Resource Scheduling Approach for LTE-A based Network Incorporating a Moving Relay Node System Equipped Train

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Abstract—Recent trends show that mobile users accessing the wireless communication network from public transportation such as the high speed train are on the increase. To serve onboard users effectively, the use of moving relay nodes in a two-hop communication link is a promising solution. However, the direct use of known resource scheduling methods will not be appropriate to efficiently and fairly share resources between ground macro users (GMUs) and moving relay nodes (MRNs) used on the high speed trains. In order to address this challenge, we examine two hybrid resource scheduling methods based on system level simulations and analyze joint and disjoint scheduling approaches for efficient and fair resource sharing between GMUs and MRNs on the downlink of a long term evolution advanced (LTE-A) cellular communication system.

I. INTRODUCTION

Demand for cellular broadband wireless communications by high mobility users has tremendously increased due to the rapid deployment of large public transport vehicles such as the high speed train (HST) in many parts of the world. Providing high data rates and good quality of service (QoS) required by onboard users in an HST is a challenging task in the presence of rapidly varying channel conditions. An effective way to improve data rate is to take advantage of the spatial dimension of the high speed train using a two-hop system architecture and applying advanced multiple-input multiple-output (MIMO) and orthogonal frequency division multiplexing (OFDM) techniques [1]. One advantage of the OFDM technique is the ability to split the system bandwidth into several orthogonal channels, thereby providing the possibility of sharing radio resources to multiple users within the same time slot. Maximizing the downlink throughput of moving relay nodes installed on a HST within LTE-A cellular communication system was studied in [2]–[5]. However, the issue of fairness and the impact on the throughput of macro users scheduled along with the MRNs were not addressed. Various scheduling strategies have been proposed for traditional OFDM systems. For example, studies in [6] demonstrate that enhanced system throughput and fairness among users can be achieved with maximum carrier to interference ratio scheduling. Proportional fair scheduling was proposed for OFDM systems in [7]–[9] where fairness among users was addressed while maximizing system throughput. With the introduction of relaying concept into the cellular network, some studies have addressed the issue of scheduling with the presence of relays such as in [10]–[12]. To the authors’ knowledge, no contribution has been done on the investigation and impact of scheduling macro users along with MRNs installed on a HST to serve passengers. The notion of the employing MRN systems for HST was presented in [13]. The idea is to deploy interconnecting individual moving relay node in each of the carriages, which connects to the donor cellular network(s) with multiple wireless backhaul links in a coordinated and controlled manner. This concept ensures that the access link is an integrated extension of the cellular network and sufficient high data rates are achieved due to the multiple backhaul links established.

In this study, we develop a system model for the downlink cellular network with a train equipped with an MRN on each carriage of the train. The radio resources available in each cell, the train is present are shared fairly with other GMUs with the assumption that onboard users are only served by the MRNs on the access link. We analyze the effect of joint and disjoint scheduling approaches. We also derive two hybrid scheduling algorithms and show that disjoint scheduling approach leads to a fair balance in throughput performance for both the GMUs and the MRNs. The LTE framework is adopted and simulations are carried out on an LTE-A compliant system level simulator.

The rest of the paper is organized as follows. In Section II, the system model is introduced. The scheduling problem within the LTE framework is presented in Section III. Section IV presents the two hybrid scheduling algorithms and scheduling approaches. Section V describes the simulator and the results are shown in Section VI with Section VII concluding the paper.

II. SYSTEM MODEL

We consider a train with a two-hop network system architecture created with the use of MRNs in a multi-cell system as shown in Fig. 1. The train consists of 8 carriages, each equipped with an MRN and having an external antenna array that is evenly spaced along the length of the train and interior antennas to serve onboard users. The multi-cell system is modelled as an hexagonal layout consisting of 19 trisector cells with replicas of the layout wrapped around the main layout as shown in Fig. 1. This is to ensure uniform interference levels across the main layout. Each sector operating at 2 GHz band with a 10 MHz bandwidth has $N_t$ transmit antennas transmitting on $L$ transmission layers with the MRN having...
where $\mathbf{H}_c$ is the estimate of $\mathbf{H}_c$, $p_{c,l}$ denotes the transmission power for the $l^{th}$ stream at subcarrier $c$ and $w_{c,l}$ denotes the $l^{th}$ column of $\mathbf{W}_c$.

III. SCHEDULING PROBLEM

GMUs and MRNs are associated with any of the 57 BSs in the central layout based on variation in the instantaneous channel conditions, shadow fading and distance-dependent path loss. Hence, with the possibility of having more than one GMU/MRN associated with a BS, scheduling is achieved based on the channel quality of each GMU/MRN. Scheduling ensures that the available radio resources are shared with as many users as possible, while still satisfying GMU/MRNs’ QoS requirements. The throughput of each GMU/MRN and the throughput of the entire network are affected by the type of scheduler used. The type of scheduling method used also influences the impact of the HST on the throughput of the GMUs. Hence, evaluating the efficiency of different scheduling methods as it relates to the GMUs and MRNs, is required.

We consider an LTE-A system with a radio frame structure, such that each radio frame is divided into 10 subframes. Resources are allocated to users on a subframe basis at every 1 ms transmission time interval (TTI), (i.e., the scheduler allocates resources to GMU/MRN in minimum portions of two consecutive resource blocks (RB)), due to signalling overhead limitations. One RB consists of 12 adjacent subcarriers and corresponds to 0.5 ms (i.e., $\frac{1}{2}$ of a subframe) in the time domain. In any given cell, GMUs are always allocated resources at every TTI. However, MRNs are allocated resources at every second TTI, since we assume half duplex functionality of the MRNs. Let us assume a time slot $t$ equals 1 TTI (1 ms) and the overall system bandwidth is $B$ MHz. With a scheduling block (SB) corresponding to two consecutive RBs, the bandwidth of each SB is $\frac{B}{N_{SB}}$, where $N_{SB} = 2N_{RB}$ is the number of SBs within a specified bandwidth and $N_{RB}$ corresponds to the number of RBs. In every TTI, scheduling is done across $N_{SB}$ scheduling blocks and we assume uniform distribution of the total transmit power across all subcarriers. The capacity of the $r^{th}$ scheduling block for the $m^{th}$ GMU/MRN on the $t^{th}$ TTI that establishes a connection link is given by

$$C_{m,r}(t) = \frac{B}{N_{SB}} \log_2 \left( 1 + \frac{C}{\sum_{c=1}^{L} \sum_{l=1}^{C} \gamma_{c,l}} \right)$$

where $C$ is the number of subcarriers in the $r^{th}$ scheduling block. Let $\mathbb{1}_{t,m}$ denote an indicator function that describes GMUs/MRNs that are eligible to be allocated resources such that

$$\mathbb{1}_{t,m} = \begin{cases} 1 & \text{if } \{l_{ind} \in [1, 2] \land m \in \text{GMU}\} \lor \{l_{ind} \in [1] \land m \in \text{MRN}\} \\ 0 & \text{Otherwise} \end{cases}$$

where $l_{ind} = (t \mod 2) + 1$ is an index that ensures an MRN is not scheduled on every second TTI and $m$ is the GMU/MRN being allocated resources on the $r^{th}$ scheduling block at the $t^{th}$ TTI. The total achievable rate up to $T$ TTIs in the $b^{th}$ cell can be calculated as

$$\gamma_{c,l} = \frac{p_{c,l}|\mathbf{w}_{c,l}^H \mathbf{H}_c|^2}{\sum_{j=1, j \neq l}^{L} p_{c,j}|\mathbf{w}_{c,j}^H \mathbf{H}_c|^2 + \mathbf{w}_{c,l}^H \mathbf{R}_c \mathbf{w}_{c,l}}$$
where $\mathcal{U}$ is the set of GMU/MRNUs associated with the same BS. The overall throughput across the network, i.e., $\sum_{b \in B} R_{\text{tot}}(b)$ is maximized using a scheduling method, where $B$ is the set of BSs within the network. However, $R_{\text{tot}}(b)$ is a combination of the throughputs for GMUs and MRNs, i.e., $R_{\text{tot}}(b) = R_{\text{gmus}}(b) + R_{\text{mrns}}(b)$. Therefore, combined scheduling of both GMUs and MRNs may not necessarily ensure fairness between the two groups of users. To ensure adequate fairness between the two groups of users with minimal impact on the throughput, we analyze the performance of joint and separate scheduling of GMUs and MRNs using two hybrid scheduling methods.

IV. RESOURCE ALLOCATION METHODOLOGY

A. Hybrid Scheduling Algorithms

Here, we consider two hybrid scheduling algorithms based on existing algorithms with the aim of optimizing the scheduling performances.

1) Round Robin with Max Rate (RRMR): This algorithm is a combination of round robin scheduling algorithm and maximum rate scheduling algorithm to bring about a balance between fairness and performance. The RRMR scheduling brings a balance between fairness among users and scheduling users with the highest achievable rate. In one TTI, users are scheduled across $N_{SB}$ scheduling blocks. The user with the best channel condition is first allocated resources on a corresponding pair of scheduling blocks, then the user with second best channel condition is allocated resources on the next available pair of scheduling blocks. This process continues for all users associated with the BS. After all the users have been allocated resources, the first user with the best channel condition is assigned two more scheduling blocks. This process continues until there are no more available scheduling blocks or until the target rate of each user is reached. More details are given in Fig. 2. The principle is to allocate a small number of SBs to all users cyclically in a predetermined order based on maximum rate. Hence, the total SBs are shared as evenly as possible on a best performance basis, without unduly reducing the throughput.

2) Modified Proportional Fair (MPF): This algorithm is a slight modification of the proportional fair algorithm. The proportional fair scheduling algorithm provides a balance between optimized throughput and fairness among the users. The balance provided by the PF, the MPF also provides a balance between fairness and performance such that the selected scheduling block for a user is based on the user with the best available rate on the scheduling block and the minimum average available rate of all the users associated with the BS. Therefore, at each TTI, resources are allocated to users with the relatively best channel condition such that a user is allocated resources on a scheduling block according to

$$\hat{m}^* = \arg \max_m \frac{\hat{R}_{\hat{m},r^*}(t)}{m}$$

where $\hat{R}_{\hat{m},r^*}(t) = \mathbb{I}_{t,m} C_{\hat{m},r^*}(t)$ is the feedback data rate for user $\hat{m}$, with the selected scheduling block $r^*$ described as

$$r^* = \arg \min_r \left( \sum_{m \in \mathcal{U}} \hat{R}_{m,r^*}(t) \right) / |\mathcal{U}|.$$

$\hat{R}_{\hat{m},r^*}(t)$ is the moving average throughput on the $r^*$th scheduling block for user $\hat{m}$ and $\epsilon$ is a small positive constant to prevent the error of dividing by zero. The moving average throughput (transmission history) is calculated over a certain proportional window length $P_w$ and updated as

$$\hat{R}_{\hat{m},r^*}(t + 1) = (1 - \frac{1}{P_w}) \hat{R}_{\hat{m},r^*}(t) + \frac{1}{P_w} \hat{R}_{\hat{m},r^*}(t).$$

B. Scheduling Approaches

We consider the joint and disjoint scheduling approaches w.r.t. the two groups of users, i.e., GMUs and MRNs.

1) Joint Scheduling: In the joint scheduling approach, the GMUs and MRNs are scheduled together. All users associated with a BS are given equal priority. Hence, for both scheduling algorithms in Section IV-A, the set $\mathcal{U}$ which consists of users available to share resources include both GMUs and MRNs.

2) Disjoint Scheduling: The disjoint scheduling approach identifies and separates the types of users before applying the scheduling algorithm. Hence, the GMUs are scheduled separately from the MRNs. However, scheduling priority has to be established. The idea of scheduling with priority is to either schedule the GMUs first or the MRNs first. The separate scheduling of the GMUs and MRNs gives the possibility of using different scheduling methods for
each group of users, thereby enhancing the flexibility of the achievable rate and fairness between the groups.

V. SIMULATOR DESCRIPTION

The LTE-A based system level simulator was configured to follow the guidelines established by the international telecommunications union radiocommunications sector (ITU-R) for IMT-A radio interface evaluation [15]. The simulation parameters were set to closely follow the LTE system. The central layout with inter-site distance of 1.3 km was modelled as shown in Fig. 1 and the antenna configurations for $N_t$, $N_m$, and $N_r$ were set to 4, 4 and 2, respectively. The simulation runs consist of 1000 drops, with 100 GMUs randomly distributed across the central layout at the start of each drop. A track with a radius of approximately 5 km is placed across the central layout such that the minimum distance between the track and any BS is 50 m. At the start of the first drop, the train is positioned on one end of the track and as the drops go on, the train moves along the track to the other end. At the start of each drop, each of the GMUs and the train equipped with MRNs are paired with 57 cells that provide the strongest received signal strength. The received signal strength is calculated based on path-loss distance and angular antenna gain.

Scheduling of mobile users (GMUs and MRNs) at the BS rely on channel state information (CSI) feedback, i.e., the channel quality indicator (CQI), which is derived from the mobile users and is made available at the BS after a delay. A target rate of 10 Mbps is set for the GMUs, and full buffer traffic model is considered for the MRN with the assumption that the number of users in the train can be large. A link to system (L2S) interface is employed such that the SINRs obtained are mapped to mutual information values using mutual information effective SINR metric (MIESM) link layer abstraction [16]. A modulation and coding scheme (MCS) is set for each mobile user and the MCS values determine the frame error probability (FEP) at the link to system level interface and the transport block size, i.e., the number of bits transmitted for throughput calculations. Successful transmissions/retransmissions are identified by hybrid automatic repeat request (HARQ) acknowledgements, which are determined in the system level interface and fed back to the BS after a delay. For mobile users with successful transmissions/retransmissions, the number of correctly received bits is calculated and used in throughput calculations.

VI. SIMULATION RESULTS

We provide simulation results according to our model for downlink transmission. Fig. 3 gives the cumulative distribution function (CDF) of the GMU/MRN throughput for different scheduling approaches using the RRMR scheduling algorithm. The following scheduling approaches are considered:

- RRMR algorithm giving MRN priority (RRMR MRN)
- RRMR algorithm giving GMU priority (RRMR GMU)
- RRMR algorithm with joint scheduling (RRMR Joint).

With the RRMR GMU approach, the total GMU throughput in Fig. 3(a) improves significantly compared to the joint and

MRN priority approaches. However, in Fig. 3(b), the MRNs are in outage for a significant part of the journey. On the other hand, when the GMUs and MRNs are jointly scheduled (i.e., RRMR Joint), the total MRN throughput in Fig. 3(b) is significantly improved with no outage. But the total GMU throughput for RRMR Joint approach suffers a significant reduction, even when compared to RRMR MRN approach. This is because, in a given cell the MRNs are more likely to have better channel conditions than the GMUs and as a result, the GMUs are most often not allocated the best resources. The MRNs will most often have better channel conditions because the antenna heights are much higher than the GMUs’ since the antennas are mounted on the top of the train. In a case where the GMUs are much closer to the BS than the MRNs, the GMUs can have better channel conditions. This explains what happens, when RRMR MRN and RRMR Joint approaches are compared at the cell edge in Fig. 3(b).

Fig. 3: CDF throughputs with RRMR scheduling method.

Fig. 4: CDF throughputs with MPF scheduling method.

The MPF scheduling method is applied using the scheduling approaches discussed with the CDF throughputs shown in Fig. 4. The following scheduling approaches are considered:

- MPF algorithm giving MRN priority (MPF MRN)
- MPF algorithm giving GMU priority (MPF GMU)
- MPF algorithm with joint scheduling (MPF Joint).
As expected, With the MPF GMU approach, the total GMU throughput (Fig. 4(a)) is significantly improved as compared to the other two approaches, but the total MRN throughput (Fig. 4(b)) is poor with outage. The total MRN throughput for the other two approaches show that giving MRN priority (i.e., MPF MRN approach) can achieve about 5 Mbps improvement as compared with joint scheduling (MPF Joint). However, considering Fig. 4(a), the total GMU throughput for MPF Joint approach gets a large improvement in throughput compared to MPF MRN approach from the 50% point of the CDF, but at the cell edge, the MPF MRN approach performed better than MPF Joint approach. This is because in the MPF Joint approach, the MRN that is jointly scheduled brings an increase in interference to the cell edge GMUs. From Fig. 3 and 4, it can be seen that scheduling MRNs first, brings a fair balance in the GMU and MRN throughputs. Due to the ability to separate the scheduling of each group of users, we can use different scheduling algorithms for each group of users with the aim to improve performance on both throughputs.

Fig. 5 shows the throughput CDF performances of GMUs and MRNs, where MPF scheduling algorithm is applied for the GMUs and maximum rate (MR) scheduling algorithm is applied for the MRNs. We call it the MPF-MR scheduling algorithm and compare scheduling GMU first (MPF-MR GMU) with scheduling MRN first (MPF-MR MRN).

![Fig. 5: CDF throughput with MPF scheduling for GMU and MRN scheduling for MRN.](image)

The results show that to avoid outages on the train, it is better to schedule MRNs first. The total MRN throughput as seen in Fig. 5(b) shows that giving MRN priority with MR algorithm can further improve throughput performance by about 5 Mbps compared to MPF MRN scheduling approach in Fig. 4(b) with minimal impact on the total GMU throughput performance (Fig. 5(a)) when compared with MPF Joint scheduling approach in Fig. 4(a). The gain of using MR scheduling algorithm on the MRNs stems from the fact that the train with multiple carriages equipped with an MRN in each carriage can be made to cooperate in a coordinated fashion.

VII. CONCLUSION

In this paper, we have provided a system model to evaluate the throughput performance of both GMUs and MRNs mounted on a train in a communication network under different resource scheduling approaches. We also proposed two hybrid scheduling algorithms which were used to implement the scheduling approaches. The simulations were carried out on an LTE-A compliant system level simulation platform. Results show that Joint scheduling does not provide the best overall performance and there is a need to schedule each group of users separately. Specifically, scheduling MRNs first gives a fair balance in throughput performance and improved performance can be achieved by taking advantage of the MRN cooperation that can be achieved on the train.

ACKNOWLEDGMENT

This research was supported by the Finnish Funding Agency for Technology and Innovation (TEKES), Nokia, Keysight Technologies, and Huawei Technologies.

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