Performance Analysis of Distributed and Centralized Scheduling in Two-hop Relaying Cellular System

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Abstract — We consider the resource allocation of centralized and distributed scheduling in the two-hop relaying cellular system. The limited spectrum resource is one of the obstacles which conflicts with the evolution of being wider coverage and larger capacity in the wireless system. In this paper, system performance and signaling overhead are analyzed and compared. Then we propose a novel routing strategy for choosing the access link and three practical scheduling strategies. Simulation results are provided and analyzed in several scenarios, which show the benefit of adopting the relay technique.

Keywords - distributed scheduling; centralized scheduling; two-hop cellular system; relaying system; routing metric

I. INTRODUCTION

To achieve wider coverage and larger capacity have been leading the main direction of evolutions in the wireless mobile communication network from the beginning. Meanwhile many obstacles such as limited spectrum resource and using higher frequency which implies much more transmission loss lie in this progress. From the viewpoint of environmentalism, radiation power of base station (BS) and user terminal should be strictly restricted in order to relieve the electromagnetic wave pollution. Moreover, the higher transmission data rate leads to lower energy per bit. In a word, the fact seems to go to the opposite way from the development of wireless network. Indeed, new physical layer transmission techniques emerged recently such as multiple-input multiple-output (MIMO) and new coding techniques compensate these defects. However, they are not concerned in this work.

Relaying technique brings us a new practical and effective approach to achieve this goal. By placing one or more fixed relay station(s) (RS) in the coverage area of the original BS, a special cell splitting technique is equivalently carried out. Compared to adding new BSs, adding a RS can not bring additional available resource but occupy some resources controlled by the BS formerly. Unlike the equal relationship between the BSs, a RS is subordinate to a specific BS (we call it the home BS) like a user equipment (UE). Moreover, a relay link needs to be established between the RS and its home BS to transmit data and signal information frequently.

This work was supported by Research Institute of China Mobile Communications Corporation.

The strategy of Radio resource allocation in mobile communication system is a hot topic in the academic research field. Resource allocation strategy relates closely with the architecture of network so that whenever there is a great change in the network framework or physical technique in the low layer, it should always be modified or even redesigned. On the other hand, what kind of resource allocation strategy can be used should be taken into consideration when a new system framework or low layer technology is adopted or designed.

In the relay-assist system, each UE can access to a BS or RS actively or passively. Suppose a UE chooses the BS as access node, then it is scheduled by the BS and it can be called as a UE in BS domain. Otherwise, the UE that access to a RS is called the UE in RS domain and can be scheduled either by BS or by RS. Generally, the scheduling mode in relay-assist system can be classified into two types that one is centralized scheduling and the other is distributed scheduling. In the centralized scheduling mode, the BS takes charge of scheduling all the UEs in the cell (including the UEs in BS domain and RS domain), and the RS is just a relaying node between the BS and UEs. While in the distributed scheduling mode, after allocated a part of the radio resources by the BS, the RS can schedule the UEs in RS domain on these resources, and the BS only schedules the UEs in BS domain.

In distributed scheduling mode, if the resources controlled by RS are allocated by BS, it is called “semi-distributed”. Because that the RS is still not independent on BS in resource allocation. In contrast, it is “full-distributed” when RS can freely reuse all the resources with BS. But intra-cell interference is also produced in the mean time.

Benefiting from the awareness of all the channel information and the capability of controlling all the radio resources in the cell, centralized scheduling can reach the optimal system efficiency theoretically. However, large interactive information between BS and RS may be required, including service request, resource allocation, channel quality information feedback, and HARQ information, etc., which increases the computational burden and complexity in BS.

In contrast, distributed scheduling (also called hierarchical scheduling as in [2]) will save much signaling overhead and
overcome the defects mentioned above. Meanwhile, as a result of being able to schedule, RS can be seen as an equivalent BS to some extent and the delay in the user plane will be reduced. Also, with RS sharing some part of scheduling task, computation burden in BS is cut down. The performance in the semi-distributed scheduling mode may not as well as it in centralized scheduling mode due to the fact that both BS and RS can only control part of the resources instead of the whole resources. So semi-distributed scheduling may not lead to global optimal resource allocation. But in full-distributed scheduling, the resource utilization efficiency would improve much because of the resource reutilization.

References [2], [3], [4] research distributed or centralized scheduling separately. As far as we know, there are few literatures aiming at resource allocation strategy design of both the scheduling modes and performance analysis both in engineering community and research field. However, they are important issues in relaying system design and this work mainly considers the scheduling mode and the corresponding analysis.

The rest of this paper is organized as follows. In Section II, the system model is briefly introduced. Some analysis related to two scheduling modes are made and a routing metric is proposed in Section III. In Section IV, we give the detailed description of our resource allocation strategy. And the simulation model, results and analysis are presented in Section V. Finally, Section VI concludes this paper.

II. SYSTEM MODEL

One of the greatest changes in the 4th mobile communication system is the adoption of multi-hop technique. Considering of the smoothness of evolution, two-hop non-cooperative fixed relay is introduced at the beginning. To be specific, one or more RS(s), which is (are) placed properly in the coverage area, cooperate(s) with the BS to serve all of the UEs in the cell. In this work, we adopt 3GPP LTE-Advanced [5] system as our system mode and, to simplify the situation, a single RS is placed in each cell.

Each UE is routed to access a BS or a RS by some routing protocol. Then, in the distributed scheduling mode, the BS assigns some resources to the RS according to estimation of loads in both BS domain and RS domain.

Therefore, three types of links are formed (see Fig. 1): links between the BS and the UEs in BS domain are called BS access links (or direct links); links between the RS and the UEs in RS domain are called RS access links (or second-hop links); links between the BS and the RS are called relay link (or first-hop links). These three links occupy the whole radio resources in the cell. And it can use frequency division, time division or the combination of frequency and time division to allocate the radio resources among the three links. Theoretically, none of the division method is superior to the others, since their spectrum efficiency or time utilizing rates is almost the same if they are applied appropriately. However, frame structure should be redesigned when time division is adopted as it requires allocating slot resources to the three links, which may impact greatly on the current system. Hence, frequency division is preferred for resources allocation among links. In addition, resources can be overlapped in time domain but orthogonal in frequency domain.

Some literatures used out-of-band allocation method [2] [7], where relay links only use a dedicated band permanently or reuse part of the band of the neighbor cells (inter-cell interference coordination). The advantage of out-of-band allocation is that coordination of resource allocation among three types of links is simplified to two types of links. But it will cause much trouble in re-planning frequency coordination since it’s hard to assign an accurate band to relay link before scheduling the RS access link, because it will waste resources if assigning too much, or limit the scheduling of RS access link if assigning not enough. The strategies we proposed are based on in-band allocation, which means that three types of links share the band adaptively.

Parameters such as the transmission power of the BS and the RS, the position of the RS, antenna pattern are associated with the performance of multi-hop cellular system. And we note them as sensitive parameters.

It should be noted that the relay link is scheduled by the BS in both centralized and distributed scheduling modes. When using relay for transmission, data are transmitted from BS to RS in the first TTI, then the RS demodulates and decodes the received data and passes them to the intended UE in the second TTI. The length of delay involved in the RS depends on the processing ability of RS. And we assume it is almost the same if they are applied appropriately. However, frame structure should be redesigned when time division is adopted as it requires allocating slot resources to the three links, which may impact greatly on the current system. Hence, frequency division is preferred for resources allocation among links. In addition, resources can be overlapped in time domain but orthogonal in frequency domain.

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III. ROUTING STRATEGY AND RELATED ANALYSIS

A. RUE Routing Strategy

Routing strategy describes how the UE chooses the path to connect with the system. Different routing strategies may apply to different metric. In this part, a new metric based on resource utilization efficiency (RUE) and the relative routing strategy is proposed.

The RUE is defined as the ratio of data quantity and the resource amount it is occupied in an access path, which includes all the hops links if the UE accesses to a RS.
Let $R_{BS}$, $R_{RS}$ and $R_{relay}$ denote the maximum data rates that the BS access link, RS access link and relay link can afford in a specific sub-carrier cluster in the current TTI (this space-time resource is also referred as a resource block, i.e. RB), respectively. Accordingly, $1/R_{BS}$ represents the frequency resources needed by one bit data in this link, so as to $1/R_{RS}$ and $1/R_{relay}$. The main idea is to choose a path with the highest RUE after comparing the BS with each RS. The rule for the RUE is expressed as following:

$$\frac{1}{R_{BS}} < \frac{1}{R_{RS}} + \frac{1}{R_{relay}}, \quad (1)$$

otherwise, UE accesses to the RS link..

This metric can assure that the total resources the relaying system needs is no more than those single-hop system needs so that relaying technology will definitely improve the system spectrum efficiency. In practice, it is hard to calculate the exact rate before the link selection and scheduling, hence $R_{BS}$, $R_{RS}$ and $R_{relay}$ can be estimated by average SINR or the geometry instead.

B. Signaling Interactive Information

The signaling interactive information between BS and UE in traditional signal-hop system includes ACK/NACK of the HARQ process, downlink CQI feedback in uplink channel and the resource allocation information transmitted through uplink and downlink channels. To ensure a smooth evolution, the user experiences in multi-hop system must be the same with that in signal-hop system. So the interaction between BS and UE in BS domain and that between RS and UE in RS domain is both the same with that in signal-hop system, and need not to redesign.

Relative to BS, a RS is equivalent to a UE. So what’s the same interactive information between BS and RS in two scheduling modes is that RS needs to report the information of relay link to BS, including the downlink CQI, ACK/NACK of the HARQ process and the resource allocation information. Besides, in the centralized scheduling mode, RS needs to report the aggregate information contained ACK/NACK of the HARQ process of every UE in RS domain, downlink CQI and resource allocation information. But in the semi-distributed scheduling mode, it only needs to interact with BS for the information of how much the resources are allocated to RS while full-distributed scheduling mode doesn’t need. Therefore, the signaling overhead for centralized scheduling is much larger than that for distributed scheduling.

IV. RESOURCE ALLOCATION STRATEGY

We divided the distributed scheduling mode into two sorts: semi-distributed scheduling mode (relay can only schedule on part of the resources in the cell) and full-distributed scheduling mode (relay can reutilize all the available frequency resource). Allocation strategies for centralized scheduling, semi-distributed scheduling and full-distributed scheduling are discussed in the following.

A. Semi-distributed Scheduling

The resources allocated to RS by BS for scheduling the UEs in RS domain can be dynamic or static. Dynamic allocation will achieve the best performance with the cost of huge amount of signal interaction among BS, RS and UEs, while static allocation may gain less performance but can save much bandwidth for signaling. To balance between the amount of signal interaction and performance, we suppose that the resource allocation for RS should be maintained for a certain period before updating.

Within a TTI, we assume that the amounts of RBs in a cell occupied by BS access link, relay link and RS access link are $a$, $b$ and $c$, respectively. And the sum of them equals to the amount of all RBs available in the cell. We assume that all the UEs in the cell should be treated equally, no matter they access to BS or RS. Therefore, the proportion of the amount of resources used in the two access links should equal to the proportion of numbers of access UEs in each link. So, we have

$$a = \frac{N_{BS}}{N_{RS}}c,$$  \quad (2)

where $N_{BS}$ and $N_{RS}$ refer to the numbers of the UEs in BS and RS domain, respectively. This proportion can be obtained after the routing process.

Since the channel condition is time-varying, the resource amount needed for relay is dynamic and is hard to determine. Therefore, the relation of $b$ and $c$ can only be estimated. We can measure and calculate out the distributions of the channel condition of RS access link and relay link in certain period, then figure out the proportion of $b$ and $c$. This proportion is the average of actual conditions and is used for initial allocation. After the proportion of $a$, $b$ and $c$ is determined, we can allocate the resources to RS for its scheduling. So except for these $c$ RBs, the other RBs are reserved for BS and used in RS access link and relay link.

It should be noted that the channel condition between BS and RS should be considered when placing the stations. Try to ensure line of sight (LOS) transmission, at least favorable condition. BS can use high power in relay link, adopt directional antenna and employ more complex physical layer technology. So, in general situation, we believe that $b < c$.

Herein, we propose a two-phase semi-distributed scheduling strategy. In the first phase, RS schedules the UEs in RS domain on the resources it can control, and sum up the data amount needed to be transmitted according to the scheduling results. Meanwhile, BS schedules the UEs in BS domain on the resources it can control (a total of $a+b$ RBs). Then the resource pre-allocation process is over. The scheduler in BS or in RS calculates out a two-dimensional priority value matrix (the priority value of a UE in all RBs might be different with each other) according to the channel condition, delay, QoS requirements and other services’ information of every UE in each RB by some scheduling algorithm. The scheduler
allocates each RB to the UE which has the highest priority value in this RB, and takes that value as the priority value of this RB.

The second phase is to allocate resource for relay link. We cancel the pre-allocation for RB of the lowest priority value which is scheduled and pre-allocated by BS, and re-allocate this RB to the relay link. The canceling and re-allocating process is continued (to cancel the RB which has the second lowest priority value and so on) until the resources allocated to relay link are sufficient for transmission. And the scheduling process of current TTI is finished. The flow chart of semi-distributed scheduling is shown in Fig. 2 (a).

![Flow chart of semi-distributed scheduling](image)

Figure 2. Semi-distributed scheduling and Full-distributed scheduling

### TABLE I. MAIN SYSTEM SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular layout</td>
<td>Hexagonal grid, 19 cells, 3 sectors/cell</td>
</tr>
<tr>
<td>Antenna pattern</td>
<td>( A(\theta) = -\min{2\theta/\theta_a, 3\theta/\theta_b} ) dB, ( \theta_a = 70^\circ, \theta_b = 20^\circ )</td>
</tr>
<tr>
<td>Scenario</td>
<td>BS-RS: LOS; RS-MS &amp; BS-MS: NLOS</td>
</tr>
<tr>
<td>Slow fading</td>
<td>Standard deviation: 8.9 dB (Log normal distribution)</td>
</tr>
<tr>
<td>Scheduling algorithm</td>
<td>Proportional Fairness</td>
</tr>
<tr>
<td>Station total Tx power</td>
<td>46 dBm for BS, 40 dBm for RS</td>
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<tr>
<td>BS antenna gain</td>
<td>14 dBi</td>
</tr>
<tr>
<td>Relay antenna gain</td>
<td>5 dBi for relay to UE</td>
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<tr>
<td>Antenna configuration</td>
<td>1*1</td>
</tr>
<tr>
<td>Channel bandwidth</td>
<td>10 MHz</td>
</tr>
</tbody>
</table>

### B. Full-Distributed Scheduling

Full-distributed scheduling shown in Fig. 2 (b) can be seen as a special case of semi-distributed scheduling where RS reuses all the resources that BS controls permanently. It does not need the initialization of \(a\), \(b\) and \(c\) noted in above. It also contains a two phase structure that BS and RS schedule independently in the first phase and BS completes canceling and re-allocating process in the next phase.

### C. Centralized Scheduling

In centralized scheduling mode, the BS is in charge of scheduling all the radio resources in the cell. A two-phase centralized scheduling strategy which is similar to distributed scheduling is proposed. The centralized scheduling is more flexible in the scheduling process, in which all the resources in the cell are controlled by BS and all the links are scheduled by BS.

In the first phase, BS pre-allocates all the available RBs to two access links (BS and RS access links). In the second phase, BS re-allocates the RBs to relay link by the way of canceling the pre-allocated RBs which have the lowest priority values in the BS access link. Then the allocation for three types of links is finished. The canceling of pre-allocation in the second phase is according to the scheduling results in the previous TTI. The process of centralized scheduling is denoted in Fig. 3.

### V. SIMULATION MODEL, RESULTS AND ANALYSIS

Simulations based on multi-cell LTE system are showed in this section. The cell model is described in Fig. 4. A cell is divided into 3 hexagonal sectors. A fixed RS (indicated as a round) is placed 2/3 cell radius distance away from BS in each of the sectors where the BS locates in the central of the cell. The main system simulation parameters are listed in Tab. I.

System throughput and system edge user throughput is always the key factors to evaluate the system performance. System throughput is the sum of all the users’ average data rates in the sector, which represents the maximum system ability. System edge user throughput is the 5%-tile user throughput, representing the fairness for users to some extent.

We investigate the theoretical upper bounder of four scenarios under RUE routing strategy assuming that the channel
condition of the relay link is good enough, which include semi/full-distributed scheduling, centralized scheduling and the traditional system without relay. Upper bound of the number of RB that relay access link can schedule in centralized and semi-distributed mode is set to be 20. Fig. 5 compares the distributions of UE rate with different site-to-site distances. To cover larger area transmit power of relay in distributed scheduling mode is, meanwhile, increased to 50dBm when the site to site distance is 1732m. As the site-to-site distance goes larger, full-distributed scheme can be deployed properly with some adjustment of power to act as a kind of cell splitting. Fig. 6 and Fig. 7 show the system throughput and cell edge user’s rate versus different UE numbers per sector respectively. We can see that relaying technology can improve system performance significantly. Full-distributed mode gains more system throughput as the number of UE per-sector increases, since more UE will access to RS and the resources are fully reused by BS and RS. Moreover, the centralized scheduling performs better than the semi-distributed scheduling due to the awareness of the global information, which is a promising direction for us to improve the scheduling strategy and system design. In addition the routing metric based on RUE can improve the average rate of most of UEs to a certain degree compared to SINR metric when the interference in the relay link is comparatively strong, which is showed in Fig. 8.

VI. CONCLUSION

This paper considers scheduling strategies for semi/full-distributed and centralized scheduling two-hop relaying cellular system. We analyze and compare the characteristics of these three scheduling modes both in system performance and signaling overhead. Three practical scheduling strategies and an efficient routing metric are proposed to enhance the performance in some aspects. Simulation results are provided and analyzed in different scenarios, which show the benefit of adopting the relaying technology.

REFERENCES


