Hybrid Beamforming for Multi-User Massive MIMO Systems at Millimeter-Wave Networks

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HYBRID BEAMFORMING FOR MULTI-USER MASSIVE MIMO SYSTEMS AT MILLIMETER-WAVE NETWORKS

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ABSTRACT

The design procedure of hybrid beamforming is investigated considering multi-user MIMO communication systems taking into account the number of independent data streams for each user. Hybrid precoding and combining are utilized at the transmitter and receiver sides of millimeter-wave multi-user massive MIMO. The obtained results indicate the trade-off in performance based on the ratio of the number of antennas to the number of data streams at the transmitter as well as the receiver. The optimization of the number of parallel data streams per user allows the increase of transmitted data rate while keeping the levels of error vector magnitude (EVM) at acceptable levels.

Keywords: millimeter-wave; hybrid beamforming; massive MIMO.

I. INTRODUCTION

Attractions are being directed to millimeter-wave (mm-wave) frequency bands, to meet the demands of modern communication systems. One of the main challenges of such systems is the high propagation loss associated with the mm-wave frequency range [1]. The reduced wavelength however allows the increase of the number of antennas and thus the introduction of massive MIMO architecture. Efficient beamforming can be obtained with massive MIMO and can lead to augmenting the spatial multiplexing gain, improving the SNR level, and enhancing the data throughput [2]. For multi-user systems, massive MIMO architecture can increase spectral efficiency in two ways. First, the base station (BS) can interact with multiple users at the same time and with frequency resources. In addition, more than one stream can be associated with the link between the BS and each user equipment (UE). Massive MIMO architecture provides high array gain which is useful to overcome the high path loss associated with mm-wave frequencies.

Digital beamforming used for MIMO systems requires one dedicated RF chain per antenna element [3]. Because of that, digital beamforming necessitates a large number of hardware components and is not practical for massive MIMO systems [4]. Analog beamforming systems depend on phase shifter networks [5] to steer a single stream of data and thus cannot fully exploit the spatial resource. Hybrid beamforming allows the reduction of the number of RF chains compared to digital beamformers while supporting a large number of streams [6]. In this study, hybrid beamforming is developed for a multi-user massive MIMO communication system with both single/multiple independent data streams for each user. The proposed simulation parameters for a hybrid beamforming system are presented next, followed by a discussion of the obtained results and conclusions.

II. SIMULATION PARAMETERS FOR PROPOSED HYBRID BEAMFORMING SYSTEM

Figure 1 shows the block diagram of hybrid beamforming architecture for a multi-user massive MIMO system structure. This block diagram consists of user data streams that are modulated and processed with digital beamforming subsystem, RF chains, and analog beamforming and then combined before the antenna array. Beamforming is performed by utilizing the channel matrix to determine precoding and combining digital weights of the baseband signals and the analog phase shifts of the analog RF phase shifters. A model is built using the Matlab environment of the downlink for data transmitted from BS to multi-users. This model considers scattering 3D multipath propagation channels. Transmitted signals are scattered from a large number of scatterers associated with the fading channel. Beamforming makes use of precoding to direct each data stream to a particular scatterer from the transmit side, and combine signals coherently at the receiver side using appropriate shaping.

The developed model implements hybrid beamforming for massive MIMO systems at the frequency spectrum band of 28 GHz. Hybrid beamforming of a single user is conducted based on the orthogonal matching pursuit technique. For multi-user scenarios, user groups are assigned for users with similar transmit channel covariance, using the joint spatial division multiplexing methodology.

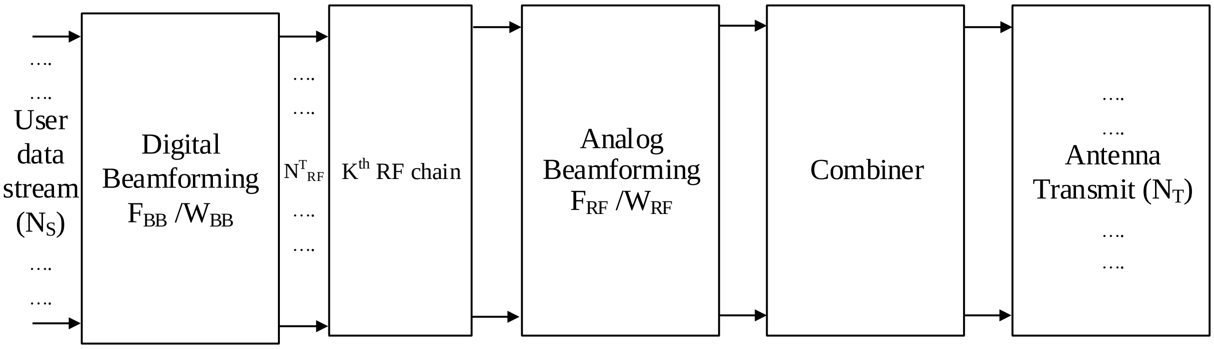


Fig. 1: Block diagram of hybrid beamforming for multi-user massive MIMO system at the transmitter.

The simulation model assumes an OFDM communication system. The number of OFDM data symbols is chosen to be ten, and all mobile stations are placed within 1000 meters of BS. In addition, the positions of mobile stations are distributed randomly. The azimuth and elevation angles are chosen in the ranges [-180 to 180] and [-90 to 90], respectively. The channel sampling rate is set to 100 Mbps, and the code rate per user is 1/3. The configuration of the antenna at the transmitter uses a uniform rectangular array while a uniform linear array is utilized at the receiver. The number of antennas at the BS side is chosen to be 64 and 128.

The number of users is chosen to be four and eight. Every user is allocated independent channels and every RF chain is utilized to transmit a separate data stream. In four users, the mobile stations are placed at [546 859 686 332]m with azimuth angles of [-158.4° -40.94° -103.27° 155.7°], and the elevation angles of [40.11° -81.56° 57.84° 16.54°], respectively. Also for eight users, the mobile stations are placed at [546 859 686 332 60 387 214 933]m, the azimuth angles in degree are [80.22° -163.12° 115.67° 33.07° -89.25° -66.57° -112.38° -53.89°], and the elevation angle in degree are [-43.7° -87.99° -16.27° -15.79° -82.23° 81.91° -18.42° 5.34°], respectively. The simulation is conducted for a single data stream and multiple data streams. The number of independent multiple data streams for each user for four user cases is chosen as [3 2 1 2] and for the eight-user case is [2 3 2 1 3 1 2 2]. The number of antennas at the user side is also investigated by adjusting it to be a multiple k of a number of streams where k is chosen as 2, 4, 6, and 8.

III. RESULTS AND DISCUSSIONS

Results of the model are obtained of the root means square Error vector magnitude (EVM) values for both 16-QAM and 64-QAM modulation schemes for multi-user massive MIMO systems considering four and eight users with 64 and 128 BS antennas. Figures 2 and 3 are given for a single data stream, and the results show that the EVM of 64 BS antennas is greater than that of 128 BS antennas. The modulation scheme affects EVM and it is found that 64-QAM has slightly less EVM compared to the 16-QAM modulation scheme. For a multiple data stream, Figures 4 and 5 demonstrate the RMS EVM values for both 16-QAM and 64-QAM modulation schemes. Simulation is conducted assuming four and eight users with 64 and 128 BS antennas. The results show that for users with a single data stream for a certain number of BS antennas, the RMS EVM is reduced at higher modulation order. In addition, the increase in the number of BS antennas is found to improve the EVM. Compared to customers with more than one data stream, the EVM reduction rate for users with a single data stream is highly affected by the increase in the number of BS antennas.

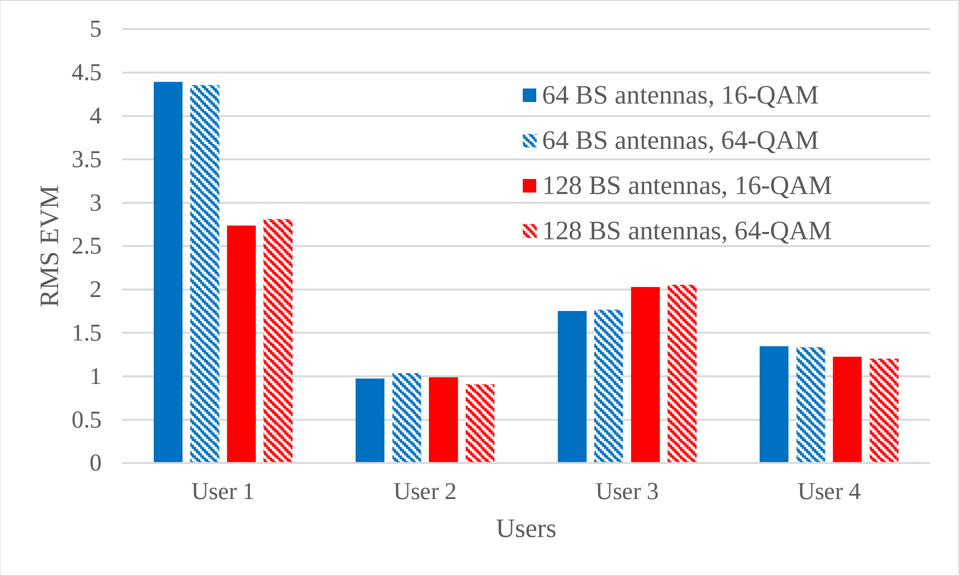


Fig. 2: RMS EVM values of single data stream using M-QAM schemes and multiple BS Antennas for four users when using four receiver antennas.

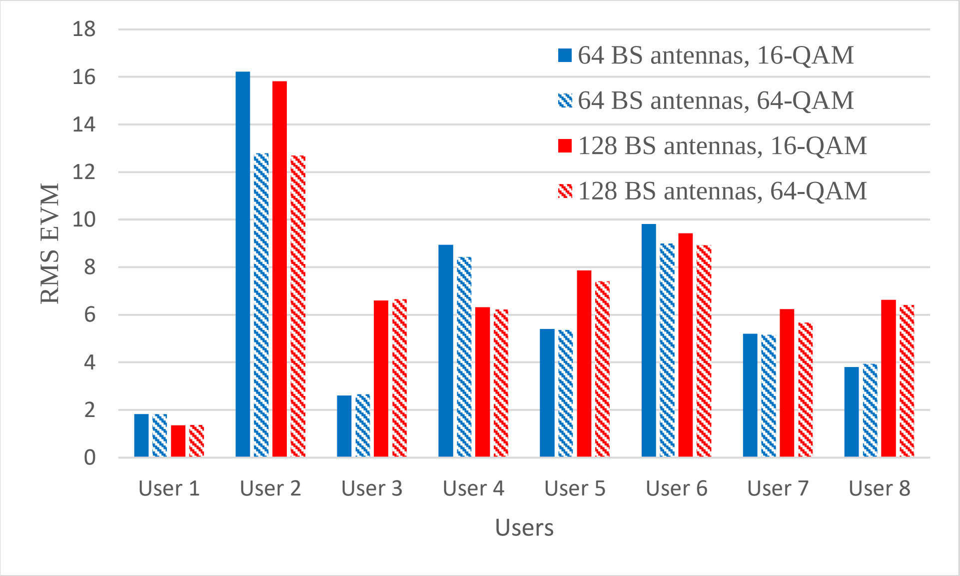


Fig. 3: RMS EVM values of single data stream using M-QAM schemes and multiple BS Antennas for eight users when using four receiver antennas.

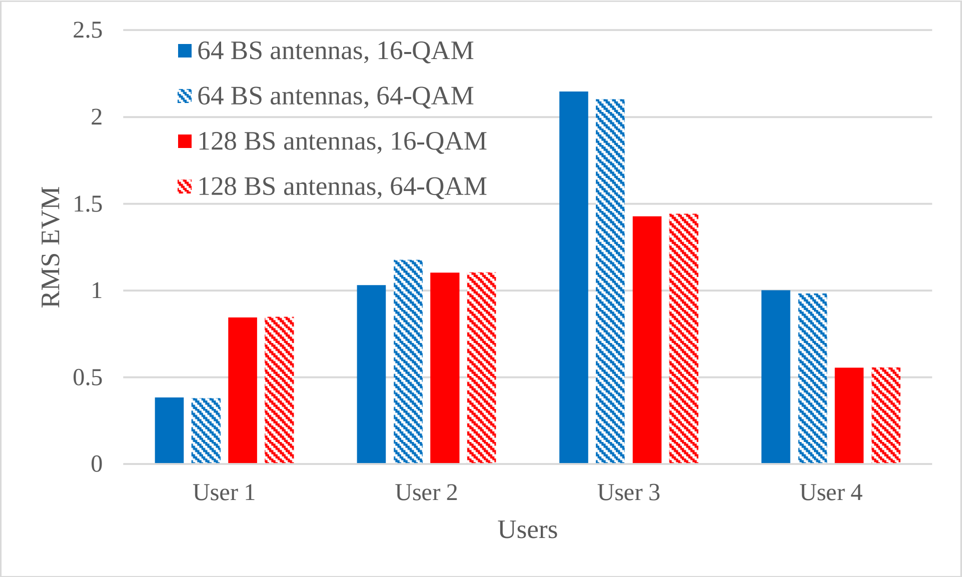


Fig. 4: RMS EVM values of multiple data streams using M-QAM schemes and multiple BS Antennas for four users when using four receiver antennas per stream.

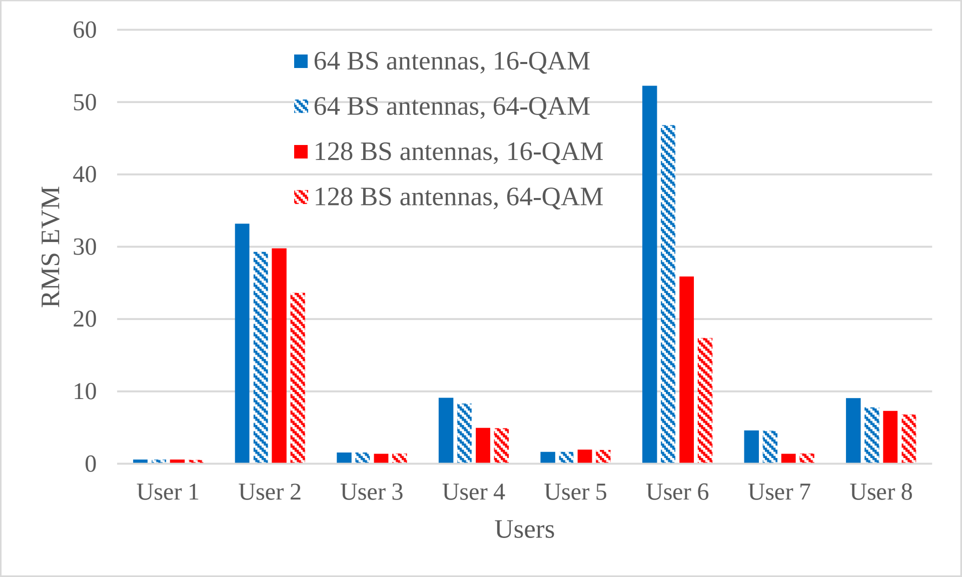


Fig. 5: RMS EVM values of multiple data streams using M-QAM schemes and multiple BS Antennas for eight users when using four receiver antennas per stream.

Figures 6 and 7 show the RMS EVM values of antennas per user for multiple *k* of a number of streams using 64-QAM schemes and 128 BS antennas for four and eight users, respectively. It is clear from the results that the EVM representation is improved by growing the number of user antennas. The EVM for 64 BS antennas is larger than that of 128 BS antennas with multiple data streams, whereas the EVM for the 16-QAM modulation scheme is greater than that of the 64-QAM modulation scheme. Also, the EVM performance depends on the user's location, azimuth angles, and elevation angles. The equalized symbol constellation per data stream with 128 BS antennas for four users in single data streams with16-QAM and multiple data streams with 64-QAM is shown in Figures 8 (a) and (b), respectively. Figures 9 (a) and (b) illustrate the symbol constellation after performing the equalization, with 128 BS antennas for eight users in single data streams with 16-QAM and multiple data streams with 64-QAM. For the same user, the variation of the recovered data streams is high for fewer independent transmitted data streams as depicted in the constellation diagrams.

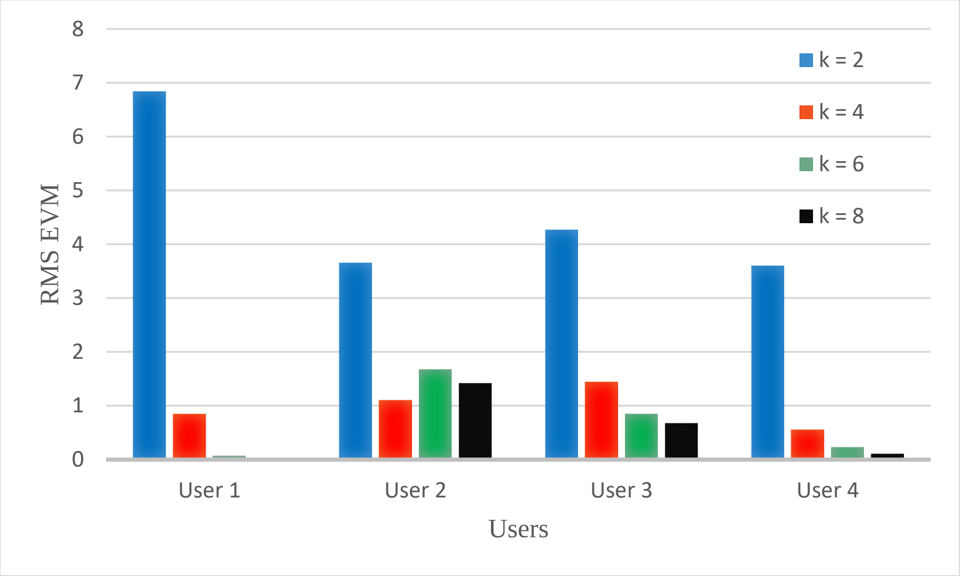


Fig. 6: RMS EVM values for four users consider the increase of the ratio k of the number of antennas and the number of streams of each user.

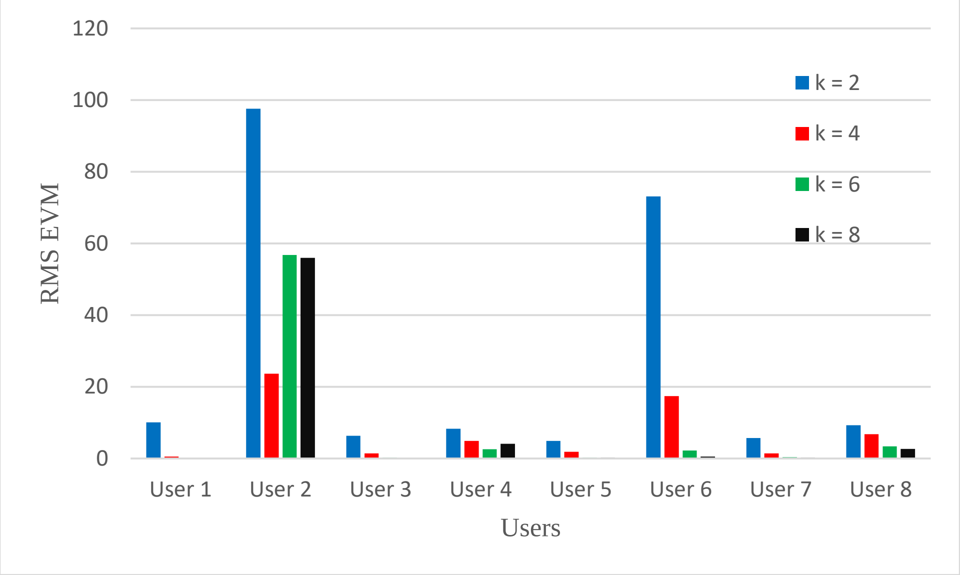
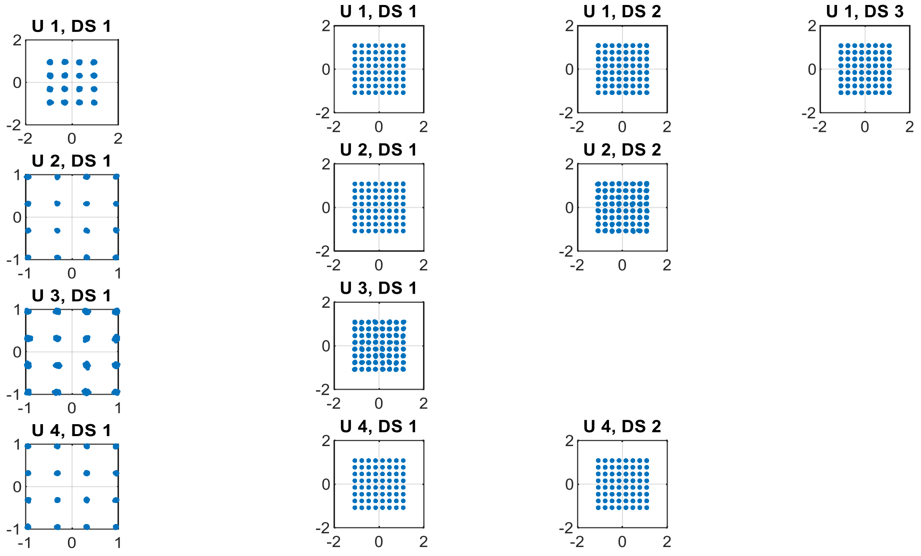
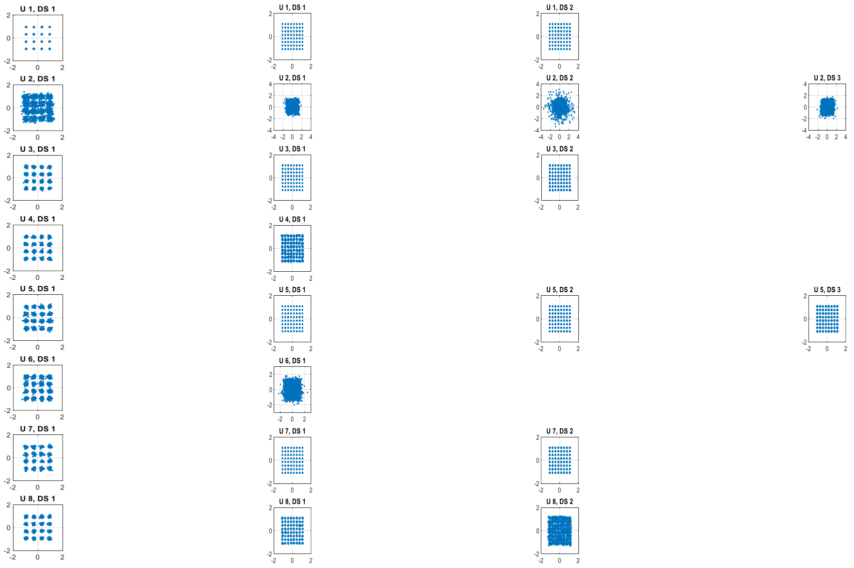


Fig. 7: RMS EVM values for eight users consider the increase of the ratio k of the number of antennas and the number of streams of each user.



(a) (b)

Fig. 8: 128 BS antennas with equalized symbol constellation per data stream for four users. (a) Single data streams for 16-QAM, (b) Multiple data streams for 64-QAM.



(a) (b)

Fig. 9: 128 BS antennas with equalized symbol constellation per data stream for eight users. (a) Single data streams for 16-QAM, (b) Multiple data streams for 64-QAM.

IV. CONCLUSIONS

Hybrid beamforming of mm-wave communication system for a multi-user massive MIMO systems is presented. Single, as well as multiple independent data streams per user, are considered. The outcomes indicate the potential of hybrid beamforming in decreasing the RF chains compared to digital beamforming and thus reducing the hardware cost. It is noted that the EVM performance is improved when the number of BS, as well as user antennas, are increased. RMS EVM values are found to be reduced as the number of antennas per stream is increased per user. Results also demonstrated the dependence of EVM on the modulation scheme and the user's location.

ACKNOWLEDGMENT

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