Radio Resource Management for Fast Fading Environments

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***Abstract*—Adaptive resource allocation based on perfect Channel State Information (CSI) can significantly improve the performance of Orthogonal Frequency Division Multiple Access (OFDMA) systems. However, in real systems, accurate CSI is impossible because of noisy channel estimates, channel feedback delays, and processing delays. Therefore, only imperfect CSI can be used for resource allocation purposes. In this paper, we minimize the impact of errors caused by imperfect CSI and evaluate the significance of periodic CSI feedback in a fast fading environment. In a fast fading environment, periodic CSI feedback requires a high overhead load; and the uplink resources reserved for feedback purposes are limited. Thus, we present a strategy that optimizes the usage of those uplink resources. Simulation results show that this strategy leads to a higher overall fairness and system throughput.**

***Index Terms*—orthogonal frequency division multiple access (OFDMA), partial CSI, Radio Resource Management, Call Admission Control, fast fading.**

I. INTRODUCTION

Orthogonal Frequency Division Multiple Access (OFDMA) is used on the downlink of the 3GPP Long Term Evolution (LTE) system as it is inherently able to combat frequency selective fading and offers degrees of freedom in radio resource management (RRM) by taking advantage of diversity effects [1]. Efficient RRM over an OFDMA system depends on accurate Channel State Information (CSI) at the transmitter side [2]. Its knowledge allows for the system bandwidth to be fully exploited through adaptation of the transmission parameters used on each OFDMA carrier. Although the system throughput can be improved with accurate CSI [2], this assumption is unrealistic. Noisy channel estimation, along with a delay between the moment of channel estimation and the actual transmission, results in imperfect or outdated CSI being used for RRM purposes. RRM in OFDMA systems involves the application of adaptive modulation/coding (AMC). AMC provides the flexibility to match the Modulation-Coding Scheme (MCS) to each user's channel conditions. It was concluded in [3] that AMC is not significantly affected by noisy channel estimation if a reasonably good estimator is used. However, when the mobility of the users is high, the CSI becomes more outdated, which will lead to errors in the resource assignments; and thus, to a decrease in overall system performance. As user mobility is a principal driving force for mobile-OFDMA based wireless systems such as LTE, it becomes more important to consider the time-varying nature of channels for resource allocation problems in order to further enhance the system throughput. In LTE, resources are allocated to users every 1msec [1] which allows for a quick response to the varying channel conditions of the link. However, under significant user mobility the small coherence time means that the CSI measurement reports need to be frequent; otherwise, the CSI used by the base-station (BS) to perform AMC will not be correlated with the current channel states. In this paper, we define correlated CSI (CCSI) as the CSI that is correlated to some degree with the current value of the channel. Frequent CSI measurement reports lead to increased system overhead requirements, especially when a large number of active users are present in the cell [4]. Instead of feeding back the instantaneous channel coefficients to the BS, it is feasible that users simply send the mean of the subchannel SNR distribution [5]. We define this knowledge as statistical CSI (SCSI). Using SCSI to perform resource allocation requires significantly less resources to be occupied for feedback purposes.

In practical systems, only imperfect/outdated CSI and SCSI can be used to perform resource allocation. Therefore, practical resource allocation schemes that account for CSI inaccuracy are required. The impact of imperfect and outdated CSI on the performance of adaptive OFDM has already been studied in the literature [3],[6]. Using SCSI to perform resource allocation for OFDMA systems has been analyzed in [5]. In this work we distinguish between these two different forms of partial CSI (SCSI and CCSI) and address CCSI and SCSI based resource allocation strategies for LTE systems.

Most works [7] − [9] on resource allocation for OFDMA systems under the partial CSI assumption do not differentiate between the SCSI and CCSI concepts. In [5], a comparison that focused on the continuous rate case (i.e Shannon capacity based formulation) was performed between the two cases. In the first part of this paper we compare the two cases for the more practically relevant case where only a discrete number of modulation and coding levels are available. In order to do so, we quantify the performance degradation created by CSI errors. These results are then applied to allocate resources to users with the objective of maximizing the overall system throughput while ensuring that the target bit error rates are kept below a given threshold and each users queue length is kept within stable bounds. We also investigate the impact of this maximization on the system throughput for both the SCSI and CCSI based resource allocation schemes.

The majority of research on OFDMA resource management does not consider the presence of a Call Admission Control (CAC) unit [7] – [9], [5]. The CAC unit limits the number of admitted flows in order to maintain the user QoS. Also, it distributes the network throughput between the supported services[10]. Motivated by our comparison between the CCSI and SCSI based resource allocation schemes in the second part of this paper we propose a strategy that leads to a good tradeoff between overhead consumption and fairness as well as throughput when

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the presence of the CAC unit is considered.

In summary our contributions are as follows:

Quantify the performance degradation due to CSI errors for both the SCSI and CCSI cases when only a discrete number of modulation and coding levels are available and a constraint on the target bit error rate is imposed.

Apply these results to a throughput maximizing scheduling algorithm and compare the performamce difference between the CCSI and SCSI based resource allocation schemes.

Propose a strategy that leads to a good tradeoff between overhead consumption and fairness as well as throughput when the presence of the CAC unit is considered.

The rest of this paper is organized as follows: the system model and the methodology used to calculate the probability of successfully selecting an MCS level is given in Section 2. The scheduling algorithm used in our simulations and the method proposed to make optimal use of the available resources for feedback is presented in Section 3. Simulation results are presented in Section 4. Finally, the paper is concluded in Section 5.

II. SYSTEM MODEL

We consider a downlink OFDM system with K users and N subchannels. The time axis is divided into Transmission Time Intervals (TTIs). During each TTI, packets of fixed length arrive for each user at a given rate.We consider a downlink OFDM system with K users and N sub-channels. The time axis is divided into Transmission Time Intervals (TTIs) of length 1msec as specified in the LTE standard [1]. Each user accesses the same service whereas a CAC unit is assumed to limit the number of incoming flows so that the network can offer each flow its required QoS. If a request is accepted, the arriving packets are buffered in separate queues for each user. At the beginning of each TTI the BS schedules bandwidth transmission and allocates resources to each user according to their queue state and estimated/average SNR.

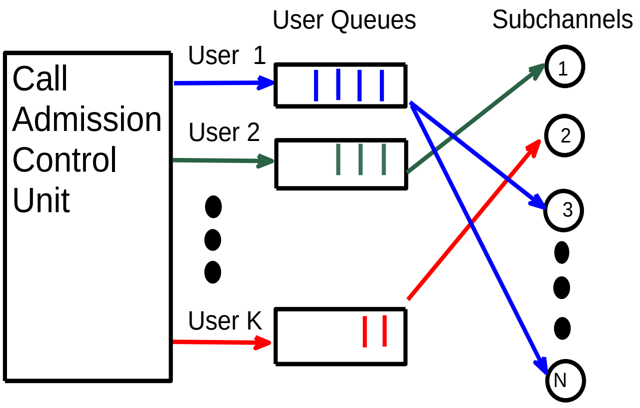

Figure 1. System Structure

A set of MCS levels are employed for AMC. Each MCS level is indexed by $m \in \{1, ..., M\}$, and its selection is determined by the value of the imperfect SNR which is denoted by $\hat{\gamma}$. The range of SNR values used for transmission is divided into M intervals by M SNR thresholds which are chosen in such a way that the information rate is supportable subject to a target BER constraint. These thresholds are denoted by Γ_m. Therefore, MCS m will be applied when $\Gamma_m \leq \gamma < \Gamma_{m+1}$. Also, it is assumed that $R_1 < R_2 < ..... < R_M$, where R_m is the spectral efficiency of MCS m. Each user k's channel gain on sub-channel n is denoted by h_{kn}. The channel gains are assumed to follow a complex Gaussian distribution with zero mean and unit variance, $h_{kn} \sim NC(0, 1)$.

Consider mobile user k whose outdated channel gain for sub-channel n is denoted by $\hat{h}_{kn}$ and the current channel gain which is denoted by h_{kn} . According to [3], when both $\hat{h}_{kn}$ and h_{kn} are complex Gaussian variables with a zero mean and unit variance, the conditional probability distribution function (pdf) $P(h_{kn}|\hat{h}_{kn})$ follows a complex Gaussian distribution with a mean equal to $\mu_k = \rho_k \hat{h}_{kn}$ and a variance of $\sigma_k = 1 - \rho_k^2$. In these expressions, ρ_k denotes the correlation coefficient between h_{kn} and $\hat{h}_{kn}$ and its value is $\rho_k = J_0(2\pi f_{d,k}\tau)$. Here, J_0 is the zeroth order Bessel function of the first kind, $f_{d,k}$ is the maximum Doppler frequency for user k, and τ is the channel feedback delay. In practical systems, if we can estimate the maximum Doppler frequency, this correlation coefficient can be obtained[11]. As $P(h_{kn}|\hat{h}_{kn})$ is Gaussian distributed, $P(|h_{kn}|\Big|\hat{h}_{kn})$ follows a Ricean distribution. When the CSI is outdated, there will always be a nonzero probability of selecting an MCS level which is not optimized for the region where the current SNR lies (i.e selecting an MCS level which cannot meet the target BER). We define P_{knm} as the probability of successfully selecting an MCS level m on sub-channel n for user k. It is given as

$$P_{knm} = P(\gamma_{kn} > \Gamma_m) = Q_1\left(\frac{\rho_k\sqrt{\frac{\hat{\gamma}_{kn}}{\bar{\gamma}_{kn}}}}{\sigma_k}, \frac{\sqrt{\frac{\Gamma_m}{\bar{\gamma}_{kn}}}}{\sigma_k}\right), \quad (1)$$

where

$$Q_1(\alpha, \beta) = \int_{\beta}^{\infty} xI_o(\alpha x)\exp^{(-\frac{\alpha^2+\beta^2}{2})}, \quad (2)$$

is the Marcum Q function [12] and $\bar{\gamma}_{kn} = \frac{P_r}{N_o B}$ is user $k's$ mean SNR on sub-carrier n. The outdated and current SNR are $\hat{\gamma}_{kn} = \frac{P_r|\hat{h}_{kn}|^2}{N_o}$ and $\gamma_{kn} = \frac{P_r|h_{kn}|^2}{N_o}$, respectively, where P_r is the received power and N_o is the noise spectral density. When SCSI is used to select MCS levels, P_{knm} for a Rayleigh fading channel becomes [13]

$$P_{knm} = P(\gamma_{kn} > \Gamma_m) = \exp\big(-\frac{\Gamma_m}{\bar{\gamma}_{kn}}\big). \quad (3)$$

As the use of outdated CSI or SCSI leads to errors when AMC is performed, it is useful to minimize them. In order to achieve optimal utilization of the available spectral resources whilst meeting the target BER requirements, the optimum MCS level m^* for each user k on subchannel n is chosen according to the following rule

$$m^* = \arg\max_m P_{knm}R_m \quad (4)$$

where P_{knm} is given by either (1) or (3) depending on whether outdated CSI or SCSI is used.

In this setting, we denote the maximum bandwidth normalized information rate that can be reliably transmitted by user k on subchannel n by G_{kn} which is given as

$$G_{kn} = P_{knm}R_m \quad (5)$$

The quantity G_{kn} is referred to as throughput throughout this paper.

III. SCHEDULING

A. Scheduling Algorithm

Scheduling generally aims to maximize the system throughput; however, user fairness needs to also be accounted for. Algorithms that simply maximize the system throughput lead to starvation of users at the cell edge and to an oversupply of bandwidth to users that are close to the BS.

A number of scheduling algorithms which assign resources to a set of selected users can be integrated into an OFDMA system. Queue and Channel aware algorithms are able to meet user QoS requirements, as one may need to sometimes schedule users whose delays/queues are becoming large even though their current channel state is not the most favorable. It was shown in [14] that Queue and Channel aware scheduling algorithms are throughput optimal, and that they lead to significant performance improvements for the LTE system [15]. In our work, equal power allocation across all sub-channels is assumed. It is noted in [16] that the throughput degradation arising from such an assumption is negligible when AMC is applied as with the case of LTE.

In order to maximize the throughput of the system whilst meeting the target BER of each user, a simple Queue and Channel aware algorithm will allocate sub-channel n to the user k^* for which the following holds

$$k^* = \arg\max_k P_{knm^*} R_{m^*} W_{k^*}(t) \tag{6}$$

where $W_k(t)$ is the head-of-line packet delay or queue length for user k during TTI t; and $P_{knm^*} R_{m^*}$ is the channel capacity that meets the target BER requirement assuming that the optimum MCS level m^* is selected according to (4). The throughput user k^* can achieve on subchannel n is

$$G_{k^*n} = P_{knm^*} R_{m^*} B \tag{7}$$

where B is the bandwidth of a subchannel.

For a subchannel n to be assigned in accordance with (6) the scheduler needs to search KM values of $P_{knm} R_m$ as the queue length can be considered a constant. Therefore, the computational complexity associated with allocating N subchannels to K users is $O(KMN)$.

B. Scheduling to provide a tradeoff between overhead and throughput/fairness

As the user velocity increases, the CSI has to be updated more frequently. Thus, large amounts of spectrum resources need to be reserved for overhead purposes if AMC is to be performed using CSI values that are correlated with the current value of the CSI. This leads to increased overhead requirements. The overhead load increases when a large number of active users are simultaneously present in the cell [4]. In particular, we require NKM bits per timeslot where M is the number of bits required to quantize a real number with negligible quantization error. This is clearly impractical for future mobile OFDMA systems such as LTE, as the capacity allocated for signaling purposes is limited [17]. Therefore it is useful to limit the amount of feedback bits. In this work, we confine the feedback to a set of users by making use of the following considerations.

In networks that support heterogeneous applications with diverse throughput requirements the call-admission control (CAC) unit becomes crucial. Firstly, it limits the number of incoming flows so that the required QoS can be provided to each flow. Secondly, it provides QoS guarantees by distributing the network throughput between the supported services. This is particularly important in networks that support a variety of services as one group of users may be more demanding than the rest, which results in an allocation of the network resources to the former and leaves the latter unsupported. Limiting the aggregate rate that the group of demanding subscribers receives imposes fairness and guarantees QoS for each service.

When the CAC unit functionality is accurate all users admitted into the network need to be satisfied in terms of QoS. A user situated at the edge of the cell requesting access to a specific service will need to be allocated more subchannels than a user with a high average SNR accessing the same service. By limiting periodic CSI feedback to the set of users with the lowest geometry (i.e., users SNR induced by the path-loss/shadowing model) more of the channels assigned by the scheduler will be loaded with CCSI. This scheme is also expected to increase the fairness of the system.

IV. NETWORK SIMULATION

In order to evaluate the importance of periodic CSI feedback as well as the strategy used to reduce the amount of feedback bits we perform system level simulations. Simulation parameters are based on [18] and these are typical values used for LTE simulation studies [14]. We consider a system with $10MHz$ of bandwidth divided into 666 subcarriers, 624 of which are used for data. The remaining 32 sub-carriers are used as guard subcarriers which also need to be accounted for. The width of each carrier equals 15KHz. Resource allocation cannot be performed on a per sub-carrier basis due to the resulting overhead but is based on subchannels. In LTE [14] each subchannel consists of 12 subcarriers. Thus, N= 52 subchannels can be assigned to the users. The wireless environment is typical Urban Non Line of Sight (NLOS) and the carrier frequency equals 2GHz. The cell diameter is 1km; and the distance, d_k, between the kth user and the BS is a 2-D uniformly distributed random variable. The most suitable path loss model in this case is the COST 231 Walfisch-Ikegami (WI) [19] as it allows estimation of the pathloss from 20m [19]. The system level simulation parameters are summarized in Table I.

A schematic diagram of the simulation flow is given in Fig.2. When the simulation begins, each of the (K=25) users moves in a given random direction. The simulator updates the user location every 100 TTIs. During each TTI packets arrive for each user k's queue at a rate equal to the packet arrival rate. The packet size is selected such that the system capacity is roughly equal to 1 packet/user/TTI. In order to assign subchannels to these users so that packet transmission can occur the optimum MCS level m^* is required $\forall k, n$. When SCSI is used the pathloss model leads to the the average user SNR $\bar{\gamma}$ through which m^* can be obtained using (4). However, when CCSI is used, the values of $\hat{h}_{kn}$ are also needed. These depend on the power delay profile and the distribution of h_{kn} $(h_{kn}|\hat{h_{kn}} \sim NC(\rho\hat{h}_{kn}, \sqrt{1-\rho^2})$. Moreover, the values of ρ are also required. These are a function of τ (delay time between the channel estimation and the actual transmission) and the user velocity. The value of τ differs in each simulation run and is added to the CSI processing delay in order to obtain the total delay time. Using these values and (4) allows the optimum MCS level m^* to be found $\forall k, n$ for the case of CCSI. Finally, the queue and channel aware scheduler allocates subchannels to the users in accordance with (6). For each point in the figures presented in the Results section, we run the simulator for $1,000$ TTI's which for the LTE system is equivalent to a 1 second real-time period.

In order to reduce the computational load, link level simulation results are prepared in advance in the form of look-up tables for the throughput calculation, and these give the required SNR values needed to meet a specific target bit error rate. The defined MCS levels use coding rates between $1/8$ to $2/3$ combined with QPSK, 16QAM, and 64QAM modulation schemes. The MCS levels used in our simulations are shown in Table II.

TABLE I
KEY SIMULATION PARAMETERS

Parameter	Value	Comments
Carrier Frequency	2GHz	
Cell Configuration	single cell	
Cell Radius	1 km	
Channel Bandwidth	10MHz	In LTE the supported bandwidths are 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15, MHz, 20 MHz[1]
subcarrier spacing	15KHz	This subcarrier spacing in LTE is 15KHz[1].
Total Number of data subcarriers	624	This results in 52 data subchannels.
BS Tx Power	46dBm	
BS Antenna Height	50m	
MS Antenna Height	2m	
Mean Buliding Heights	12m	
Mean Width of Streets	50m	
Mean Building Separation	100m	
Incident angle relative to street	90^o	
Path-Loss Model	COST 231 Walfisch-Ikegami	The Walfisch-Ikegami model is more appropriate for the cell size considered
Propagation Model	ITU Vehicular A	
Shadowing Log-Normal Deviation	8dB	
Thermal Noise Density	-174dBm/Hz	
Number of active Users	25	
Packet Size	500 bits	Packet size selected such that the system capacity is roughly equal to 1 packet/user/TTI
Packet Arrival Rate (P.A.R)	1,3 packets/user/TTI	
CSI Measurement Error	Ideal	Noisy channel estimation will not be a significant problem when a reasonably good estimator is used [3]
CSI Processing Delay	1 TTI	A 1 TTI processing delay is considered
CSI Reporting Period	2TTI	The BS requests feedback information every 2TTIs. When added to the CSI processing delay the feedback delay is equivalent to the baseline standard value in LTE [18]
TTI length	1msec	Length of a TTI in the LTE standard [1]

TABLE II
SELECTION OF MCS BASED ON RECEIVED SNR AND THE CORRESPONDING THROUGHPUT (TP)

SNR(dB)	Modulation	Coding Rate	Throughput (bps/Hz)
$\sim$ -5	No use		
-5 $\sim$ -1.9	QPSK	1/8	0.25
-1.9 $\sim$ 1.8	QPSK	1/4	0.5
1.8 $\sim$ 3.8	QPSK	1/2	1
3.8 $\sim$ 7.1	QPSK	2/3	1.33
7.1 $\sim$ 9.3	16QAM	1/2	2
9.3 $\sim$ 11.3	16QAM	2/3	2.67
11.3 $\sim$ 14.5	64QAM	1/2	3
14.5 $\sim$ 17.2	64QAM	2/3	4
17.2 $\sim$ 19.5	64QAM	0.81	4.86
19.5 $\sim$	64QAM	2/3	5.25

V. RESULTS

In this section, we present the impact of optimally selecting MCS levels on the system throughput when either CCSI or SCSI are used to perform AMC. By system throughput we refer to the maximum spectral efficiency that can be reliably transmitted. A comparison between the SCSI and CCSI resource allocation schemes in a fast fading environment is also presented. Then, we show that the limited resources reserved for feedback can be optimally used when the users with the lowest average SNR's send their CSI to the BS.

A. Impact of optimally selecting MCS levels

As AMC is always performed using imperfect CSI there will be a nonzero probability that the selected MCS level will not be optimized for the region where the current SNR lies. Fig.3 compares the throughput of a system when MCS levels are

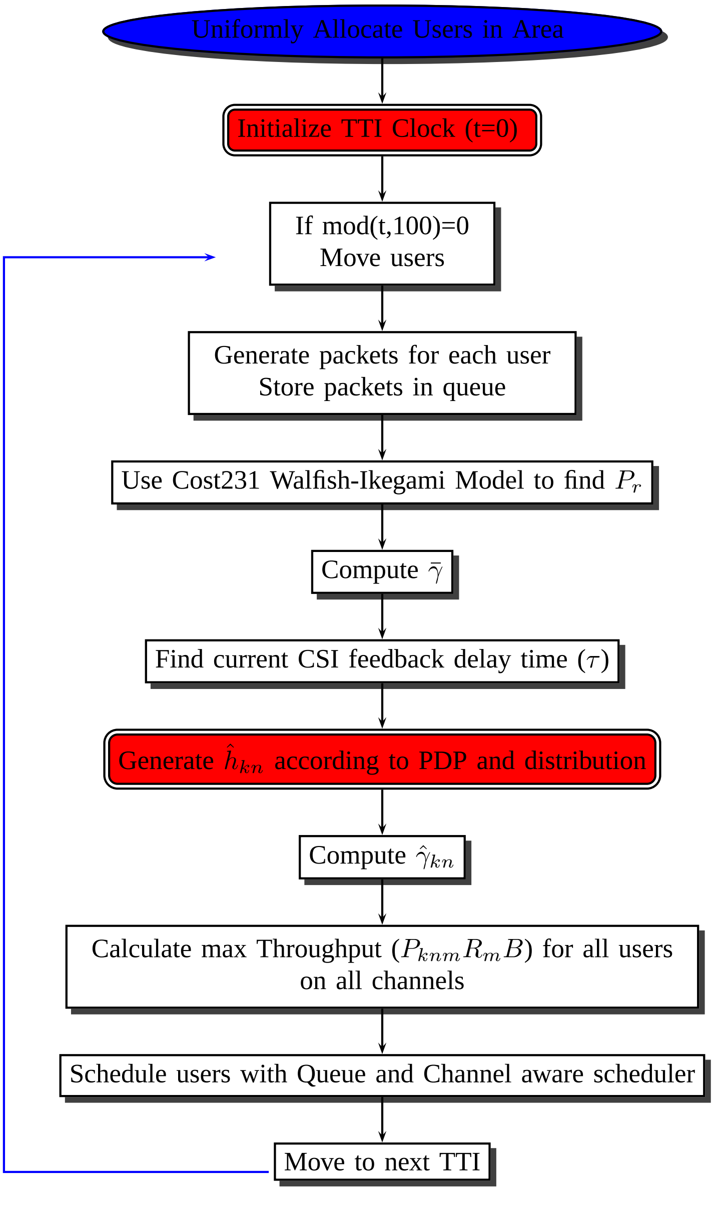

Figure 2. Block Diagram of Simulation Flow

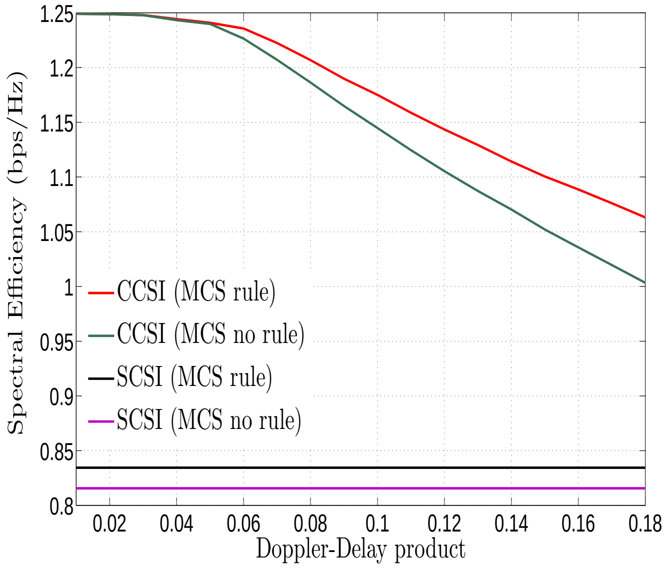

Figure 3. Spectral Efficiency vs $f_d\tau$ (packet arrival rate=1 packet/user/TTI)

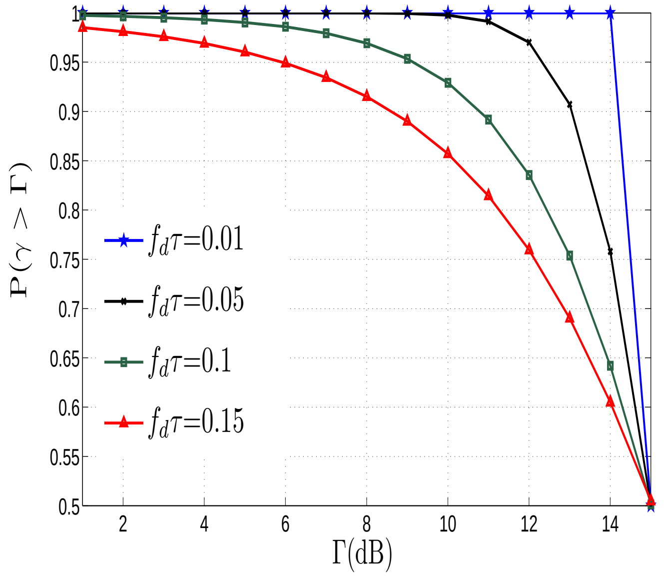

Figure 4. Probability of Exceeding an SNR threshold (Γ) vs Γ for different values of the Doppler-Delay product and $\hat{\gamma} = 15dB$

selected using the outdated/average SNR with the performance of the same system when (4) is used to perform AMC.

For the periodic CSI feedback scheme, these gains are lower when the value of the Doppler-Delay product $f_d\tau$ is small. As the value of $f_d\tau$ grows, the CSI becomes more outdated, and more MCS level selection errors occur. Therefore, the impact of the MCS level selection scheme is stronger. In Fig.4, we show that the probabilities of successful MCS level selection remain high as the value of $f_d\tau$ grows. This implies that high values of the throughput can be realized.

Using the rule of (4) to select MCS levels also leads to performance gains when SCSI is used to perform resource allocation. These results show that for the case where only a discrete number of modulation and coding levels are available maximizing the expected sum-rate leads to important throughput gains. These results are in agreement with those of [5] which focus on the continuous rate case (Shannon-capacity based formulation) and therefore have more theoretical rather than practical significance.

It is also important to present the impact of imperfect CSI on the bit error rate of the system as the value of $f_d\tau$ varies when a constraint on the target BER is not imposed on the system. As shown in [16], the instantaneous BER for M-QAM modulation schemes (as well as for BPSK) can be approximated for each user as

$$BER(\gamma) \approx 0.2\exp^{-1.6\frac{\gamma}{2^{\lfloor r(\gamma)\rfloor}-1}}, \tag{8}$$

where $r(\gamma)$ denote the number of bits per symbol corresponding to the applied modulation scheme and $\lfloor x \rfloor$ is the floor operation which provides the largest integer not greater than x. Fig.5 presents results showing the variation of the bit error rate with $f_d\tau$. Results show that in this case the use of CCSI leads to improved BER performance with the BER of the two cases approaching as the Doppler-Delay product grows.

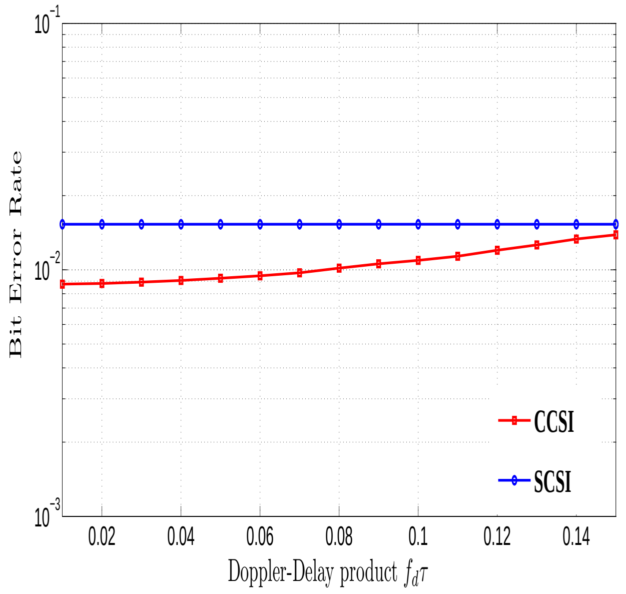

Figure 5. BER vs $f_d\tau$ for CCSI and SCSI based resource allocation schemes when a constraint is not imposed on the target BER

Fig.6 shows throughput vs velocity curves for a CSI measurement reporting period equal to 2 TTI's. The packet arrival rate for each user equals 1 packet/user/TTI. A processing delay time of one TTI is assumed with velocities ranging from 2km/h through 40km/h. Beyond these speeds, there is little correlation between the outdated and current CSI for the parameters considered. Results obtained for the case when the BS knows the instantaneous CSI (ICSI) are also plotted to provide a baseline comparison. When compared to SCSI, this figure shows that periodic CSI measurements lead to significant throughput gains for all of the velocities considered. In particular, a 43% throughput gain is observed when the user velocity equals $40km/h$.

B. Providing a tradeoff between overhead and throughput/fairness

It was established in the previous subsection that when the scheduler works with CSI that is correlated with its current state, significantly higher overall system throughput gains can be achieved. These gains are important even at high user velocities. However, they come at the cost of increased overhead requirements. This overhead load increases with user velocity and the number of active users present in the cell. Therefore, in a fast fading environment it is impractical to assume that all users feedback their CSI to the BS. In this section, we apply the strategy presented in Section 3 to the network under consideration. We divide the $K = 25$ active users present in the cell into two groups according to the value of their average SNR. The first group consists of the 13 users with the highest average SNR which are named Group A users. The remaining 12 users are called Group B. It is assumed that appropriate Connection Admission Control is performed so that the minimum user data rates are feasible for each user. For the duration of this simulation, users of Group B cannot move closer to the BS than any of the Group A users so that accurate results can be obtained.

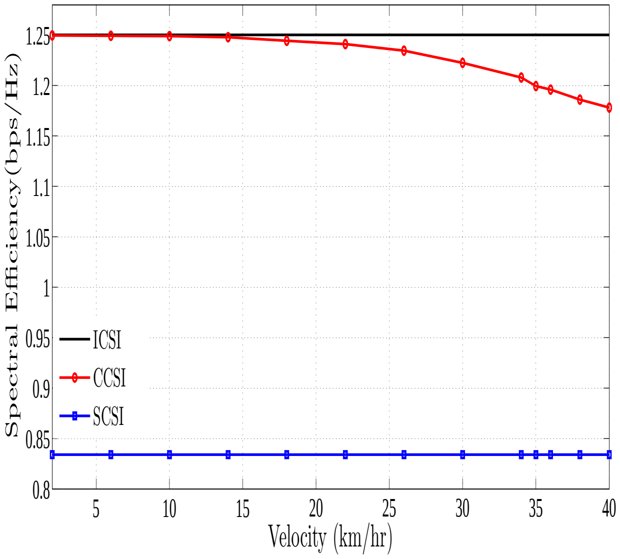

Figure 6. Spectral Efficiency vs Velocity when ICSI, SCSI and CCSI is used to perform resource allocation (packet arrival rate=1 packet/user/TTI)

The following cases are considered for evaluation

Case 1: Periodic CSI is received by the BS for all of the active users in the cell.

Case 2: Periodic CSI is received by the BS for only Group B users.

Case 3: 12 users (half from Group A and the other half from Group B) periodically send their CSI to the BS.

Case 4: Only Group A users send their CSI to the BS.

Case 5: No users send their CSI to the BS (only the average SNR of each active user is known by the BS).

In order to quantify the degree of fairness, we use Jain's fairness index which is defined as [20]

$$J = \frac{(\sum_{k=1}^{K} T_k)^2}{N \sum_{k=1}^{K} T_k^2} \tag{9}$$

where T_k is user $k's$ average throughput.

This factor measures the spread in the users' average throughputs T_k, and its value will always be within the range $1/N$ to 1 [20]. It can easily be verified that J = 1 indicates absolute fairness, whereas $J = 1/N$ indicates no fairness (all resources are allocated to a single user).

Figs 7 and 8 present the variation of the system's throughput and Jain's fairness factor with velocity for each of the cases considered. These figures show that when the users of Group B periodically send their CSI to the BS, higher throughput and fairness compared to the other cases (Case 3,4,5) is achieved. To see why Case 2 performs better we note that the employed CAC scheme has admitted 25 users into the network and that the packet arrival rate equals 1 packet/user/TTI. When Group A users do not periodically feedback their CSI their average queue lengths are not significantly affected as can be seen from the difference between Case 2 (Group A users do not feedback their CSI) and Case 4 (Group A users feedback their CSI) in Fig.9. This implies that allowing Group A users to feedback their

CSI does not lead to efficient usage of the resources allocated for overhead purposes. However, as users move further from the BS, they require more channels to meet their QoS demands. By enabling the users furthest from the BS to feedback their CSI a higher overall system throughput can be realized. This is because a higher number of allocated channels will have been bit-loaded with CCSI. Therefore, unlike [4], where only the users whose subchannel SNR exceeds a certain threshold feedback their channel quality, these results show that when a CAC unit is employed in conjunction with a scheduler, the queue states need to also be accounted for when deciding which users should feedback their CSI to the BS.

When there is no CAC functionality Case 4 (users with high average SNR feedback their CSI) yields the highest throughput. This is shown in Fig.10 where the 25 users each request a more bandwidth intensive service. The absence of CAC is depicted in Fig 12 which shows the very high queue lengths associated with Group B users when the packet arrival rate for each of the 25 users equals 3 packets/TTI. The absence of CAC functionality also leads to poor fairness as can be seen from Fig.11. In terms of fairness, the Jain factor remains higher for Case 2 regardless of the CAC scheme. This can be observed in Figs 8,11.

All these results show that as at high velocities, a high amount of overhead is needed for the BS to work with CSI that is correlated with the current CSI and the system-wide spectral resources available for feedback are limited; allowing only the users with the lowest average SNR to periodically send their CSI to the BS leads to a better tradeoff between the bandwidth occupied for feedback and throughput/fairness when an accurate CAC scheme is employed.

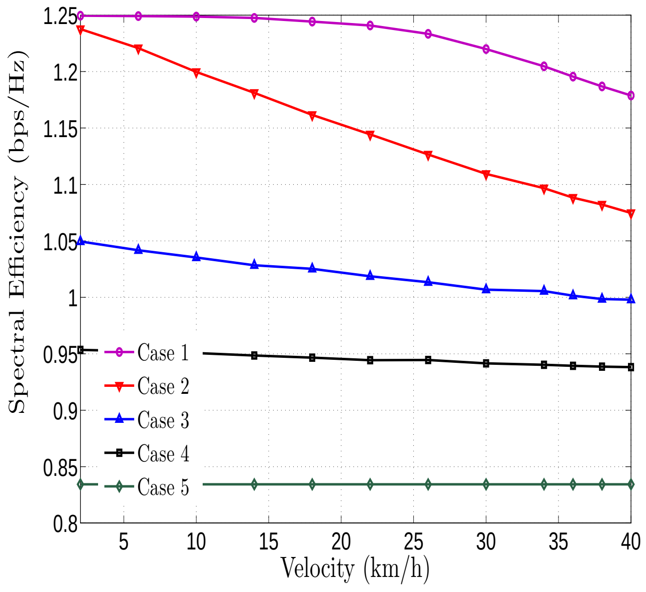

Figure 7. Spectral Efficiency vs user velocity for the 5 different cases considered (packet arrival rate =1 packet/user/TTI)

VI. CONCLUSION

This work shows that optimally selecting MCS levels leads to a performance enhancement when either SCSI or CCSI is used to perform resource allocation. A comparison between the SCSI and CCSI schemes shows that the use of CCSI leads to important throughput gains even under significant user mobility. Since in a fast fading environment, excessive overhead is required for the scheduler to continuously work with CCSI, we presented a strategy to optimally use the limited resources reserved for feedback purposes. Simulation results showed that this strategy leads to a higher overall fairness and system throughput when CAC functionality is considered.

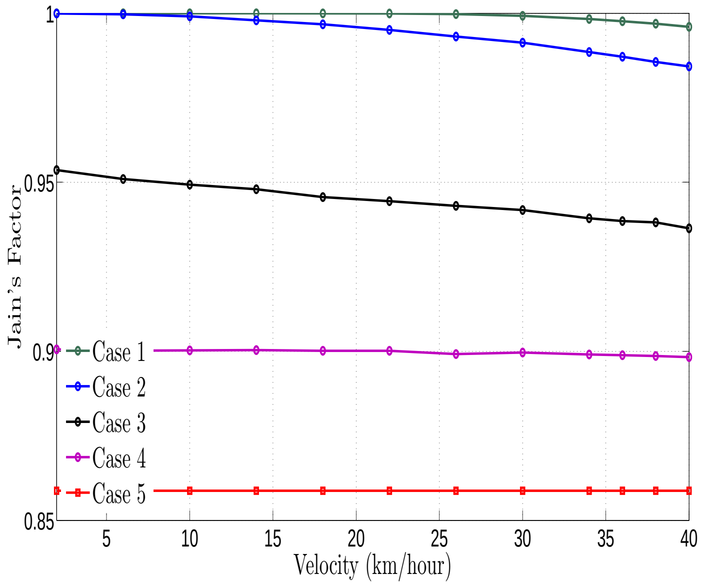

Figure 8. Jain Factor vs user velocity for the 5 different cases considered (packet arrival rate =1 packet/user/TTI)

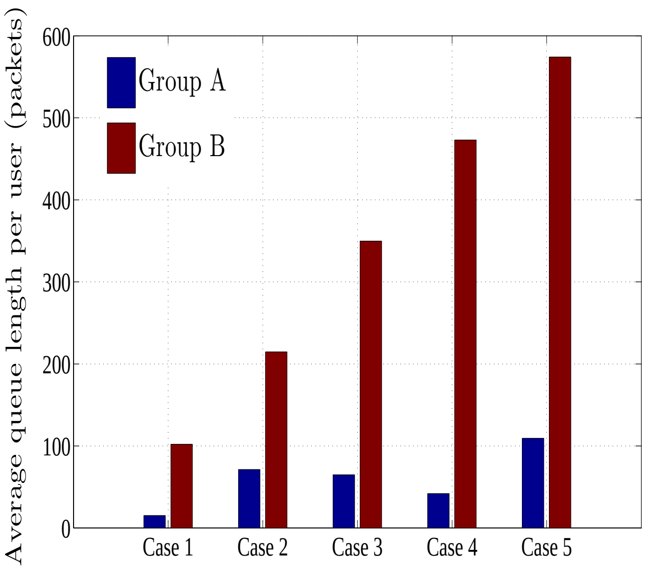

Figure 9. Average Queue length for the 5 different cases considered (packet arrival rate =1 packet/user/TTI, user velocity=40km/hour)

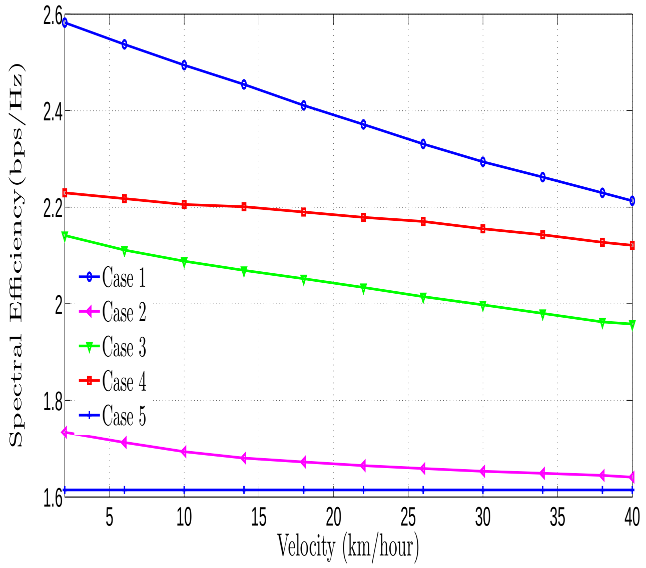

Figure 10. Spectral Efficiency vs user velocity when CAC unit not employed (packet arrival rate =3 packets/user/TTI)

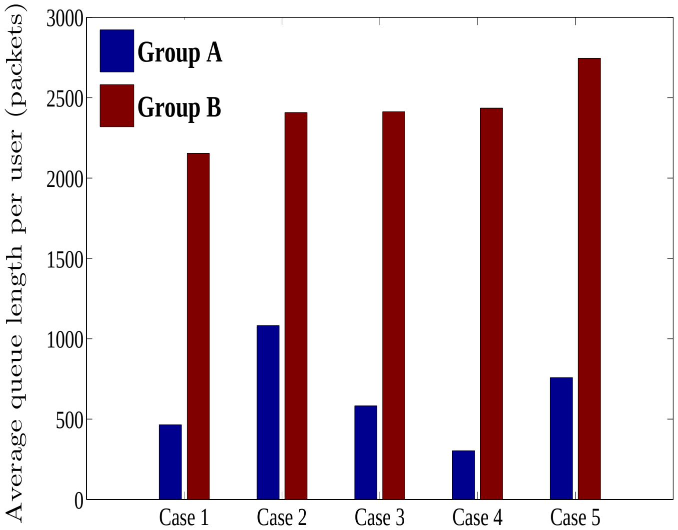

Figure 12. Average queue length when CAC unit not employed (packet arrival rate =3 packet/user/TTI, user velocity= 40km/hour)

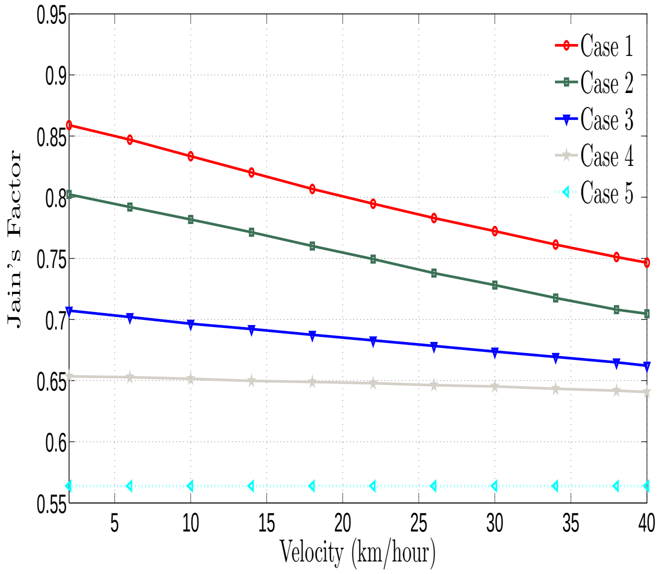

Figure 11. Jain Factor vs velocity when CAC unit not employed (packet arrival rate =3 packets/user/TTI)

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