Abstract—The multiple input multiple output (MIMO) technology and the distributed antenna system (DAS) have emerged as the promising candidates for the future mobile communications. In this paper, we observe the downlink (DL) transmission in a single-cell multi-user MIMO (MU-MIMO) system based on the distributed antennas for 3GPP Long Term Evolution-Advanced (LTE-A). It is found that the existing methods presented in 3GPP LTE discussion may deteriorate system throughput sharply due to the inaccurate channel information feedback from user equipment (UE). We propose a novel strategy including several methods for the MU-MIMO DL transmission in DAS. First, a UE-specific channel vector quantization method is proposed to enable the BS to acquire more accurate channel direction information (CDI). In addition, we develop a new method for the channel quality information (CQI) computation at the side of UE. The extensive simulation performed in the various scenarios discloses that the proposed strategy achieves the performance gain in terms of system throughput by 600% at most and 20% at least.

I. INTRODUCTION

The Third Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-A) standardization efforts aim at developing future cellular technologies to improve spectral efficiency and coverage with the reduced costs [1]. The multiple input multiple output (MIMO) antennas system is chosen for the LTE downlink (DL) radio transmission due to its nature of spatial division multiplexing [2] which brings the significant spectral efficiency improvement. In particular, the multi-user MIMO (MU-MIMO) system that serves multiple users on the same subcarrier simultaneously offers the possibility of achieving higher spectral efficiency [3]. There are two different ways to construct the MIMO system. One is the co-located antenna system (CAS) that sets all the transmit antennas together at the same location. The other is known as distributed antenna system (DAS) where many remote antenna ports are distributed over a large area and connected to a central processor by fiber, coax cable, or microwave link [4]. Recent work has disclosed that the DAS achieves higher system capacity than CAS as well as the larger coverage [5] [6].

There is wide agreement that the MU-MIMO allows for better exploitation of multi-user diversity because the spatial domain offers one additional degree of freedom in the scheduling process. However, the main challenge in MU-MIMO is that not all receive antennas can cooperate and, therefore, the transmitter has to take care of the inter-user interference by several means including the design of the precoders for spatial user separation as well as the scheduling for exploitation of multiuser diversity.

Currently, several versions of linear precoding have been discussed for 3GPP LTE-A standardization in frequency division duplex (FDD) mode. There are basically two kinds of precoding schemes taken into consideration: channel vector quantization (CVQ) [7] and per user unitary and rate control (PU²RC) [8]. In CVQ, the feedback from user equipment (UE) indicates a codebook entry known as the channel direction information (CDI), where the codebook contains quantized versions of the channel vector estimated by the UE. At the base station (BS), the zero-forcing precoders are calculated with the precoding schemes, two scheduling schemes are presented accordingly to select the UEs for DL transmission. The one corresponding to PU²RC precoding is to group UEs that report orthogonal precoding vectors and select the group providing the highest total throughput. Another greedy strategy appropriate for CVQ precoding [9], consists of adding one UE at a time, as long as the additional UE increases the overall throughput. Since CVQ scheme generally is preferable over PU²RC scheme [7], our work just focuses on the CVQ scheme.

On the other hand, while the non-codebook precoding such as the spatial correlation feedback (SCF) based method [10] can be used for FDD based DL MU-MIMO transmission, it highly relies on the correlation between the antennas of BS. On the contrary, codebook approaches have loose restriction on the correlation of BS’s antennas. Normally, the antennas of BS in DAS can be assumed to be uncorrelated, while the MU-MIMO system built by CAS is assumed to have the correlation over the antennas equipped at the BS.

The organization of this paper is as follows. In Section II, the details of the typical MU-MIMO DL transmission strategy for 3GPP LTE-A and the problems of the CVQ method in DAS are presented. Section III describes the proposed DL transmission strategy for MU-MIMO system built by DAS. Section IV provides simulation results and discussion. Finally, the conclusions are given in Section V.

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II. MU-MIMO DOWNLINK TRANSMISSION IN DAS OF 3GPP LTE-A

In this section, we first give the brief description about the DAS in 3GPP LTE-A and CVQ method. Then, the problems of CVQ method in the DAS of 3GPP LTE-A are clarified.

A. DAS in 3GPP LTE-A

As illustrated in figure 1, DAS in 3GPP LTE-A [11] is the system where the BS is equipped with an extremely powerful base band unit (BBU) that is connected with several remote radio units (RRUs) over high-speed optical fibers. The base band processing as well as radio resource and network management functionalities are included in the BBU, while RRU usually equipped with multiple antennas is responsible for the conversion between radio frequency (RF) and digital intermediate frequency (IF) signals.

B. CVQ Method for MU-MIMO system in 3GPP LTE-A

In CVQ discussed in 3GPP LTE-A, each UE selects a quantization vector, \( \hat{h}_k \), from a codebook of unit-norm row vectors of size \( N = 2^B \), which is expressed as

\[
C = \{ e_1, \ldots, e_N \}
\]

\( \hat{h}_k \) is identified as the CDI of UE \( k \) and determined according to the minimum Euclidean distance criterion, such that

\[
\hat{h}_k = e_n, \quad n = \arg \max_{i=1, \ldots, N} |h_k e_i^H|
\]

The codebook \( C \) is previously known to all the UEs and the BS. It is usually defined as the Discrete Fourier Transformation (DFT) matrix where the quantization vectors are obtained by truncating the top rows of the DFT matrix of size \( N \). Each UE estimates its actual channel \( h_k \) and feeds back the index \( n \) to the BS with \( B \) bits.

The UE should additionally report the estimated channel quality information (CQI) to BS expressed as

\[
\text{CQI}_k = \frac{\frac{P}{M_t} |h_k \hat{h}_k^H|^2}{1 + \frac{P}{M_t} (|h_k|^2 - |h_k \hat{h}_k^H|^2)}
\]

where \( M_t \) is the number of BS’s antennas, \( P \) is the transmission power of BS, \( P = P/N_0 \) and \( N_0 \) is the noise power.

At the BS, the precoding matrix is given by

\[
\mathbf{G}(S) = \hat{\mathbf{H}}(S)^H \left( \hat{\mathbf{H}}(S)\hat{\mathbf{H}}(S)^H \right)^{-1} \text{diag}(p)^{1/2}
\]

where \( S = \{ s_1, \ldots, s_{|S|} \} \) is the set of selected UEs, \( \hat{\mathbf{H}}(S) = [\hat{h}_k^T, \ldots, \hat{h}_s^T]^T \) represents the concatenated quantized channel vectors of the selected users and \( p = [p_{s_1}, \ldots, p_{s_{|S|}}]^T \) is the vector of power normalization coefficients that impose the power constraint on the transmitted signal. As the total power \( P \) is assumed to be allocated equally to each transmit antenna, we have

\[
p_k = \frac{P}{|S|} \frac{1}{||f_k||^2}
\]

where \( f_k \) denotes the \( k \)-th column of \( \mathbf{F}(S) = \hat{\mathbf{H}}(S)^H \left( \hat{\mathbf{H}}(S)\hat{\mathbf{H}}(S)^H \right)^{-1} \).

Denote with \( R(S) \) the achievable sum-rate of UE set \( S \). Then, it can be computed as

\[
R(S) = \sum_{k \in S} \log_2(1 + \gamma_k),
\]

where \( \gamma_k \) is the SINR of user \( k \) and given by

\[
\gamma_k = \frac{p_k}{P/M_t} \text{CQI}_k
\]

The scheduling algorithm used by CVQ method can be described as following

**Algorithm 1 User Scheduling**

1. Initialize \( S = \emptyset \) and \( R(S) = 0 \)
2. while \( |S| \leq M_t \) do
   1. \( k^* = \arg \max_{k \notin S} R(S \cup \{k\}) \)
   2. if \( R(S \cup \{k^*\}) > R(S) \) then
      1. \( S = S \cup \{k^*\} \)
   3. else
      1. break
   end if
3. end while

C. Problems of CVQ in DAS based MU-MIMO

Although the RRU+BBU architecture is helpful to increase the system capacity and coverage, the current precoding schemes and scheduling methods, especially the CVQ method, may select the excessive users with the significant inter-user interference as they are used in the RRU+BBU architecture. Since the RRUUs are dispersedly located around the UE and may have totally different propagation path to the UE, it is possible that the UE detects the signal strength of these RRUUs as 0, namely the received signal has the strength below the sensitivity of the UE’s receiver due to the deep attenuation. Thus, the actual channel vector estimated by the UE should have several elements of 0, and then the actual channel matrix experienced by the transmitted signal is

\[
\mathbf{H} = \{ \hat{\mathbf{H}}_{K \times L}, 0_{K \times Q} \}
\]

where \( \hat{\mathbf{H}}_{K \times L} \) is the channel gain elements larger than 0, \( 0_{K \times Q} \) is the blocks with the elements of 0, \( K \) is the number

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of selected users and the number of RRUs is \( L + Q = M_t \). It is obvious that \( L + Q \) should be no less than \( K \) to ensure the null-interference transmission. However, the BS assumes wrongly that the signal from all the transmit antennas can be received by the UEs because the quantization vectors reported by the UEs have no the element of 0. Then it is possible that the BS may select more than \( L + Q \) users and generate the wrong precoding matrix, which inevitably leads to significant inter-user interference.

On the other hand, from the perspective of channel quantization, there is always significant quantization error in UEs’ feedback as the signal from some of the RRUs cannot be detected by UEs. The elements of 0 in the actual channel vectors generally caused by the large-scale fading such as deep shadow fading and large path loss may exist in a long duration. Thus, the quantization error between the actual channel vectors and the feedback vectors may always exist as well. Since the quantization error degrades the system throughput greatly [12], the traditional CVQ method is not sufficient to achieve the high throughput in the RRU+BBU architecture.

III. PROPOSAL OF MU-MIMO DOWNLINK TRANSMISSION STRATEGY IN DAS FOR 3GPP LTE-A

Motivated by the above problems, we propose a downlink transmit strategy in the architecture of RRU+BBU. Briefly, our proposal is similar to the traditional CVQ method except two points: (1) the BS constructs the UE-specific channel vector, (2) the UE takes the new method to compute its CQI.

A. UE Specific Channel Vector Construction

Unlike the traditional CVQ method, we present a new method to have the BS get the more accurate channel information for UE scheduling. In 3GPP LTE-A FDD system, the sounding reference signal (SRS) is sent from UE to BS for information for UE scheduling. In 3GPP LTE-A FDD system, the method to have the BS get the more accurate channel information for UE scheduling is feasible to use the SRS over uplink to estimate whether the reciprocity between uplink and downlink in FDD system, it is convenient to implement our solution in the 3GPP LTE-A system.

B. New Method for CQI Computation

Considering that link budget ensures the same signal visibility both over the uplink and downlink, channel visibility vector \( V_k \) is also available to UE \( k \). Thus, the UE specific channel vector \( \hat{h}_k \) can be used for CQI calculation, which is expressed as

\[
CQI_{k}^{\text{new}} = \frac{\left| \mathbf{R}_k \cdot \hat{\mathbf{h}}_k^H \right|^2}{N_0 + \left| \mathbf{R}_k \right|^2 - \left| \mathbf{R}_k \cdot \hat{\mathbf{h}}_k^H \right|^2} \tag{13}
\]

where \( \mathbf{R}_k = \sqrt{P_t/M_t} \mathbf{h}_k \) represents the vector of BS’s reference signal sensed by UE \( k \) when the transmission power of each RRU is \( P_t \).

Considering the definition of \( \hat{h}_k \), we have

\[
\left| \mathbf{h}_k \cdot \hat{\mathbf{h}}_k^H \right| \approx \sqrt{\frac{1}{2} \cdot \frac{M_t}{T_k} \left| \mathbf{h}_k \cdot \hat{\mathbf{h}}_k^H \right|} \tag{14}
\]

Then, the CQI of UE \( k \) can be given as

\[
CQI_{k}^{\text{new}} = \frac{\left| \frac{l^2}{T_k} \mathbf{h}_k \hat{\mathbf{h}}_k^H \right|^2}{1 + \frac{l - T_k}{T_k} \left( \frac{P_t}{M_t} \right) \left| \mathbf{h}_k \cdot \hat{\mathbf{h}}_k^H \right|} \tag{15}
\]

where \( \hat{P} = \frac{P_t}{N_0} \). It is observed that our method can calculate the CQI of UE \( k \) in two ways: one is to calculate CQI with the received BS’s reference signal, the other is to deduce CQI with the knowledge of \( P_t \) and \( l \) together with the channel estimation results \( \hat{h}_k \). Since it is difficult for the UE to figure out the number of RRUs in the realistic DAS environment, the method in (13) is more suitable for CQI computation in the practical system because UE can calculate CQI by simply resorting to the received BS’s reference signal.

On the other hand, (14) discloses that the DFT-based codebooks can still be used by UE to compute the CDI due to the fact that \( \arg \max_{i=1,\ldots,N} \left| \mathbf{h}_k \hat{\mathbf{h}}_k^H \right| = \arg \max_{i=1,\ldots,N} \sqrt{\frac{1}{2} \cdot \frac{M_t}{T_k} \left| \mathbf{h}_k \hat{\mathbf{h}}_k^H \right|} \).

IV. SIMULATION AND DISCUSSION

A. Simulation Setup

The system throughput is investigated by the simulation in the system model shown in figure 2, where the BBU connects two RRUs that cover three areas named as A, B and C.
Fig. 2. System Model for Simulation

TABLE I
SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of antennas per RRU</td>
<td>2, 4</td>
</tr>
<tr>
<td>Number of antennas per UE</td>
<td>1</td>
</tr>
<tr>
<td>Shadowing model</td>
<td>log-normal random variable,</td>
</tr>
<tr>
<td>standard deviation = 8.0 dB</td>
<td></td>
</tr>
<tr>
<td>Fading model</td>
<td>Flat Rayleigh fading</td>
</tr>
<tr>
<td>Distance dependent path loss</td>
<td>$126.3 + 38 \times \log_{10}(d)$ dB</td>
</tr>
<tr>
<td>Penetration loss</td>
<td>40dB</td>
</tr>
<tr>
<td>Radio Receiver Sensitivity</td>
<td>-110dBm</td>
</tr>
<tr>
<td>Transmit Power per RRU</td>
<td>20dBm</td>
</tr>
<tr>
<td>Noise Power</td>
<td>-104dBm</td>
</tr>
<tr>
<td>Bits for feedback</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RRU1 to UEs in A</td>
<td>5m</td>
</tr>
<tr>
<td>RRU1 to UEs in B</td>
<td>100m</td>
</tr>
<tr>
<td>RRU1 to UEs in C</td>
<td>200m</td>
</tr>
<tr>
<td>RRU2 to UEs in A</td>
<td>200m</td>
</tr>
<tr>
<td>RRU2 to UEs in B</td>
<td>100m</td>
</tr>
<tr>
<td>RRU2 to UEs in C</td>
<td>5m</td>
</tr>
</tbody>
</table>

To simplify the simulation, we assume that the UEs in the same area have the identical distance to the given RRU. For instance, the distance between all the UEs in A and RRU2 is considered to be a constant. In addition, there is no penetration loss and shadowing fading between the RRU and the UEs in its own coverage. The simulation parameters and the scenarios are listed in table I and table II, respectively.

B. Simulation Results Evaluations

We first measure the system throughput of our proposal and traditional CVQ method in scenario I with varying the number of active users in the cell. As shown in figure 3, our method offers considerable gains of 100% − 400% over the CVQ method as the amount of antennas per RRU ($M_e$) is 2. As $M_e$ is set as 4, the achievable throughput improvement is in the order of 50% − 100%. We also observe that there is no obvious augment in the throughput of CVQ method even if the number of users is relatively large. It can be explained that the multi-user diversity gain is counteracted by the throughput degradation due to the quantization error coming from the CVQ method.

Specifically, since all the UEs in scenario I are unable to detect the signal from RRU2, the actual channel vectors of the UEs in the cell are actually distributed in some certain directions. However, the DFT codebook utilized by CVQ method merely indicates the channel vectors of the UEs uniformly distributed in the hypersphere space. Thus, the quantization error between the CDI feedback and actual channel vector cannot decrease greatly as the users’ number increases. Hence, there is no obvious rising of throughput in CVQ method with lots of users.

Figure 4 presents the system throughput achieved in scenario II. It is observed that our proposal achieves higher throughput as compared with scenario I, whereas the throughput of CVQ method is close to that in scenario I. Then, our method obviously outperforms the CVQ method with higher gain. Therefore, the improvement on quantization error in CDI feedback can give rise to more significant enhancement on system throughput, which is at most 300% and 600% in the case of $M_e = 2$ and $M_e = 4$, respectively. The obvious throughput improvement comes from the less CDI feedback error yielded by our solution.

Figure 5 illustrates the comparison between the proposal and CVQ in terms of system throughput in scenario III. The performance gain of our proposal is generally obvious as more users appear in the cell. However, in the case of moderate number of users (i.e. about 20 users), the performance gain reduces to approximately 20%. Since the UEs in area B still use CVQ method to report CDI with larger error, the increasing number of UEs in B may cause more throughput degradation. On the other hand, more UEs in area A and C can bring the rising throughput. Thus, the system throughput in scenario III actually operates in the counteractive fashion. Considering the UEs are equally located in the three areas, it is reasonable to see the throughput improvement with the moderate number of UEs is not as obvious as those with the large and small number of UEs.

The throughput of our proposal and CVQ method with the

respectively.

TABLE II
SIMULATION SCENARIOS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>UEs are located in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario I</td>
<td>A</td>
</tr>
<tr>
<td>Scenario II</td>
<td>A and C</td>
</tr>
<tr>
<td>Scenario III</td>
<td>A, B and C</td>
</tr>
<tr>
<td>Scenario IV</td>
<td>A and B</td>
</tr>
</tbody>
</table>
Fig. 4. System Throughput in Scenario II

Fig. 5. System Throughput in Scenario III

It can be explained that the BS is able to acquire the more accurate channel information including CDI and CQI about UEs covered by the single RRU than those in the coverage of multiple RRUs. On the other hand, the simulation results in all the considered scenarios disclose that our proposal always outperforms CVQ method currently presented by 3GPP LTE-A in terms of system throughput. Therefore, it is believed that the proposed strategy is helpful to increase the throughput of MU-MIMO system based on the distributed antennas architecture defined by 3GPP LTE-A.

V. CONCLUSION

In this paper, we propose a MU-MIMO DL transmission strategy in the DAS for 3GPP LTE-A. The UE-specific channel vector quantization scheme is presented to enable the BS to acquire more accurate CDI from UE without any more overhead, while the UE can use the new method to calculate correct CQI and report it to BS. The simulation is performed in the scenarios with different UE distribution. It is shown that the system throughput improvement is significant as the UEs are in the coverage of single RRU. The gain, however, may reduce as UEs are in the overlap coverage of multiple RRUs.

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