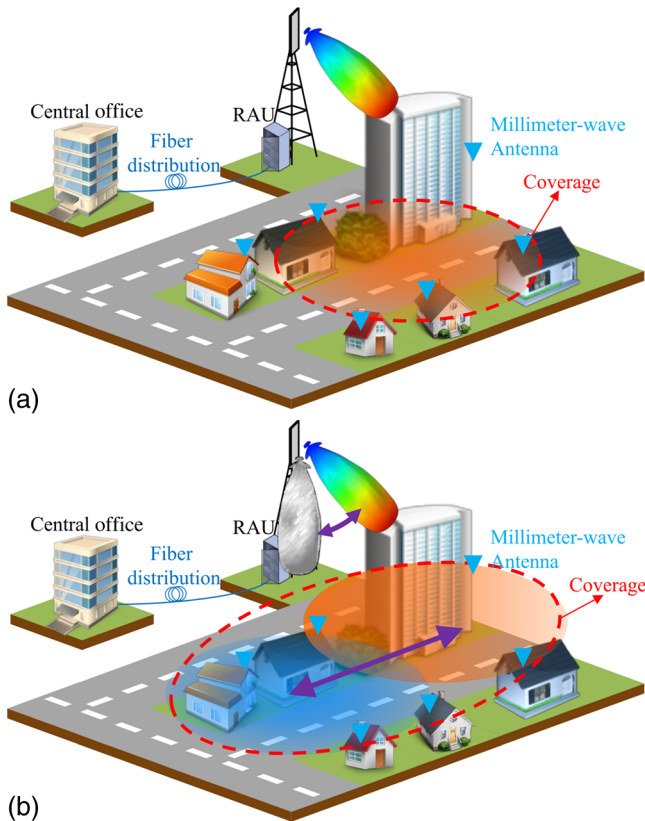
Figure 1 presents the proposed scenario for the sectorization of a W-band radio access network. The network follows the standard centralized area network (C-RAN) architecture. In the C-RAN, the central office generates and processes the wireless signal and then transports it to different RAU that are dispersed through the network. The RAUs are used only as an interface between the optical fronthaul and the wireless link to connect with the UEs.

In each RAU, the total coverage is divided into various sectors and will have one transceiver creating the channel link. The antennas will illuminate only one position of the sector at a time due to the limitations on its beam width. However, each of the antennas will have implemented a beam steering application, which will allow a single antenna to spatially switch between different illuminated regions, covering the full sector.

## 3 Experimental Setup

Figure 2 shows the setup used in the proof of principle experiment. A 2.5 Gbit/s  $2^{15} - 1$  bit long pseudorandom bit sequence (PRBS15) nonreturn-to-zero (NRZ) signal from a pulse pattern generator (PPG) is used to modulate the optical carrier of a small form factor pluggable (SFP+) module. The modulated optical signal travels 10 km of standard single-mode fiber and then is combined with an external cavity

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**Fig. 1** Proposed scenario of RoF and wireless circuit switching. Steering of the main lobe of the antenna will enable the RAU to switch to a different region of the sector, increasing the total coverage by sectorizing the cell. (a) Normal coverage of the antenna and (b) expanded coverage with circuit switching.

laser, which serves as a local oscillator (LO) with the optical input power adjusted with a variable optical attenuator. The two optical signals are boosted with an erbium-doped fiber amplifier (EDFA). A second VOA is placed for bit-error-rate (BER) measurements. Afterward, the signal is divided using a power splitter and delivered to two transmitters. The transmitters are composed of a high bandwidth photodiode (PD), a medium power amplifier (MPA) of gain 8 dB and a 24 dBi horn antenna. The PD (Finisar XPDV4120R with 90 GHz of

bandwidth) is used to perform the upconversion process by direct heterodyning.<sup>2,3</sup> The upconversion processes will create a double side band modulated signal in the electrical domain with a central carrier of 81 GHz, resulting in the transmission on the W-band (75 to 110 GHz). The electrical signal in each transmitter is then fed to the horn antennas to be wirelessly transmitted. In order to decorrelate the transmitters, a waveguide is placed between the PD and the antenna in the first transmitter.

At the receiver, a 24-dBi horn antenna recovers the signal and delivers it to a 40-dB gain low noise amplifier, before a Schottky diode-based W-band envelope detector (ED) down-converts the data signal. Then, a clock recovery stage is used to provide both data and timing information to a bit-error-rate tester (BERT), allowing the real-time measurements of the BER.

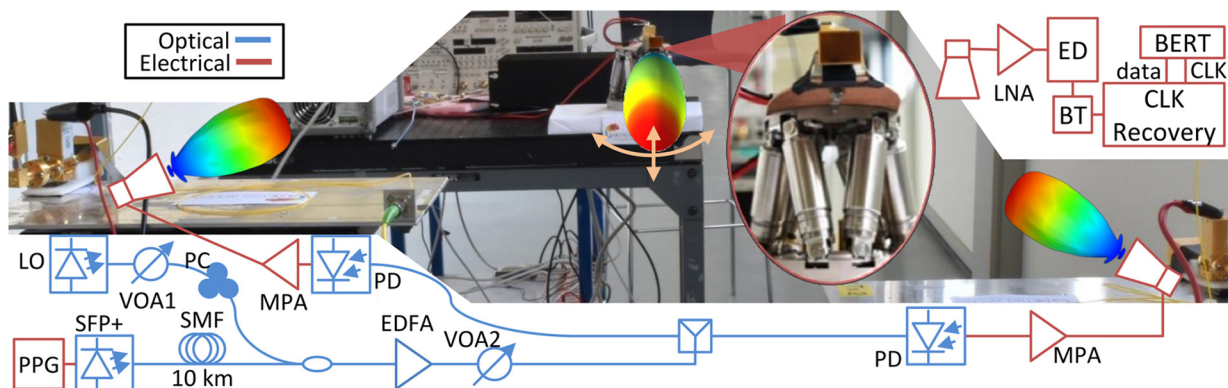
The implemented beam steering solution is a mechanical steering technique based on Stewart platform. The Stewart platform is a robot with high accuracy ( $\pm 0.06 \mu\text{m}$ ), on a 6-axis ( $XYZ$ , pitch, roll, and yaw) actuator system arranged in parallel between two platforms. The receiver is mounted over the Stewart platform, giving it 6 deg of freedom and allowing it to select between the two transmitters. The full system will then act as a wireless switch, with the insertion losses (IL) and crosstalk (XT) defined as a function of the radiation pattern of the antenna and the distance between transmitters:

$$IL_{\text{TXi-RX}} = G_{\text{TXi}} G_{\text{RX}} \left( \frac{\lambda}{4\pi R_{\text{TXi-RX}}} \right)^2, \quad (1)$$

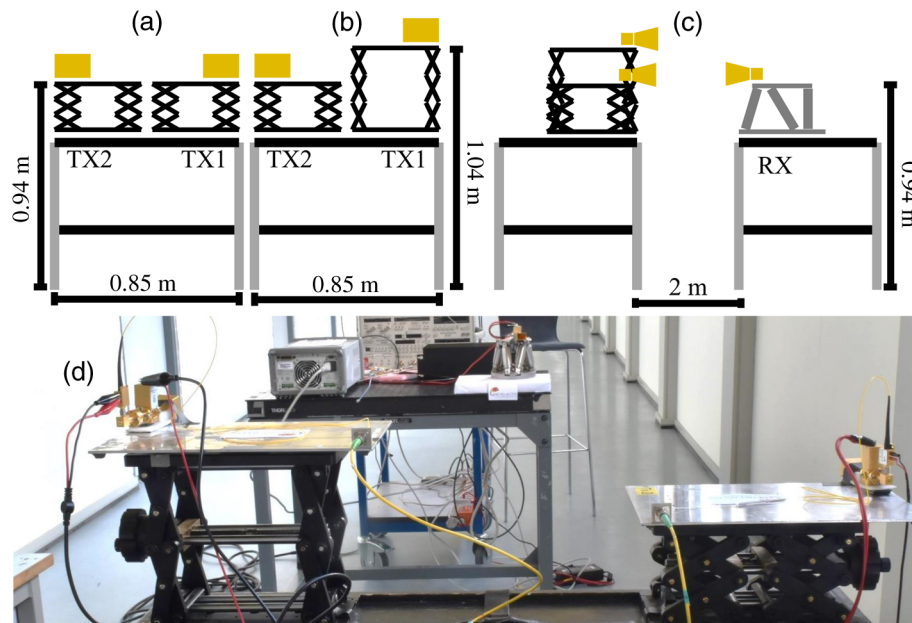
$$XT_{\text{TXi-TXj}} = G_{\text{TXj}} G_{\text{RX}}(\theta) \left( \frac{\lambda}{4\pi R_{\text{TXj-RX}}} \right)^2. \quad (2)$$

Here  $G_{\text{TXi}}$  and  $G_{\text{RX}}$  are the gain of the transmitter and receiver, respectively,  $G_{\text{RX}}(\theta)$  refers to the gain at the angle in sight of the other transmitter,  $\lambda$  is the wavelength in the air, and  $R$  is the distance.

To test the system two cases were implemented: case A, with both transmitters in the same height, as in Fig. 3(a); and case B with the transmitters at different heights, exemplified in Fig. 3(b). As shown in Fig. 3(c), the distance between the



**Fig. 2** Experimental setup. PPG, pulse pattern generator; SFP, small form factor pluggable; LO, local oscillator; VOA, variable optical attenuator; PC, polarization control; SMF, single mode fiber; EDFA, erbium-doped fiber amplifier; PD, photo diode; MPA, medium power amplifier; ED, envelope detector; BT, bias tee; CLK, clock; BERT, bit error rate tester.



**Fig. 3** Implementation of the experiment: (a) front view for case A, (b) front view for case B, (c) side view of the implementation, (d) real implementation. Video 1 shows the switching operation with the two antennas at the same height (MP4, 10 MB) [URL: <http://dx.doi.org/10.1117/1.OE.56.2.026104.1>].

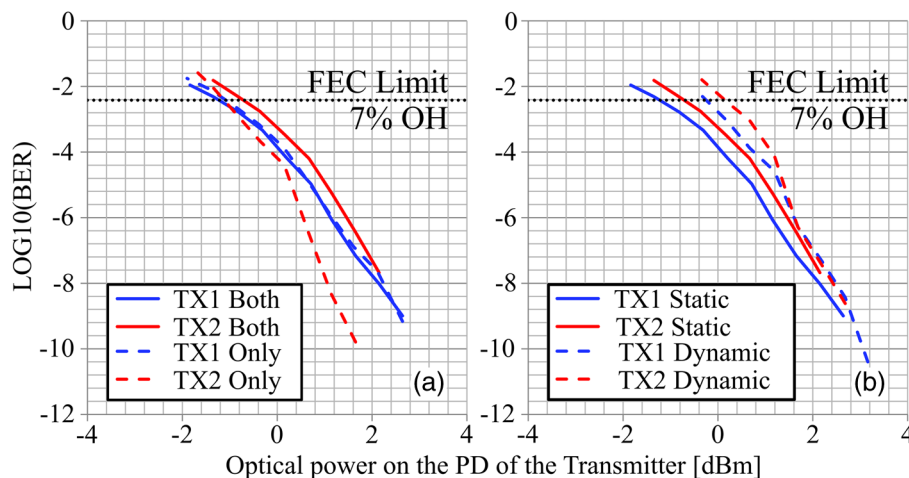
receiver and the center of the two antennas was 2 m. The final implementation for the second case can be seen in Fig. 3(d).

#### 4 Experimental Results

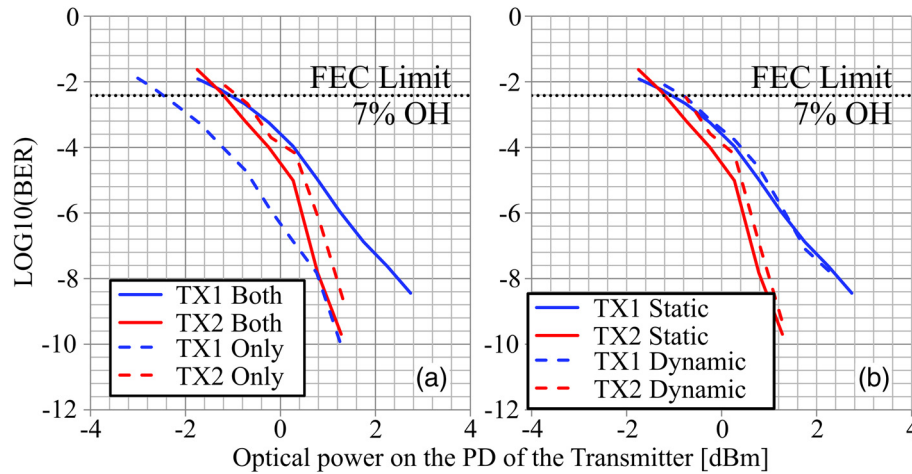
In order to test the performance of the system, two sets of measurements were performed in each case. The first test was made to check the interference between the two channels. In this test, the receiver was aligned to each transmitter and the BER traces were measured in two steps: with both transmitters turned on and with only the one selected transmitting. The second test was performed to show the effects of the switching. Here the receiver was set to move between the transmitters and wait 10 s in each before moving again. During the experiment the transmitter 1 (TX1) received

around 0.5 dB more optical power than the transmitter 2 (TRX2), stemming from differences in both the coupler and the fiber path before the PDs.

For the case A, the antennas were set at the same vertical distance. Video 1 shows the switching process. The measurements for the interference are shown in Fig. 4(a). For the case of the TRX1, having higher power, the effects of the TRX2 are not appreciable. Meanwhile, in the results for TRX2, a big aperture on the BER traces can be seen due to the presence of TRX1, lowering the performance of the system with a penalty of 0.4 dB. The measures of the switching for this case are presented in Fig. 4(b). In both cases, the BER traces show similar tendencies as their static counterpart, but with a little extra attenuation of around 0.8 dB, due to the small misalignment created while the antenna is moving.



**Fig. 4** Real time measurements of the BER versus the optical power on the PD of the transmitter, for the same height case: (a) Interference test and (b) static and dynamic switch mode comparison. Video 2 shows the switching operation with the two antennas with different height (MP4, 10.2 MB) [URL: <http://dx.doi.org/10.1117/1.OE.56.2.026104.2>].



**Fig. 5** Real-time measurements of the BER versus the optical power on the PD of the transmitter, for the different height case: (a) interference test and (b) static and dynamic switch mode comparison.

For case B, the height of TX1 was increased, effectively increasing the distance between the transmitters. Video 2 shows the switching operation of this case. Figure 5(a) shows the results for the interference test. For TX1, the presence of the second transmitter becomes more notable, causing a total penalty of 1.2 dB. The TX2 is less affected, making only a difference of 0.2 dB between the two traces. Figure 5(b) shows the dynamic switching for this case. Once again the performance has a low penalty of 0.4 dB for the worst case and showing only as an extra attenuation on the system.

## 5 Conclusions

We have performed the real-time measurements of a 2.5 Gbit/s signal, wirelessly transmitted on the W-band (75 to 110 GHz), in two different cases of spatial circuit switching. The first one with the two transmitters at the same height and equally spaced from the receiver antenna, and the second increasing the height of one of the antennas. The spatial circuit switching was performed by moving the receiver antenna between two transmitters simultaneously enabled.

In both cases, the measured BER successfully achieved levels below the FEC limit for 7% of overhead. These results demonstrate the viability of wireless spatial switching in the future generation of mobile networks. Although the test was done by moving the receiver, the theorem of reciprocity in antennas allows us to extend these results to the case of beam steering performed in the transmitter.

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