Investigation on NOMA based 60 GHz Radio-over-Fiber Fronthaul Links

Christina Lim
Dept of Electrical & Electronic Engineering, The University of Melbourne, VIC 3104, Australia
chrislim@unimelb.edu.au

Yijie Tao
Dept of Electrical & Electronic Engineering, The University of Melbourne, VIC 3104, Australia
yijie.tao@unimelb.edu.au

Ampalavanapillai Nirmalathas
Dept of Electrical & Electronic Engineering, The University of Melbourne, VIC 3104, Australia
nirmalat@unimelb.edu.au

Abstract— **Advanced coordination scheme such as Non-Orthogonal Multiple Access (NOMA) is able to improve the spectral efficiency and fairness amongst users in a multi-user environment. However, the inherent issue associated with NOMA successive interference cancellation tends to degrade the performance of the link. This paper presents our work on multi-level code (MLC) NOMA to overcome this limitation and further study the impact of different clustering on 60 GHz radio-over-fiber based fronthaul links.**

Keywords—radio-over-fiber, NOMA, fronthaul

I. Introduction

The projected growth of the next generation mobile traffic has foreseen an unprecedented growth in the current 4G optical fronthaul as a result of the native Common Public Radio Interface (CPRI) [1] which is expected to grow exponentially with the wireless channels and bandwidth [2]. This creates a scenario where the optical fronthaul becomes the key bottleneck of the next generation wireless system and a costly network segment [3]. This issue has been actively researched with many different solutions being introduced, ranging from data compression schemes to minimize the fronthaul bandwidth [4,5] to the use of functional splits [6]. One potentially simple approach is to use analog optical transport based on radio-over-fiber (RoF) technology in place of CPRI [7,8] which is able to overcome the inherent CPRI limitations while supporting centralized control architecture with minimal latency. The centralized control capability enables advanced coordination functionalities such as non-orthogonal multiple access (NOMA) to be implemented to further improve the performance of end users, in addition to facilitating network management.

We have previously demonstrated a NOMA scheme based on multi-level code (MLC) for 60 GHz RoF based fronthaul links that removed the propagation error which is inherent to superposition code (SPC) based NOMA [9]. We further extended the MLC NOMA investigation to study the impact of different cluster size on the overall performance in a multi-user environment [10]. This paper reviews the work we have carried out in the fronthaul link incorporating RoF technology with MLC NOMA scheme.

II. Multi-Level Code Non-Orthogonal Multiple Access (MLC NOMA)

Orthogonal multiple access is commonly used in the distribution of communication channels that relies on channel multiplexing in the time or frequency domain, which is dependent on the finite orthogonal resources. On the other hand, non-orthogonal multiple access (NOMA) multiplexes different channels linearly in the power domain. A typical centralized radio access architecture is shown in Fig. 1, where the baseband unit (BBU) pool is located in a centralized location while serving a large number of remote radio heads (RRHs) via optical fronthaul links. Here we implement NOMA via joint processing within the BBU pool to serve multiple users located at different locations within the same cell. NOMA will improve the performance of disadvantaged users with poorer signal-to-noise ratio, especially those located further away from the RRH or at the cell edge.

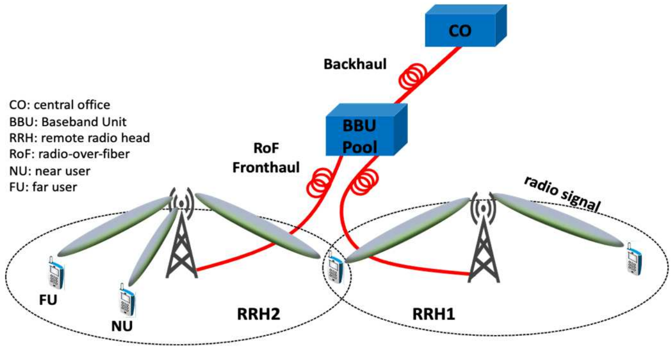

Figure 1 Schematic showing RoF based fronthaul network for next generation wireless systems

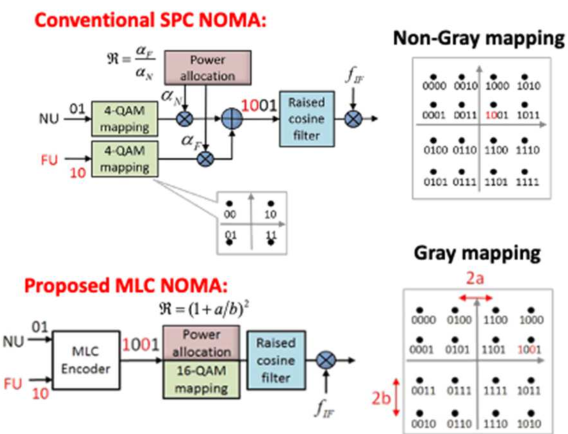

Figure 2 NOMA generation for 2-user cluster based on (a) SPC and (b) MLC

We have recently demonstrated a NOMA scheme based on multi-level code (MLC) for 60 GHz fronthaul for two-user cluster [9]. Shown in Fig. 2, is the NOMA signal generation for a two-user cluster based on SPC (Fig. 2a) and MLC (Fig. 2b). In this demonstration, the NOMA signal is generated for 2-user with 4QAM transmission. Fig. 2b shows our proposed MLC NOMA scheme where the bit streams from the near user (NU) and far user (FU) are first interleaved to generate the composite 16QAM symbol. In this configuration, the generated 16QAM symbol maintains Gray-code mapping. Here the power allocation ratio is determined by the distance between the symbols and is defined by $R = (1 + a/b)^2$, where 2a is the minimum distance between the two symbols in

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different quadrants while 2b is the minimum distance between two symbols in the same quadrant. However, for SPC NOMA (Fig. 2a), the composite 16QAM signal generated does not maintain Gray-code mapping. We have quantified the results experimentally and our results showed that the MLC NOMA scheme was able to eliminate the inherent propagation error phenomenon in NOMA incorporating SPC and had better performance compared to SPC NOMA [9].

III. Investigation on N-Cluster MLC NOMA

Our proof-of-concept experimental study on MLC NOMA was limited to only two-user cluster. The question remains whether cluster size plays a role to further improve the performance of MLC NOMA. This study will also provide an insight into the behavior of MLC NOMA and the potential of extending this towards dynamically reconfigurable cluster size to optimize the overall performance according to the channel conditions.

To systematically quantify the performance of the MLC NOMA scheme as a function of cluster size, we have carried out the study analytically [10]. The analytical model is built upon 2 bits per transmission symbol for each user. At the transmitter, the symbols from each user within the cluster are interleaved together to form a composite M-QAM symbol with Gray-code mapping with predefined power allocation ratios. The composite symbols are then broadcast to all users within the cluster. At the receiver, all the users will perform only one QAM demodulation to obtain the composite bit stream, from which they will extract their designated bits.

In this investigation, the power allocation scheme is crucial to ensure the users' performance is optimized. Here the power allocation per user within the cluster is chosen to maximize user fairness by equalizing all users' symbol error rate within the cluster. The model for the multi-user MLC NOMA under different user clusters was analytically developed with the following assumptions:

- The optical losses associated with opto-electronic conversions, optical components and fiber dispersion are assumed to be constant
- All the transmission channels between the RRH and the user are Additive White Gaussian Noise (AWGN) channels with zero mean and a variance of σ^2 which is a typical noise model in communication channel
- The 60 GHz wireless path loss is modelled by Friis' free space path loss model with no obstruction loss [11]
- Phase of transmitted signal can be perfectly recovered, and all receivers experience the same noise level

Assuming AWGN maximum-likelihood detector, the symbol error rate is determined by the distance between the symbols and the detection threshold. For this power allocation scheme, to ensure user fairness, the distance between the symbols is equalized taking into account the detection threshold and the user channel gain. Under the assumption of equal noise level at all receivers, the power allocation criterion translates to ensuring that the received symbol, after being scaled by the channel gain, must be an equal distance away from the detection threshold of interest to the respective receiver. This is further illustrated in Fig. 3 for a 2-user cluster, where the red arrowed line represents the distance from the symbol to the detection threshold of interest to User 1, who is closer to the RRH, and the black arrowed line, on the other hand, represents the distance of interest to User 2, who is further away. The power allocation scheme will assign power to the symbol, such that the distances marked by red and black arrowed lines will be of the same distance when seen at the respective users.

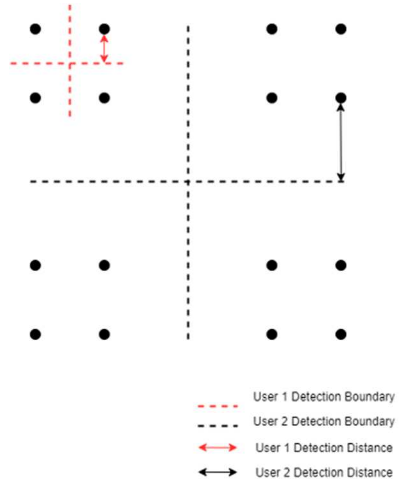

Figure 3 Schematic showing 2-user cluster MLC power allocation

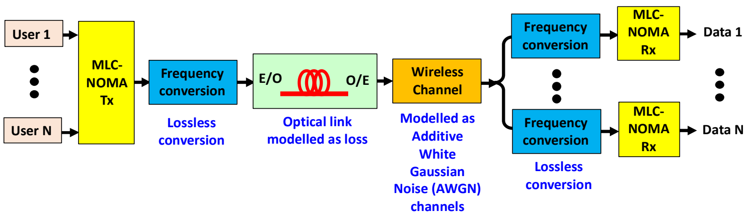

Figure 4 Simulation setup for n-user cluster investigation for MLC NOMA

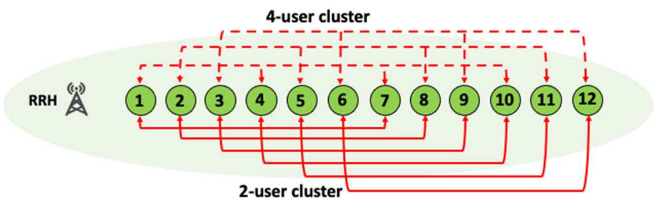

Figure 5 Clustering of 2 users and 4 users

Fig. 4 shows the schematic of the analytical model. In this investigation, 12 users are randomly generated and are uniformly distributed between 0.5m to 4.5m from the RRH within a cell size of 10 meters in diameter. To systematically quantify the performance, the users are named according to their distance relative to the RRH which is located at the center of the cell. Here user closest to the RRH is identified as User 1 and the user farthest away from the RRH is named as User 12. These users are then clustered into a group of 2, 3, 4 or 6 for the performance study. The clustering of n users is based on the position of the user in accordance to $12/n - 1$, where users $12/n - 1$ positions away will be clustered into one group. To illustrate how the clustering works, Fig. 5 graphically shows an example of 2-user and 4-user grouping. In this 2-user example, the far user within the cluster is located 5 (12/2 -1) position away from the near user. Therefore, we have user 1 and 7, 2 and 8, 3 and 9, 4 and 10, 5 and 11, and 6 and 12 are grouped into groups of 2 within the cell. Likewise, the same procedure is applied for 4-user clusters where user 1, 4, 7, and 10 are grouped together while user 2, 5, 8, 11 and user 3, 6, 9, 12 will be grouped as the other 4-user clusters. Such clustering scheme is chosen to ensure that users within the same cluster are located considerable distance apart to minimize overcrowding issue that may introduce undesirable performance variations amongst the clusters.

As illustrated in Fig. 4, the user data are first processed to generate MLC NOMA signal via bit interleaving and constellation mapping. The generated MLC constellation map incorporates the optimized power allocation criterion that maximizes user fairness. The channel gain information in this case is considered known in real-time and is converted from the user distance via Friis' free space path loss model. The generated M-QAM signal is then transported over the AWGN channel. At the receiver, the signal is demodulated, and the relevant bits are extracted for each user. The bit-error-rate (BER) is calculated based on the received data when compared to the sent bits.

IV. Results and Discussions

The simulations were carried out for 60 GHz fronthaul links and the results were obtained for both MLC and SPC-based NOMA for different user clusters. The simulation was carried out over 122 runs with 1e8 samples generated per run. For each simulation, the 12 users' locations are uniformly redistributed over the cell. The BER results are averaged over 122 runs and presented in Figs. 6a-6d, as a function of user locations where User 1 is the closest to the RRH and User 12 is the furthest, for the different cluster size.

The results show that MLC scheme achieves better performance overall for all user clusters. Comparing the results with SPC scheme, we can see that the performance degradation of the near users is particularly obvious in comparison to the far user, i.e. User 2 compared to User 8 in 2-user cluster and User 1 compared to User 9 in 3-user cluster. Here User 8 and User 9 are the far users within the 2- and 3-user cluster configuration. This is due to the error propagation from the far user to the near user which is inherent to SPC based NOMA. The periodical nature of the curves observed for MLC is due to the clustering algorithm. As a result, users within the same cluster achieve very similar performance. Hence, the users within the cluster closest to the RRH will have better performance compared to the users located in the cluster further away from the RRH. This is mainly due to the lower received power for users in the further cluster. For instance, from Fig. 6a, User 1 and User 7 are located in the same cluster which is the closest to the RRH and have the best BER performance compared to User 6 and User 12 who are in a cluster furthest away from the RRH. For both SPC and MLC, we see that the more users within the cluster, the worse the BER performance. The performance for 6-user cluster in this investigation are so badly degraded for both SPC and MLC as such that the information cannot be recovered. Based on this study, we can see that fewer users in a cluster are preferred for MLC based NOMA to ensure the good performance for all users within the cluster.

V. Conclusions

We have reviewed the work we have done in MLC-based NOMA for 60 GHz RoF-based fronthaul applications. We have shown that MLC-NOMA is able to overcome the error propagation issue inherent to SPC-NOMA. We have also extended the investigation to increase more users within the cluster to quantify the upper bound. Our analytical results indicate that larger cluster size is more prone to noise and rapidly degrades the performance of the users within the same cluster. Hence, to maintain error-free reception for all users, smaller user cluster is preferred with 2-user and 3-user clusters showing good performance over the cases investigated.

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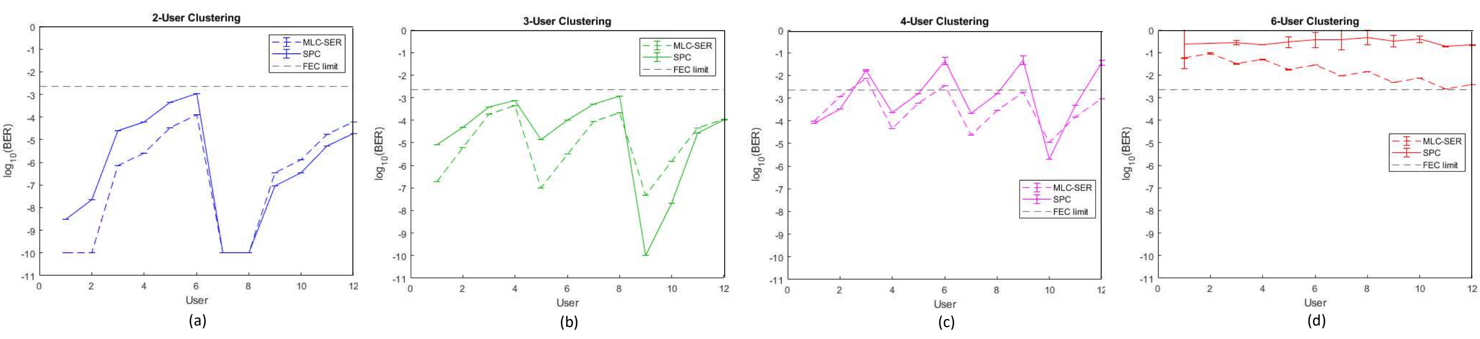

Figure 6 Calculated BER per user for (a) 2-user clusters (b) 3-user clusters (c) 4-user clusters and (d) 6-user clusters
The forward error correction (FEC) limit with 7% overhead is used to mark the recoverable error rate limit.