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Radio-over-Fiber-supported Millimeter-wave Multiuser Transmission with Low-Complexity Antenna Units

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Abstract— **A system for serving a large number of users at millimeter-wave (mmW) frequencies using a single Radio Frequency (RF) chain is presented. A single Remote Antenna Unit (RAU) supported by Radio-over-Fiber transport is used to transmit multiple 60GHz band signals to various users located at different spatial locations using the beamsteering characteristics of a Leaky Wave Antenna (LWA). Error Vector Magnitude analysis has been performed for each user signal up to a maximum of seven users per RF chain with wireless transmission over 2m. A performance comparison for different user-signal frequency spacings has been provided to understand the limitations of the system and results show that the proposed system design with the LWA performs better than systems using waveguide and horn antenna transmitters. A realization to double the number of served users is also presented which shows that up to 10 users can be served using half region of the LWA, with each user transmitting 1Gb/s data rate, delivering an aggregate data rate of 10Gb/s.**

Keywords———Multiuser Transmission, Radio-over-Fiber, Millimeter-wave, Subcarrier Multiplexing SCM.

I. INTRODUCTION

Multiuser transmission at millimeter-wave (mmW) frequencies is a key technique for the next generation mobile networks where a large number of users or devices is anticipated [1]. The ultra-wide bandwidth available at 60GHz provides a promising solution to accommodate a large number of user channels at considerably high data rates [2]. Traditional mmW system designs suggest numerous RF chains, each having a number of mmW components, for the Remote Antenna Unit (RAU) design in order to cope with the large number of users in its vicinity. Beamforming with antenna arrays and massive MIMO is gaining much interest in RAU design and these are considered to be key technologies for future mobile systems to mitigate the high penetration loss at mmW frequencies [3]. The large number of RF components in such arrays adds high cost to the design of a RAU. In dense user environments, the complexity and cost of the RAU design is an important factor to be considered where a large number of RAUs need to be deployed. Another significant feature to be considered in the design is the selection of an appropriate fronthaul which needs to provide low cost and centralized access to the Central Unit (CU).

Radio over fiber (RoF) transport provides a low cost solution to carry ultra-large bandwidth signals from the Central Unit (CU) to the RAUs with significantly low loss, without the loss of data integrity [4]. Subcarrier Multiplexing is a potential candidate to transport a large number of channels over optical access networks [5] as it consists of legacy robustness of RF components which are compatible with the commercial optical devices. This paper presents a RoF-supported SCM based multiuser transmission approach which uses the beamsteering feature of a V-band array antenna. Fig. 1 shows the radiation characteristics of the developed Leaky-Wave Antenna (LWA) [6] which directs different mmW frequencies in particular directions. The SCM signals are transported from the CU to the RAU at lower Intermediate Frequencies (IFs), upconverted to mmW and transmitted to the intended user locations [7]. The LWA directs the beam towards the users in the spatial domain allowing every user to receive a high-gain beam with its own data with low interference from the neighboring signals. A performance analysis has been performed for different numbers of users and guard bands to maximize the number of users to be served using a single LWA.

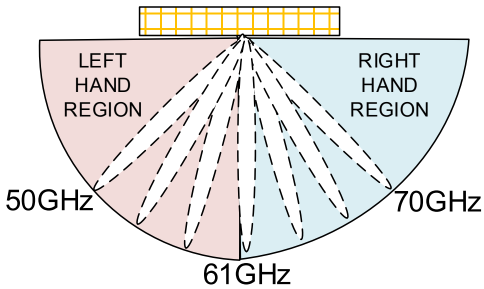

Fig. 1. Spatially Distributed LWA Transmission for V-Band Frequencies

II. SINGLE RF CHAIN DESIGN FOR LARGE NUMBER OF USERS

Fig. 2 shows the system setup used to exploit the single RoF link and single RF chain while serving a large number of users. At the CU, a composite SCM signal is generated using Simulink and an Arbitrary Waveform Generator (Tektronix 70001A) for seven users. The central frequency for the first user is generated at 1GHz and an offset of 1GHz is used to set the central frequency for the other users. Each user is served a 305MHz bandwidth OFDM signal with data generated using different pseudo-random number (PRN) sequences. The OFDM signals use a 512 IFFT, 1/8 cyclic prefix and 16-QAM modulation. The analog waveform generated by the AWG, is amplified and

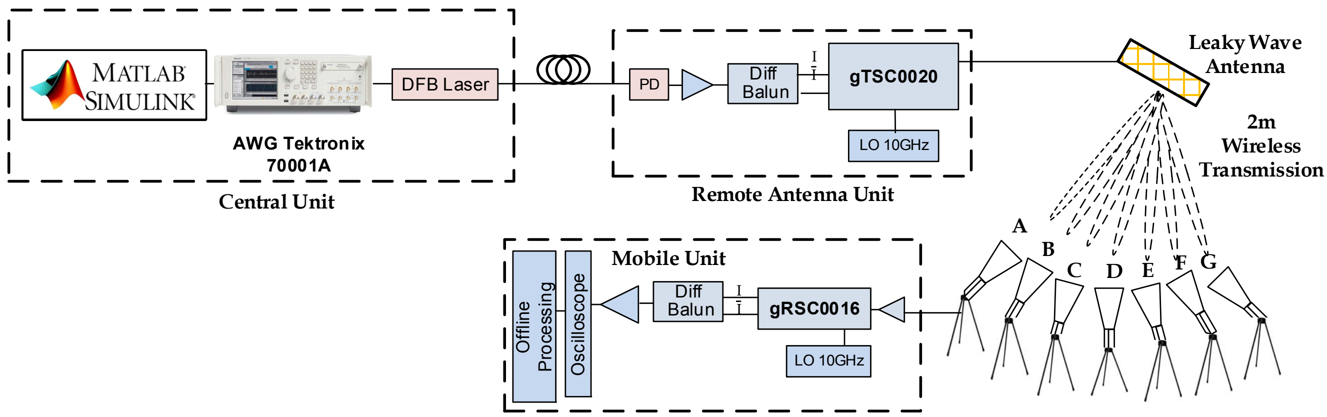

Fig. 2. System Architecture (experimental) for Single RF Chain based Multiuser Transmission

modulated onto an optical carrier at a directly modulated distributed feedback laser (DFB) with 5dBm output power. After 2.2km of RoF transport, a high bandwidth photodiode is used to recover the composite SCM signal which is amplified by 19dB at the RAU to compensate for the loss in RoF transport and optical/RF conversion. At the RAU, an integrated 60GHz transmitter is used to upconvert the user signals to mmW frequencies. The transmitter uses a 10GHz LO and upconverts the 1GHz IF signal to 61GHz for the first user and the 7GHz signal to 67GHz for the seventh user. The integrated module amplifies the mmW signal which is provided to the input port of the LWA. The 12x1 array size LWA [6] transmits each mmW signal in a particular direction from -0.6° at 61GHz to 9.6° at 67GHz. A standard gain horn antenna is used to receive the signals after 2m of wireless transmission. After the reception at the user end, the mmW signal is downconverted to IF, amplified and captured by a real-time oscilloscope with 100GS/s sampling rate for offline processing.

III. EXPERIMENTAL RESULTS

This section presents the experimental results obtained after transmission of data to seven users (A to G) in three transmitter configurations i) WR-15 waveguide as a transmitter [8] ii) Horn antenna as a transmitter iii) LWA transmitter. The IF for first user (A) was kept at 1GHz and last user (G) at 7GHz. Fig. 3 presents the EVM results for each user after 2m of wireless transmission by using the three different types of transmitter antennas and using a separate standard gain horn antenna as receiver antenna for each measurement. The measurements for waveguide as a transmitter were taken by placing the receiver horn antenna at different user locations so that the aperture of the horn was facing the waveguide to receive maximum power.

For the measurements with the horn antenna transmitter, both horns were facing each other, by rotating the transmit horn in the direction of each user location, again to allow maximum signal reception. Thus, the horn antenna transmitter measurements represent ideal LOS transmission to each user, which would not be possible simultaneously, and also requires mechanical beam steering. The EVM for the horn antenna transmitter depends on the frequency response of the antenna, even when the receiver is in perfect line of sight, which results in EVM fluctuations for the different users, as can be seen in Fig. 3.

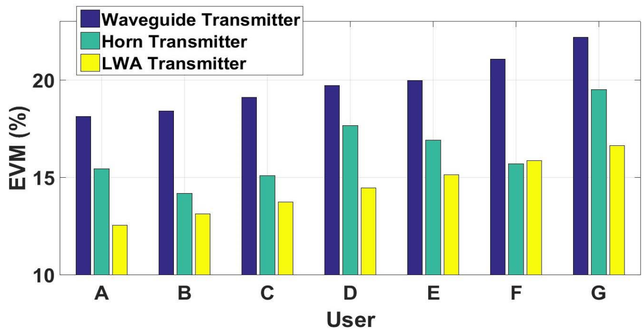

Fig. 3. EVM per user signal for back-to-back measurements for different user spacings

The next set of results provides a comparison between back-to-back and end-to-end system measurements. The back-to-back measurements are performed by first generating the composite SCM signal from the AWG for seven users. The system is first tested with the spacing between the edges of the signals at 700MHz, when the center frequency of each user signal is 1GHz from the neighboring signal(s), as before. The AWG is connected with an RF amplifier and RF attenuator, to adjust the

User	A	B	C	D	E	F	G
700MHz Guard Band	1GHz	2 GHz	3 GHz	4 GHz	5 GHz	6 GHz	7 GHz
500MHz Guard Band	1 GHz	1.8 GHz	2.6 GHz	3.4 GHz	4.2 GHz	5 GHz	5.8 GHz
300MHz Guard Band	1 GHz	1.6 GHz	2.2 GHz	2.8 GHz	3.4 GHz	4 GHz	4.6 GHz

Table. 1. Center Frequency for the users for a particular signal-to-signal spacing between the users, each of which is upconverted to mmW afterwards

output power, and data is captured at the oscilloscope for each user. The edge- to-edge spacing is then decreased to 500MHz, and then 300MHz, to analyze performance when the user signals are closer to each other, in order to increase the efficiency of the bandwidth usage. The details for the center frequency of each user are given in Table 1 for a particular signal spacing (guard band), with the bandwidth for each user kept constant (305MHz). Fig. 4 shows the EVM performance of users A to G; no considerable effect from reducing the frequency spacing between user signals is observed. Larger spacing causes a high center frequency for the last user, for which the AWG has to increase the internal sampling rate for the SCM signal. The increase in overall sampling rate improves performance for signals at lower IFs but SNR for higher IF signals degrades as they approach the limit of the AWG.

Fig. 5 shows the end-to-end performance after 2m of wireless transmission. The difference in the performance for different user-signal spacing clearly shows that EVM degrades with the increase in transmission frequency. The potential causes of this performance degradation are: (principally) the limited bandwidth of the RoF link (limited modulation bandwidth of DFB laser Emcore 1933 and bandwidth of the photodiode), and degradation of the gain from mmW amplifiers in the setup.

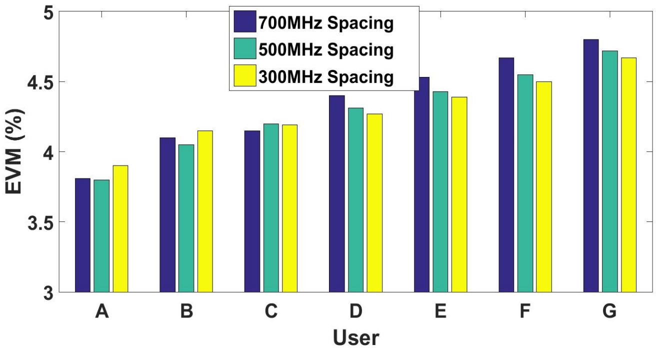

Fig. 4. EVM per user signal for back-to-back measurements for different user spacings

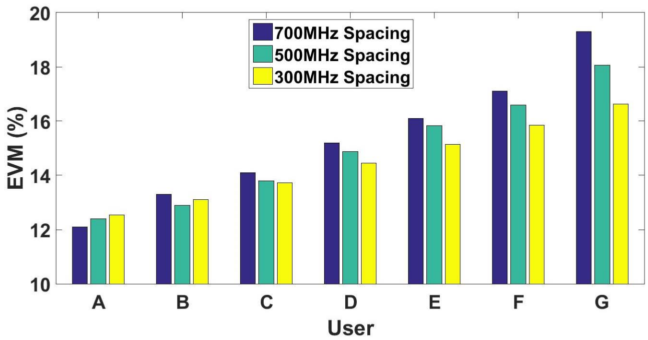

Fig. 5. EVM per user for end-to-end transmission for different user spacings

IV. Coupled RF Chain Design For Large Multiuser Transmission Using Single LWA

A demonstration to serve a large number of users using the bandwidth of one LWA can be performed. Due to the limited bandwidth of our AWG the demonstration consists of transmitting the SCM signals in two groups with different ranges of IF frequencies, one group a time. Fig. 6 shows the experimental setup where different sets of user data are generated at the CU, for seven users in the first group and for another seven in the second group. The signals for both groups have 600MHz offset in terms of their central frequency (which corresponds to a guard band of 300MHz). This allows the LWA to serve 14 users (from A to N) in the spatial domain in the right hand region shown in Fig.1 using a single LWA. As the integrated transmitter gives a double sideband modulated mmW signal, the mirror image of the upconverted mmW signals are present in the left hand region of the LWA (as shown in Fig. 1) in a different direction. Here the results are presented only by using the wireless transmission on the right half region of the LWA, by using the upper sideband of the upconverted mmW signals. In real systems, the undesired lower sideband can be removed and the left hand region of the LWA can serve another set of users. The EVM results for the second group of users, as shown in Fig.7, are considerably higher due to the higher IFs and mmW frequencies compared to the first group, and the limited bandwidth of the RoF link and mmW amplifiers, as

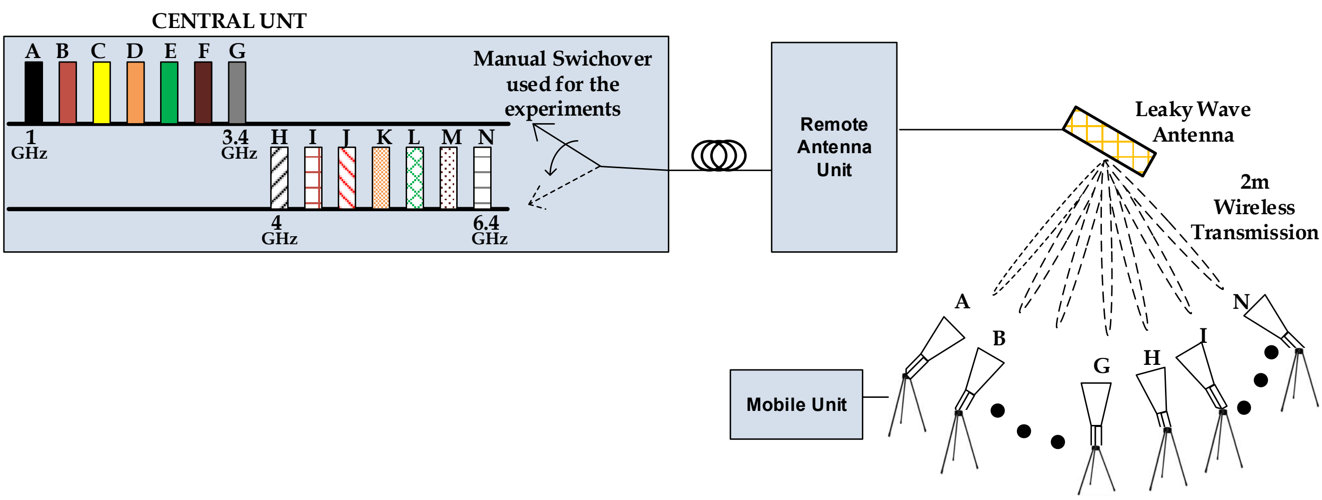

Fig. 6. Experimental Setup for two step measurements enabling Large Multiuser Transmission using single LWA

previously discussed. The end-to-end transmission results in Fig. 7 where the EVM performance for few users is higher than 16.5%, required by the FEC coding [9].

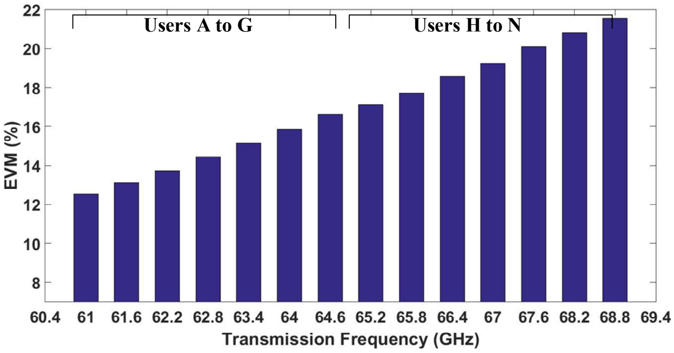

Fig. 7. EVM per User after LWA transmission for 7 users per RF chain (total 14 users)

To examine a system with a number of users that can be served from the single LWA and with the RoF link used, which can achieve receiver EVM below the considered limit, the setup was modified so that data for a total of ten users generated in two groups was tested. The results for all ten users' performance are shown in Fig. 8, and suggest that EVM performance is acceptable for this configuration. It is important to note that mmW transmission using the LWA is only performed for the right hand region in the measurements. The other half can serve another ten users if single side band modulation is performed at the RAU or using a mmW bandpass filter after the integrated transmitter, so 20 users (each with 1Gb/s data rate) can be served by the LWA.

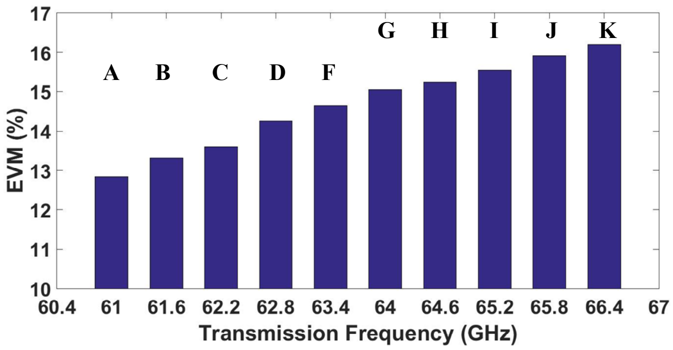

Fig. 8. EVM per User after LWA transmission for 5 users per RF chain (total 10 users)

The extension of this work may include comparison of multiuser transmission consisting of smaller number of users but with large-bandwidth transmission. The power degradation of the large bandwidth signal due to the beamsteering behavior of the LWA needs to be investigated to completely characterize the system and thus determine the limitations of the proposed setup for multiuser transmission.

V. CONCLUSIONS

Performance analysis of a multiuser transmission system based on RoF transport and an LWA in an RAU consisting of a single RF chain has been presented. A characterization of the system is performed to serve the maximum number of users through different number of users at a time and investigating the effect of signal spacing among the users. The results show that the system can serve a large number of users achieving a total of 10Gb/s when serving 1Gb/s to 10 users simultaneously.

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