# Scheduling Exploiting Frequency and Multi-User Diversity in LTE Downlink Systems with Heterogeneous Mobilities

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***Abstract:*** *Long-term evolution (LTE) represents an emerging and promising technology for providing broadband ubiquitous Internet access. LTE systems involve the allocation of resources in a manner to benefit the user by providing high data rate to the users. In resource allocation there is a major role of scheduling which has become an essential component for high- speed wireless data systems. In LTE systems, frequency diversity scheduling benefits high mobility users while frequency selective scheduling or multiuser scheduling benefits low mobility users. Scheduling exploiting frequency diversity and selectivity is desired to benefit both low and high mobility users simultaneously. We first propose a user mobility classification algorithm to identify low and high mobility users , robust to different channel delay profiles for SISO systems, then extend it to MIMO systems. A low complexity scheduling algorithm is developed exploiting both frequency selectivity and diversity for low and high mobility users simultaneously. The proposed user classification algorithm is robust to different CDPs and the proposed scheduling algorithm is effective. In this paper we will discuss about various user classification algorithms and scheduling algorithms to overcome the constraints of MCS and to fulfil the requirement of Quality of Services (QoS). We'll also analyze the throughput achieved by the user selected subband feedback scheme of LTE.*

***Index Terms-*** *Resource allocation, LTE downlink, Scheduling, mobility, frequency diversity, multi-user diversity, MIMO, user classification*

## I. INTRODUCTION

The growing demand for network services, such as VoIP, web browsing, video telephony, and video streaming, with constraints on delays and bandwidth requirements, poses new challenges in the design of the future generation cellular networks. 3GPP introduced the Long Term Evolution (LTE) specifications as an answer to this need, aiming at ambitious performance goals and defining new packet optimized and all-IP architectures for the radio access and the core networks.LTE access network, based on Orthogonal Frequency Division Multiple Access (OFDMA), is expected to support a wide range of multimedia and Internet services even in high mobility scenarios. Therefore, it has been designed to provide high data rates, low latency, and an improved spectral efficiency with respect to previous 3G networks[2]. To achieve these goals, the Radio Resource Management (RRM) block exploits a mix of advanced MAC and Physical functions, like resource sharing, Channel Quality Indicator (CQI) reporting, link adaptation through Adaptive Modulation and Coding (AMC), and Hybrid Automatic Retransmission Request (HARQ). LTE aims, as minimum requirement, at doubling the spectral efficiency of previous generation systems and at increasing the network coverage in terms of bit rate for cell-edge users. To make LTE networks highly flexible for a worldwide market, a variable bandwidth feature, that gives to network operators the possibility to throttle the bandwidth occupation between 1.4 and 20 MHz, is also included[2].

The LTE system is based on a flat architecture, known as the “Service Architecture Evolution”, with respect to the 3G systems . This guarantees a seamless mobility support and a high speed delivery for data and signalling[2].

As depicted in Fig 1, it is made by a core network, namely the “Evolved Packet Core”, and a radio access network, namely the Evolved-Universal Terrestrial Radio Access Network (E-UTRAN). The Evolved Packet Core

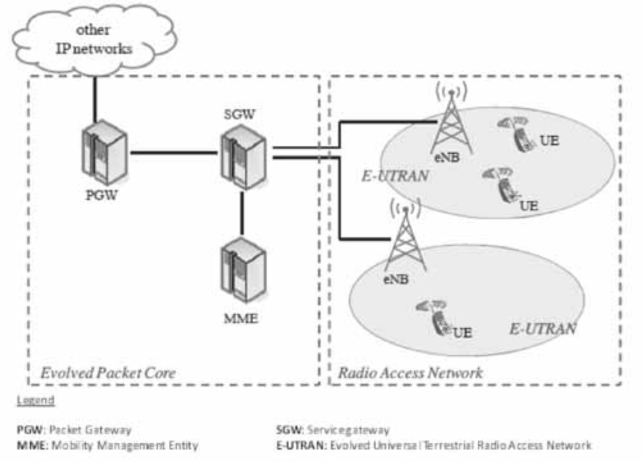


**Fig. 1: The Service Architecture Evolution in LTE network**

comprises the Mobility Management Entity (MME), the Serving Gateway (SGW), and the Packet Data Network Gateway (PGW). The MME is responsible for user mobility, intra-LTE handover, and tracking and paging procedures of User Equipments (UEs) upon connection establishment. The main purpose of the SGW is, to route and forward user data packets among LTE nodes, and to manage handover among LTE and other 3GPP technologies. The PGW interconnects LTE network with the rest of the world, providing connectivity among UEs and external packet data networks The LTE access network can host only two kinds of node:

1. The UE (that is the end-user) and
2. The eNB

Note that eNB nodes are directly connected to each other (this obviously speeds up signaling procedures) and to the MME gateway. Differently from other cellular network architectures, the eNB is the only device in charge of performing both radio resource management and control procedures on the radio interface[17].

### A. *Introduction To OFDMA*

Orthogonal frequency division multiple access (OFDMA) is a popular transmission scheme for broadband wireless communication systems, such as 3GPP LTE and IEEE 802.16 WiMAX. Frequency diversity and multi-user diversity are key features of OFDMA systems. Various resource allocation approaches have been developed to make full use of the inherent frequency and multiuser diversity in OFDMA systems. Frequency-diversity gain can be obtained by using a frequency-diversity scheduling (FDS) algorithm when accurate channel state information (CSI) of a user is not available at the transmitter, such as high mobility users. On the other hand, frequency-selectivity gain, one form of multiuser diversity gain in frequency domain, is achieved by using a frequency selective scheduling (FSS) algorithm, which allocates each user to a specific set of subcarriers with the best CSI. FSS is often used under scenarios for low-mobility users where accurate CSI feedback is possible[17].

### B. *Crossover Mobility*

Frequency selective scheduling uses BS (Base Station) estimates of MS (Mobile Station) channel conditions to approximate an optimal allocation of resources to users. It relies on reliable and timely estimates of channel conditions. Its performance is therefore commonly assumed to degrade as MS velocity is increased. The standard proposed alternative at high velocity is to use Frequency diverse scheduling, which spreads user resources over a large bandwidth so as average out the negative effects of frequency selective fading when it is no longer possible to capitalize on it. We compare the two approaches in 802.16e as MS velocity is increased to determine a practical crossover point for differential scheduling strategies[10]. User with mobility lower than the crossover mobility is classified as a low mobility user; otherwise, it is a high-mobility user.

### C. *User Mobility Classification*

The user's mobility classification should be with low complexity and exploit only limited feedback CSI in LTE downlink. CSI is fed back to the transmitter in the form of *channel quality indicator* (CQI) in LTE systems. Therefore we develop a user mobility classification algorithm based on user's CQI variance when knowing delay profiles of channels. However, CQI variance depends on both the user's mobility and delay profiles of wireless channels, and thus using a fixed value of CQI variance as a threshold to classify high- and low-mobility users for channels with different delay profiles will result in poor performance[1]. A robust user mobility classification algorithm was developed that is insensitive to the delay profiles of channels at the transmitter to facilitate the scheduling in LTE downlink systems with heterogenous user mobilities. We first focus on an algorithm for single-transmit-antenna systems. Then, we extend it to *multiple-input multiple-output* (MIMO) systems. Because of the limited resources, how to guarantee the multi-user diversity and frequency-selectivity gains simultaneously in a network becomes an important issue. If the multiuser diversity gain is guaranteed first, more resource will be allocated to the low-mobility users, only limited resource is left for high-mobility ones and the frequency-diversity gain will be diminished. So, we have developed a scheduling algorithm by taking these factors into account[3].

### D. Concept of EESM

In LTE *single-input single output* (SISO) systems, CQI is the only feedback information and is denoted as 15 different *modulation and code schemes* (MCS's) for transmission. MCS can be determined by several different schemes such as *exponential effective signal-to-interference-plus-noise ratio (SINR) mapping* (EESM) and *mutual information effective SINR mapping* (MIESM). We develop a subband-level CQI feedback scheme in which CQI is generated with group of PRBs called subband with the help of EESM . The basic idea of EESM is to find a compression function that maps the set of SINRs to a single value that is a good predictor of the actual BLER. Different from resource allocation in conventional systems, LTE specification requires that all RB's corresponding to the same user in any given *transmission time interval* (TTI) must use the same MCS. In order to guarantee *block-error rate* (BLER) performance of the resource block (RB) with the worst channel condition, it has been suggested to select an MCS for all RB's according to the worst CSI[8]. The scheme is further extended to proportional fair multiuser scheduling. Comparing the two scheduling algorithms: maximum rate scheduler and proportional rate scheduler, we found that a proportional-rate scheduler intend to improve fairness among users. Scheduling schemes were examined focusing on how the physical resource blocks were assigned. The PF scheduler is effective in reducing variations in user bit rates with little average bit rate degradation as long as user average SINRs are fairly uniform[6].

It can be easily seen that these schemes are very conservative and are unable to make full use of the RB's with better channel conditions. Therefore, a novel resource allocation scheme was proposed that allocates RB's, power, and rate (MCS) jointly to maximize the network throughput. In order to reduce the complexity, we divide the joint optimization problem into two separate ones, i.e., RB assignment and power allocation. Depending on the power allocation, we select a more aggressive but appropriate MCS .It not only ensures the BLER performance of the RB with the worst channel condition but also exploits the RB's with better channel conditions more efficiently[4].

To this end, in this paper we overview the key facets of LTE scheduling. In addition, a survey on the current research status in the field is presented along with a performance comparison of the most well known techniques.

The rest of the paper is organized as follows. In Sec. II an overview of LTE system focusing on LTE frame structure and CQI feedback is provided. In Sec. III, the radio resource management in LTE is presented. Sec. IV discusses some existing resource allocation scheduling algorithms for LTE systems. Sec. V addresses user mobility classification. Sec. VI develops a novel scheduling algorithm. Subband-level CQI Feedback scheme has been explained in section VII. Simulation results are presented in section VIII to demonstrate the performance improvement of the proposed algorithm. Conclusions are drawn in Sec IX.

## II. LTE FRAME STRUCTURE AND CQI FEEDBACK

### A. Frame structure

Orthogonal Frequency Division Multiplexing (OFDM) is the core of LTE transmission. The bandwidth is divided into sub-bandwidth in the form of subcarriers. Furthermore, the user's data transmits through time in the form of frames. In LTE, each downlink *frame* is 10 ms long and consists of ten subframes, each of duration 1 ms. A subframe consists of two 0.5 ms slots, with each slot consisting of seven OFDM symbols. In the frequency domain, the system bandwidth, *B*, is divided into several subcarriers, each of bandwidth of 15 kHz that contain a contiguous set of 12 subcarriers. Therefore, a resource block (RB) or the Physical Resource Block (PRB) is the radio resource that is available for a user in the 3GPP LTE system and is defined by both frequency and time domains. The number of RBs in a slot depends on the system bandwidth. Although scheduling a single PRBP to a user is possible, due to system efficiency and control overhead issues, it is typically performed in the unit of *resource block group* (RBG), which consists of several consecutive PRBPs[1].

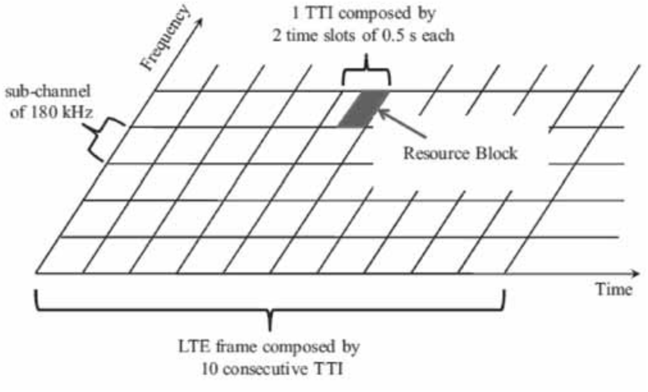


**Fig. 2: Time-Frequency Radio Resource Grid**

The feedback information sent by the (UE) is called the Channel Quality Indicator (CQI).The CQI is a 4-bit value that indicates an estimate of the MCS that the UE can receive reliably from the BS. It is typically based on the measured received signal quality, which can be estimated, for example, using the reference signals transmitted by the BS. The number of MCSs is denoted by $L$ and equals $2^4 = 16$.

## III. RADIO RESOURCE MANAGEMENT

Besides resource distribution, LTE makes massive use of RRM procedures such as link adaptation, HARQ, Power Control, and CQI reporting.

**CQI reporting**: The procedure of the CQI reporting is a fundamental feature of LTE networks since it enables the estimation of the quality of the downlink channel at the eNB. Each CQI is calculated as a quantized and scaled measure of the experienced Signal to Interference plus Noise Ratio(SINR). The main issue related to CQI reporting methods is to find a good tradeoff between a precise channel quality estimation and a reduced signaling overhead[2].

**AMC and Power Control**: The CQI reporting procedure is strictly related to the AMC module, which selects the proper Modulation and Coding Scheme (MCS) trying to maximize the supported throughput with a given target Block Error Rate (BLER). In this way, a user experiencing a higher SINR will be served with higher bit rates, whereas a cell-edge user, or in general a user experiencing bad channel conditions, will maintain active connections, but at the cost of a lower throughput. It is important to note that the number of allowed modulation and coding schemes is limited[4].

**Scheduling**: Recently, there has been an increasing demand for wireless applications with a wide range of quality of service (QoS) requirements. To meet these requirements, different proposed scheduling algorithms intend to provide bounded delay or throughput guarantees, or just simply to provide a best-effort type of service. There are three main issues that need to be considered in multiple access resource allocation. The first one is spectral efficiency, which means achieving maximum total throughput with available bandwidth and power. The second issue is fairness. In, it is studied that if the channel conditions are independent and identically distributed (i.i.d.), all users eventually will get the same service, hence fairness is maintained . On the other hand if the distance attenuations of users are different then some users will definitely get more service, and some others won't get any service. Therefore scheduling algorithms have to be proposed to provide fairness among nodes. The third important issue is satisfying quality of service (QoS) requirements.

## IV. DATA RATE AND SCHEDULING

Denote $x_m$, for m = 1,2,……., M to be the outcome of frequency resource allocation of M RBGs'. If RBG m is allocated to user k, then $x_m = k$. The resource allocation vector, $X = (x1; x2; \ldots\ldots x_M)$ will determine all RBGs allocation. If RBG m is allocated to user k at transmission time interval (TTI) n, then the corresponding instantaneous data transmission rate can be estimated as

$$R_{k;m;n} = f(C(k;m;n)) \tag{1}$$

where $C_{k;m;n}$ denotes the reported subband channel quality indicator (CQI) of user k for RBG m at TTI n, and the function f() maps the CQI to the estimated data-rate[1].

### *A. Frequency Selective Scheduling (FSS)*

In order to maximize the multi-user diversity gain using the proportional fairness (PF) based FSS algorithm, the base station will compare the PF metric for all users for each individual RBG and allocate the user with the best PF metric for each RBG. For the PF based FSS,

$$x_m = \hat{k} = \underset{k \in K}{\operatorname{argmax}} \frac{R_{k,m,n}}{\overline{T}_{k,n}} \tag{2}$$

where K = 1; 2;…….K is the index set of all K users and Tk;n denotes the average throughput for user k at TTI n. The average throughput can be obtained by low-pass filtering average

$$\overline{T}_{k,n+1} = (1-\tfrac{1}{N_T})\overline{T}_{k,n} + \frac{1}{N_T}T_{k,n} \qquad (3)$$

where T $_{k,n}$ is the actual throughput for user k at TTI n, which is obtained by the data rate of the positively acknowledged packet by user k at TTI n, and $N_T$ is the window size for filtering average.

The FSS based on PF metric selects the user with the best PF metric among all the users according to the subband CQI information. Therefore, the performance of the PF based FSS relates closely with the accuracy of subband CQI information. Thus, the PF based FSS is better for low-mobility users than high mobility ones[1].

### B. *Frequency Diversity Scheduling(FDS)*

With the increasing of mobile speed, the CQI information obtained at the transmitter becomes more and more inaccurate. As a result, the performance of the PF based FSS becomes worse and worse. In this case, frequency resource should be diversified to deal with the frequency-selective fading of wireless channels. In order to maximize the frequency diversity for one user, the PF based FDS will allocate the entire system bandwidth to it [2].That is

$$x_m = \hat{k} \qquad (4)$$

for m = 1;..........;M, and

$$\hat{k} = \arg\max_{k\in K} \frac{\overline{R}_{k,n}}{\overline{T}_{k,n}} \qquad (5)$$

where $T_{k,n}$ is the average throughput determined by (3), and Rk,n is the average data rate over M RBGs and can be obtained by

$$\overline{R}_{k,n} = \frac{1}{M}\sum_{m=1}^{M} R_{k,m',n} \qquad (6)$$

FDS has no frequency-selectivity gain. However, neither FSS nor FDS algorithm works well when high and low-mobility users coexist in a system[1].

## V. USER MOBILITY CLASSIFICATION

### A. *Existing Approach*

Performance of FSS degrades with the increase if user's mobility because of CSI while FDS is independent from user's mobilty. FSS and FDS will perform similarly at some point, called “crossover point”. The crossover point is around 15 kmph if the carrier frequency of a system is 2.6 GHz[1].

Denote $C_{k,m,n}$ to be the reported CQI of user k for RBG m at TTI n. If user k is with high mobility, then $C_{k,m,n}$ varies with n quickly. Otherwise, it changes slowly with TTI n. The variation of $C_{k,m,n}$ with time is determined by the mobility of user k. Therefore, to detect whether a user is with mobility or not, we only need to find the variance of $C_{k,m,n}$ by

$$\sigma^2_{k,m} = \frac{1}{N-1}\sum_{n=1}^{N}(C_{k,m,n}-\mu_{k,m})^2 \qquad (7)$$

Where

$$\mu_{k,m} = \frac{1}{N}\sum_{n=1}^{N} C_{k,m,n} \qquad (8)$$

For a user with low mobility, CQI varies with time but not as quickly as a high-mobility user. Therefore, variance estimation in (7) cannot be used directly. In order for identifying high and low-mobility users more accurately, we split overall available TTIs into several segments so that CQI does not change much within each one for low-mobility users but it varies for high-mobility users[1].

Denote Tc to be the coherent time of the crossover mobility. It can be expressed as

$$T_c = \sqrt{\frac{9}{16\pi}}\frac{1}{f_d} \qquad (9)$$

where $f_d$ is the Doppler shift at the crossover mobility. We choose the length of each segment based on the coherent time. Denote Tr to be the CQI reporting period, the length of time interval to report CQI for each user. As a result, each segment consists of $N_s = \left[\frac{T_c}{T_r}\right]$ ,CQI reporting periods, and the variance of CQI at RBG m in the ith time segment can be estimated by

$$\sigma^2_{i,k,m} = \frac{1}{N_S-1}\sum_{n=Tr(i-1)+1}^{Tri+Ns}(C_{i,k,m,n}-\mu_{i,k,m})^2 \qquad (10)$$

With

$$\mu_{i,k,m} = \frac{1}{N_s}\sum_{n=Tr(i-1)+1}^{Tri+Ns} C_{i,k,m,n} \qquad (11)$$

If user k operates on M RBGs and $N_l$ time segments, we can average the estimated variance over M RBGs and $N_l$ time segments to obtain a more accurate estimate of the variance of CQI corresponding to user k. Then

$$\sigma_k^2 = \frac{1}{M}\sum_{m=1}^{M}\frac{1}{N_l}\sum_{i=1}^{N_l}\sigma_{i,k,m}^2 \qquad (12)$$
$$= \frac{1}{MN_l(N_S-1)}\sum_m\sum_i\sum_n (C_{i,k,m,n}-\mu_{i,k,m})^2$$

Denote $\sigma_T^2$ as the variance of CQI when a user is with crossover mobility. Then user k will be identified as high mobility one if $\sigma_k^2 \geq \sigma_T^2$ otherwise, it is a low mobility user.

The above approach, can effectively classify users when the delay profile of the corresponding channels is known since the CQI variance also changes with the delay profile. When the delay profile of a channel is unknown, however, this approach will result in much inaccurate user classification[3].

### *B. Robust User Mobility Classification*

Different application environments of LTE systems will have different delay profiles, which results in different coherence bandwidths according to the fundamental time-frequency duality, and thus affects the CQI variance[3].

As we have analyzed that, when the delay spread of a channel is larger, the coherence bandwidth will be relatively smaller and the CQI variance will become smaller due to frequency diversity. On the contrary, when the channel delay spread is smaller, the coherence bandwidth will be relatively larger, and the CQI variance will become bigger[3].

In order to mitigate this effect, we introduce a function, f(), in computing the CQI variance of each user, that is

$$\sigma_k^2 = \frac{1}{MN_l(N_S-1)}\sum_m\sum_i\sum_n f((C_{i,k,m,n}-\mu_{i,k,m})^2) \qquad (13)$$

And

$$f(x) = \begin{cases} 1 & \text{If } x > c \\ 0 & \text{otherwise} \end{cases} \qquad (14)$$

where c is a predetermined constant and is assumed to be 0 for simplicity[3] .

### *C. Extension to MIMO systems*

MIMO is one of the most important techniques in wireless communications. It can be used in LTE to achieve high peak data rates and spectral efficiency and to improve the robustness of data transmission. Here, we will extend our robust user mobility classification algorithm to MIMO systems to facilitate scheduling in that case. Because channel varies with time and frequency in general, a user sometimes reports only one CQI for each subband while it may also report two CQIs per subband, called single-stream and dual-stream, respectively, in LTE downlink systems. In order to use the similar user classification algorithm as in the single-stream scheme, we need to use a unified CQI variance for each subband to classify users[3].

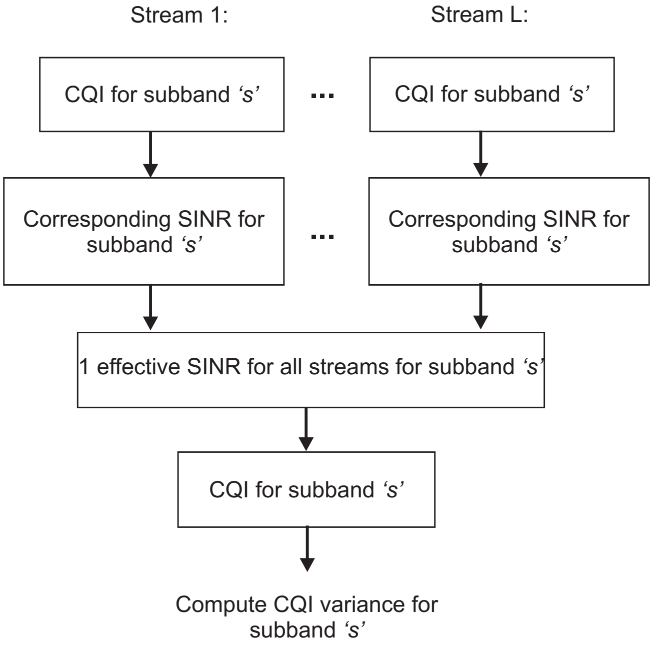


**Fig. 3: Robust user Mobility Classification for Multi-Stream MIMO Systems.**

Fig. 3 illustrates the process of extending the robust user mobility classification algorithm for single-stream systems to multi-stream systems. As shown in the figure, the critical point is to combine CQI feedback information of different streams into one effective CQI value. Denote *Ck,m,n,l* to be the reported CQI of user *k* for stream *l* on RBG *m* at TTI *n*, then the corresponding *signal to- interference-and-noise ratio* (SINR), *ãk,m,n,l* can be estimated as in [14]. Thus the overall effective SINR on subband *k* for all streams can be obtained by

$$\gamma_{k,m,n} = I^{-1}\left(\frac{1}{L}\sum_{l=1}^{L} I(\gamma_{k,m,n.l})\right) \qquad (15)$$

where *L* is the total number of streams. The function *I* (·) is the mutual information function and *I*”1(·) is its inverse.Then, the overall effective CQI value for the *L* streams can be obtained according to [14]. Once we have the overall effective CQI value, we can use the same method as (5) to compute the CQI variance for MIMO systems and then classify users[3].

## VI. FREQUENCY DIVERSITY AND SELECTIVITY SCHEDULING

In this section, a scheduling algorithm was developed that obtains multi-user diversity for low-mobility users and frequency diversity for high-mobility users simultaneously, which is called PF based frequency-diversity and selectivity scheduling (FDSS) algorithm. The FDSS algorithm is based on user mobility classification[1]. Therefore, we assume that the index sets of high and low mobility users, KH and KL, have been determined. The first step of the FDSS algorithm is to find out the optimal low-mobility user for each RBG. Therefore, the initial resource allocation indicator can be expressed as

$$x_m = \arg\max_{k\in K_L} \frac{R_{k,m,n}}{\overline{T}_{k,n}} \qquad (16)$$

for 1 d” m d” M. It is similar to FSS in (2) except that the overall set, K , is substituted by the low-mobility user set, KL, here. Then the optimal high-mobility user will be determined by

$$\hat{k}_h = \arg\max_{k\in \mathrm{K}} \frac{\overline{R}_{k,\,n}}{\overline{T}_{k,\,n}} \qquad (17)$$

Note that Rk;n in the above is found by averaging over several uniformly distributed RBGs, which is almost the same as over the entire M RBGs in (6).That is

$$\overline{R_{k,n}} = \frac{1}{M}\sum_{m=1}^{M} R_{k,m,n} \approx \frac{1}{j}\sum_{i\in Sj} R_{k,i,n} \qquad (18)$$

Where

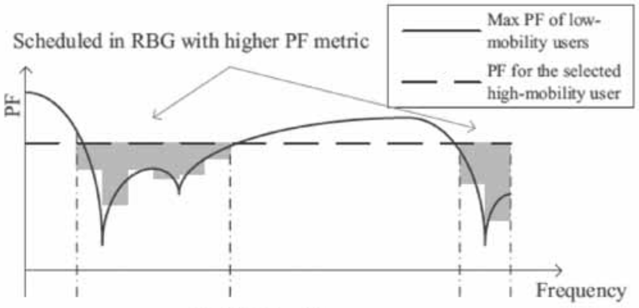
$$S_j = \{i \mid i = \left\lfloor \frac{M-1}{j-1} v + 0.5 \right\rfloor + 1, v = 0,\dots, j-1\} \qquad (19)$$

To maximize the throughput of the system, only the optimal high-mobility user will be considered whether it should be assigned resource or not. The optimal high-mobility user will be assigned uniformly distributed RBGs only if such change results in the throughput increase as compared with that when those RBGs are assigned to their corresponding low-mobility user in (18). That is

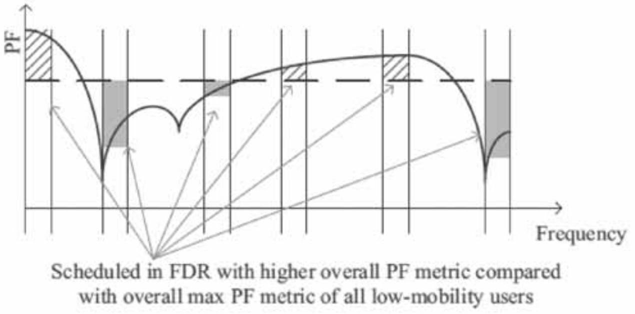
$$\Delta R_{j,k_h,n} = \frac{j.\overline{R_{k_h,n}}}{\overline{T}_{k_h,n}} - \sum_{m\in S_j} \max_{k'\in K_L} \frac{R_{k',m,n}}{\overline{T}_{k',n}} \rangle 0 \qquad (20)$$

for some j. If there are multiple j ‘s that satisfy (20), then we will choose a j to maximize the throughput increment $\Delta R_{j,kh,n}$. The average data transmission rate across the whole bandwidth for the high-mobility user, $\overline{R}_{kh,n}$ is used in (20) because of its robustness to the inaccurate CQI feedback information[1].

Fig. 4 shows the principles of the PF metric based FSS algorithm and the FDSS scheduling algorithm, where the horizontal axis corresponds to the frequency domain, the vertical axis corresponds to the PF metric, the solid line shows PF metric for the optimal low-mobility users and the dashed line shows the PF metric for the optimal high-mobility user across the entire frequency domain. For the FSS algorithm of fig 4, the RBGs containing grey shaded area will be scheduled to the high-mobility users while other RBGs will be scheduled to the low-mobility users. Fig 4 is on RBG allocation for high-mobility users, where the grey shaded area and slashed area are the difference between the PF metric of the optimal high-mobility user and maximum PF metric of all low-mobility users. For the FDSS algorithm, the high-mobility user will be scheduled if and only if the overall grey shaded area is larger than the overall slashed area. The FSS algorithm does not guarantee frequency diversity for the high-mobility users because it may allocate localized RBGs as shown in Fig. 4[1].



(a) FSS Algorithm



(b) FDSS Algorithm

**Fig. 4 : An Example of FSS and FDSS Algorithm.**

The FDSS algorithm can be summarized as the following steps:

1. Find the optimal low-mobility user for each individual RBG according to (16);
2. Find the optimal high-mobility user, kh, according to (17),(18),(19).
3. Change the scheduling information for these RBGs assigned to the high mobility users by xm = kh for m • Sj if (19) is satisfied[1].

**IFDSS-** Then we develop an improved scheduling algorithm, denoted as *improved FDSS* (IFDSS), to ensure frequency and multi-user diversity gain for both high- and low-mobility users. IFDSS utilizes the fact that PF scheduler allocates equal number of resources to each user in the long term and thus more resources will be allocated to a high-mobility user when it is scheduled. The PF scheduler compensates the loss of scheduling opportunity among high mobility users by allocating more resources per scheduling instant, resulting in more frequency diversity for them. IFDSS not only improves performance but also with low complexity at the base station and low signaling overhead. Compared with FDSS which finds optimal high mobility user by searching for all possible uniformly distributed RBG combinations, IFDSS does not need the full search and allows direct comparison among users on each RBG. In addition, the average data rate can be computed at the user side, resulting in lower feedback overhead compared with FDSS[3].

## VII. SUBBAND LEVEL CQI FEEDBACK SCHEME

In the popular frequency division duplex (FDD) mode of operation in LTE, the uplink and downlink channels are not reciprocal. Therefore, this channel information needs to be fed back to the BS by each user. Such extensive subcarrier level feedback is practically infeasible as it consumes an extremely large amount of uplink resources. Hence, a balance needs to be struck between gains due to multiuser diversity and the amount of feedback required . For this purpose we develop a subband-level CQI feedback scheme in which CQI is generated with group of PRBs called subband with the help of Effective Exponential Signal to Noise Ratio Mapping (EESM)[8].

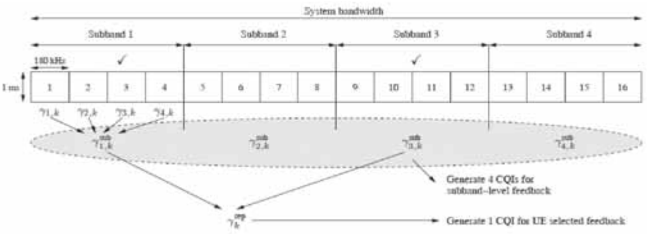


**Fig 5. Subband level CQI feedback scheme**

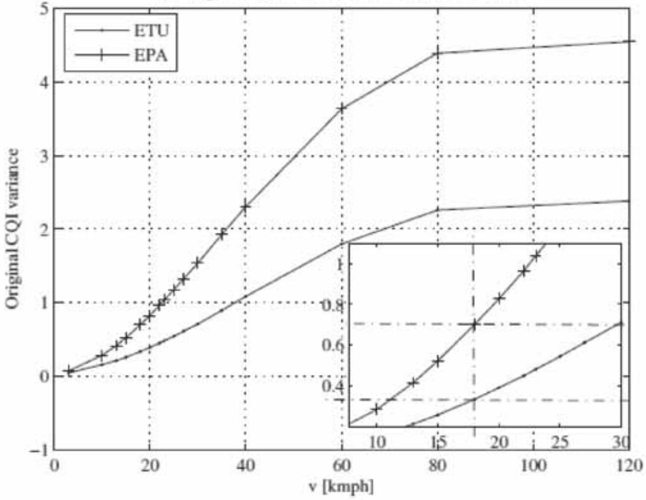
## VIII. SIMULATION RESULTS

In this section, we will demonstrate the performance of the proposed user mobility classification algorithm and scheduling algorithm under the LTE specifications, including *hybrid ARQ* (HARQ) retransmission with *incremental redundancy* (IR) combining, CQI feedback period, and CQI processing delay, etc. *Outer loop link adaptation* (OLLA) will be performed to regulate the first packet error rate to be 10%.The system level simulation is according to the IMT-Advanced technology evaluation guidelines where channel *power delay profiles* (PDPs) are implemented into the ones in 3GPP *Extended Typical Urban* (ETU) and *Extended Pedestrian A* (EPA) with root mean square channel delay spread of 991 ns and 45 ns, respectively. Users are randomly scattered over the entire network. First of all, we'll explore the original CQI variance and the modified one for different channels with average of 20 users per cell in SIMO mode. Then we will demonstrate the performance of the proposed FDSS algorithm and compare it with FSS and FDS in practical LTE deployment scenarios with mixture of high- and low-mobility users. We will study the system throughput for the case, Case A where there are 70% of users with 3 kmph and 30% of users with 120 kmph. At the end , we will study the scheduling performance of IFDSS under SIMO and MIMO modes respectively[3].

### *A. Comparison of Original and Modified CQI Variance*

We explore the original CQI variance and the modified one for different channels with average of 20 users per cell in SIMO mode in this section. We assume that all users are at the same speed, *v*, and the CQI variance is averaged over all users. Fig. 6 compares the original CQI variance and the modified one for ETU and EPA channels. From the figure, both the original CQI variance and modified one increase with the user speed. The EPA channel with smaller channel delay spread, has a large CQI variance than the ETU channel. Comparing Fig. 6(a) and (b), the modified CQI variance is less sensitive to different channel delay profiles than the original one. Different from [1], the crossover mobility is around 18 kmph under our simulation scenario due to the difference in system carrier frequency configuration. Therefore, we will use the CQI variance at the speed of 18 kmph as a threshold for user classification. From Fig. 6, the original CQI variance thresholds are 0.7016 and 0.3363 for EPA and ETU channels, respectively, while the modified CQI variance thresholds are 1.183 and 0.9648, respectively. Therefore, the threshold for modified CQI variance is less sensitive to different channels. When the delay profile of channel is unknown and the original CQI variance is sensitive to channel delay profiles, classifying users based on the threshold of one channel model will obviously not work well for other models[3].

(a) Original CQI variance under different channels.



(b) Modified CQI variance under different channels.

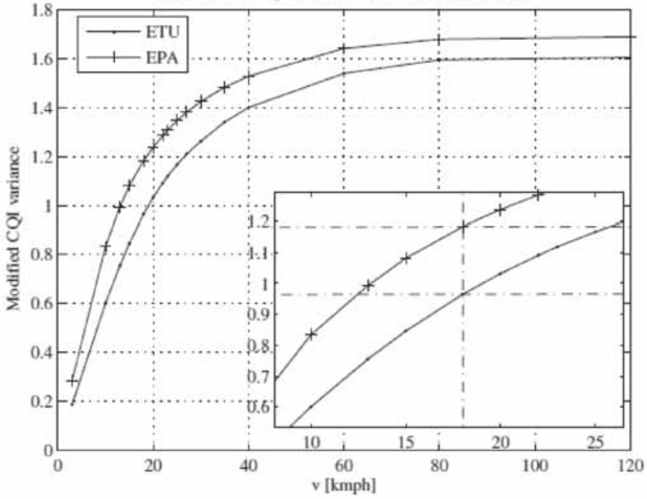


**Fig 6: Characteristic of Original and Modified CQI Variance under Different Channels.**

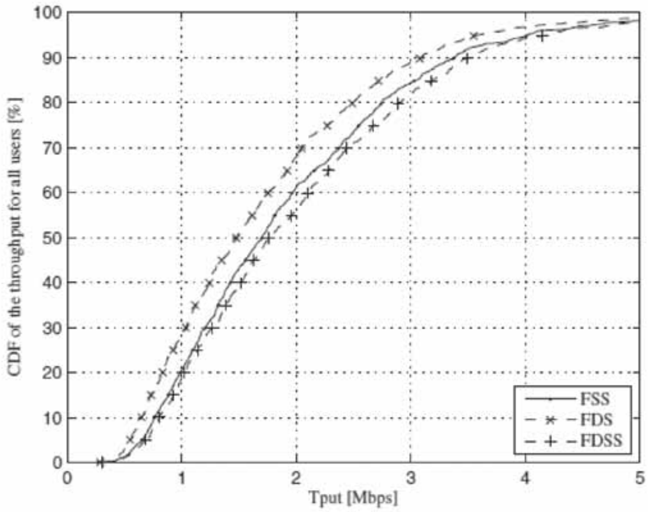
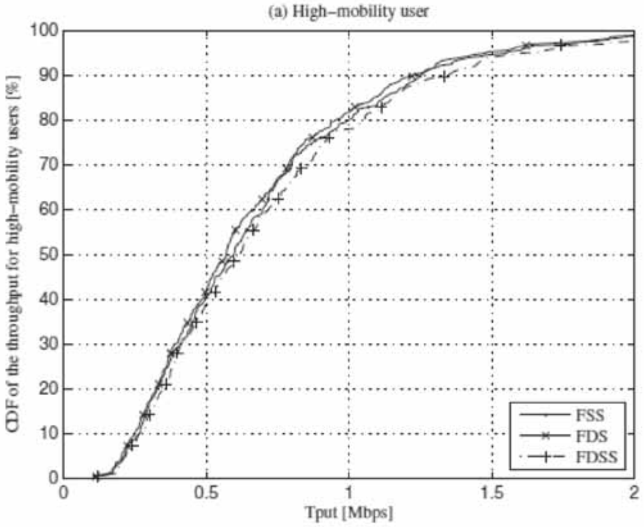


**Fig.7: Cumulative Density Function of All User Throughput Under Case A**

*B. (1) Throughput Comparison for All Users*

Fig. 7 demonstrates the *cumulative density function* (CDF) of the throughput for all users under Case A. From Fig. 7, the proposed FDSS outperforms the FSS and the FDS, and enhances throughput for all users. Note that performance of the FDS is always worse than the FSS since there are only 30% users that benefit from frequency diversity, and the frequency-selectivity gain is the dominant factor[3].

(a) High−mobility user



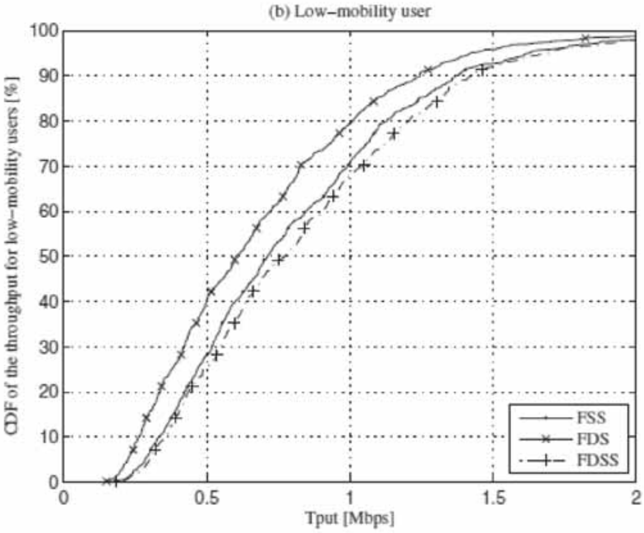


**Fig. 8: Cumulative Density Function of High and Low-Mobility users Throughput under Case A.**

### *(2) Throughput Comparison for High- and Low-Mobility Users*

Fig. 8 shows the throughput for the high- and low-mobility users separately under Case A to demonstrate where the throughput benefit for the proposed algorithm comes from. From Fig. 8 (a), the overall throughput of the high-mobility users scheduled with the FSS falls below with the FDS. Even though the proposed scheme does not always schedule users in the whole bandwidth because of distributed resource allocation, we are able to meet almost the same performance as the FDS for high-mobility users as shown in Fig. 8 (a). As a consequence, the low-mobility users have more RBGs for throughput improvement. The throughput gain of the FDSS is larger for the low-mobility users in Fig. 8 (b) than the high-mobility ones in Fig. 8(a)[3].

When high- and low-mobility users co-exist, the proposed FDSS outperforms the FSS and the FDS and improves 10th percentile and overall cell throughput simultaneously. Therefore, the proposed FDSS benefits both low- and high-mobility users.

## *C. Comparison of FDSS and IFDSS*

In this section, we will study the scheduling performance of IFDSS under SIMO and MIMO modes, respectively. User classification based on modified CQI variance is performed during the whole scheduling period. The number of windows for average, *Nl*, increases with the increasing of the scheduling TTIs. For MIMO mode, we consider MIMO with no *precoding matrix information* (PMI) feedback for simplicity, and rank adaptation between transmit diversity for rank 1 and *openloop spatial multiplexing* (OLSM) for rank 2 is implemented[3].

### *(1) Average Scheduled Resource Blocks and Scheduling Frequency:*

Fig. 9 shows the *cumulative distribution function* (CDF) of scheduled *Resource Blocks* (RBs) per TTI for all users, scheduled RBs per scheduled TTI, and average scheduling frequency for SIMO mode, with mean, *ì*, and standard variance, *ó*, marked in the figure. Fig. 9(a) shows the CDF of scheduled RBs per TTI for all users with SIMO mode, where scheduled RBs per TTI for each user is defined as

$$\mathrm{SRBTTI} = \frac{\text{Number of scheduled RBs}}{\text{Number of total TTIs}}$$

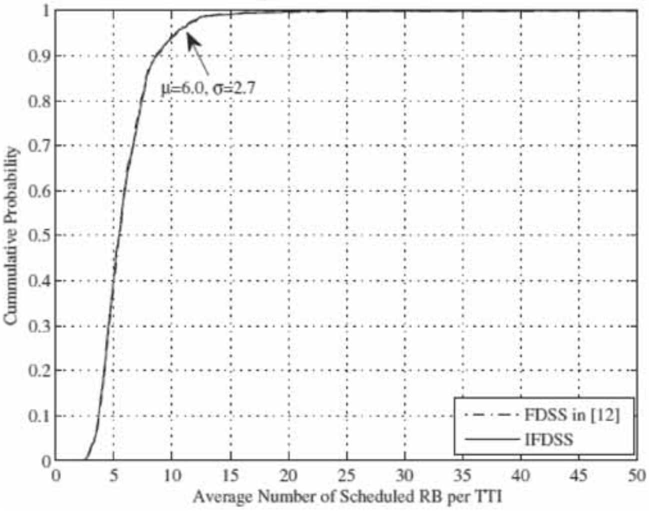
From the figure, the average number of allocated RBs is identical for FDSS and IFDSS as they both are based on PF. Fig. 9(b) shows the CDF of scheduled RBs per scheduled TTI with SIMO mode, where scheduled RBs per scheduled TTI for each user is defined as

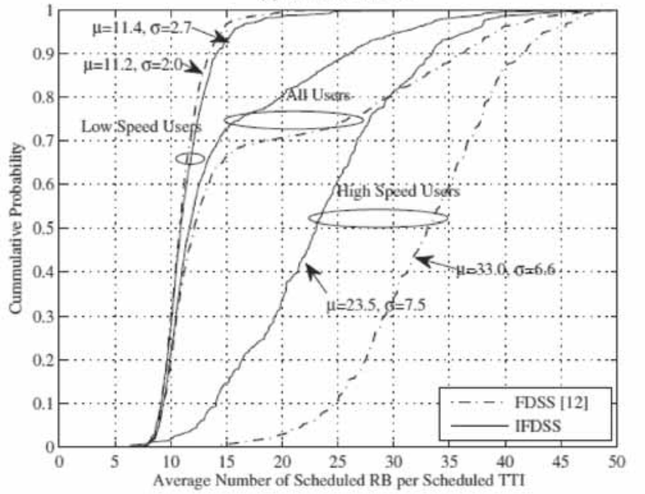
$$\mathrm{SRB}_{\mathrm{S\text{-}TTI}} = \frac{\text{Number of scheduled RBs}}{\text{Number of Scheduled TTIs}}$$

The number of allocated resources for all users is identical for FDSS and IFDSS in Fig. 9(a) while the average number of scheduled RBs per scheduling instance for high-mobility users in FDSS is larger than that in IFDSS in Fig. 9(b) since FDSS performs full search and always tries to guarantee frequency diversity for high-mobility users. However, Fig. 9 (b) shows that the average number of scheduled RBs in each scheduling instance for IFDSS is enough to capture frequency diversity gain and achieve similar performance as FDSS. Fig. 9(c) illustrates the CDF of average scheduling frequency for all users with SIMO mode, where the average scheduling frequency for each user is defined as

$$\mathrm{AvgSF} = \frac{\text{Number of scheduled TTIs}}{\text{Number of total TTIs}}$$

which indicates the average queuing time of a packet for a user. In general, shorter queuing delay, corresponding to higher scheduling frequency, is favored. From the figure, the average scheduling frequency with IFDSS is better than that with FDSS.


(a) Per TTI for all users.


(b) Per Scheduled TTI.

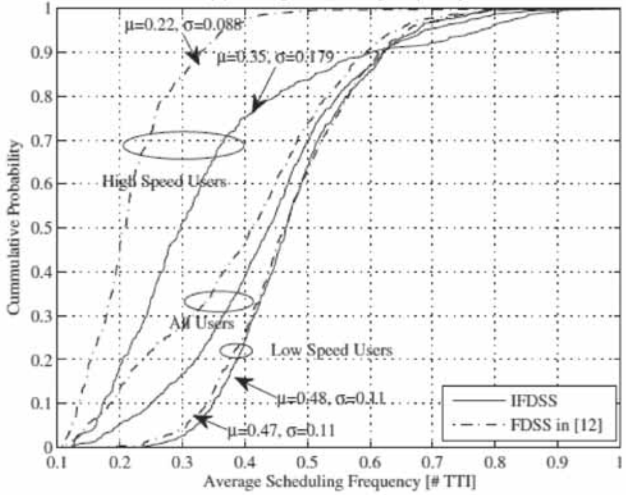

(c) Average scheduling frequency.

**Fig. 9: CDF with SIMO mode**

FDSS and IFDSS both perform better than FSS and FDS and IFDSS is best among all the scheduling algorithms for both SIMO and MIMO[3].

## IX. CONCLUSION

In this paper, we have developed a user mobility classification algorithm and a scheduling algorithm for users with different mobilities in LTE downlink systems. We have also developed a robust user mobility classification algorithm to facilitate the scheduling in LTE downlink systems with single data stream, and then extended it to multiple streams MIMO systems to take into account rank adaptation issues. We have compared the performance of frequency-selective scheduling and frequency-diversity scheduling with the proposed scheduling algorithm We have also provided an improved scheduling algorithm. In particular, the proposed algorithm benefits the low-mobility users while achieving the frequency-diversity gain needed for the high-mobility users. We have shown by simulation that the proposed user classification algorithm is robust to different channel models and the modified scheduling algorithm has significant performance gains compared with FSS and FDS algorithms.

## REFERENCES

[1] J.P. Niu, D.W. Lee, X.F. Ren, G.Y. Li, and T. Su, “Scheduling exploiting frequency and multi-user diversity in LTE downlink systems,” *IEEE Trans. Wireless Commun.*, vol. 12, no. 4, pp. 1843–1849, 2013.

[2] F. Capozzi, G. Piro, L. Grieco, G. Boggia, and P. Camarda, “Downlink packet scheduling in lte cellular networks: Key design issues and a survey”, Communications Surveys Tutorials, IEEE, vol. 15, no. 2, pp. 678_700, 2013.

[3] Jinping Niu, Daewon Lee, Tao Su, Geoffrey Y. Li, *Fellow, IEEE, and Xiaofeng Ren*, “User Classification and Scheduling in LTE Downlink Systems with Heterogeneous User Mobilities”, IEEE Transactions On Wireless Communications, Vol. 12, No. 12, December 2013

[4] J. Fan, Q. Yin, G. Y. Li, B. Peng, and X. Zhu, “Adaptive block level resource allocation in OFDMA networks,” *IEEE Trans. Wireless Commun.*, vol. 10, pp. 3966–3972, 2011.

[5] R. Kwan, C. Leung, and J. Zhang, “Multiuser scheduling on the downlink of an LTE cellular system,” *Research Lett. Commun.*, vol. 2008, pp. 1–3, Jan. 2008.

[6] H. Kim and Y. Han, “A proportional fair scheduling for multicarrier transmission systems,” *IEEE Commun. Lett.*, vol. 9, no. 3, pp. 210–212, Mar. 2005.

[7] S.N. Donthi and N. B. Mehta, “Joint performance analysis of channel quality indicator feedback schemes and

frequency-domain scheduling for LTE," *IEEE Trans. Veh. Technol.*, vol. 60, no. 7, pp. 3096–3109, Sep. 2011.

[8] Sushruth N. Denthi and Neelesh B. Mehta, "An accurate model for EESM and its application to analysis of CQI feedback schemes and scheduling in LTE," *IEEE Trans. Commun.*, vol. 10, no. 10, pp. 3436–3448, Oct. 2011.

[9] S. J. Lee, "Trade-off between frequency diversity gain and frequency selective scheduling gain in OFDMA systems with spatial diversity," *IEEE Commun. Lett.*, vol. 11, no. 6, pp. 507–509, June 2007.

[10] A. Mills, D. Lister, M. D. Vos, and Y. Ji, "The impact of MS velocity on the performance of frequency selective scheduling in IEEE 802.16e Mobile WiMAX," in *Proc. 2010 IEEE Consumer Commun. Netw. Conf.*, pp. 1–5.

[11] J. Capka and R. Boutaba, "Mobility prediction in wireless networks using neural networks," *Manage. Multimedia Netw. Services*, pp. 237– 246, 2004.

[12] Y.R. Zhen and C. Xiao, "Mobile speed estimation for broadband wireless communications," in *Proc. 2007 IEEE Wireless Commmun. Netw. Conf.*, pp. 2420–2425.

[13] J. Chan and A. Seneviratne, "A practical user mobility prediction algorithm for supporting adaptive QoS in wireless networks," in *Proc. 1999 IEEE Int. Conf. Netw.*, pp. 104–111.

[14] R. Kwan, C. Leung, and J. Zhang, "Proportional fair multiuser scheduling in LTE," *IEEE Signal Process. Lett.*, vol. 16, no. 6, pp. 461–464, June 2009.

[15] TS36.213 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Layer Procedures, 3GPP Std., Rev. 8.8.0, Sep. 2009.

[16] J.C. Fan, Q. Yin, G.Y. Li, B. Peng, and X. Zhu, "MCS selection for throughput improvement in downlink LTE systems," in *Proc. 2011 IEEE Int. Conf. Comput. Commun. Netw.*, pp. 1–5.

[17] F. Khan, *LTE for 4G Mobile Broadband: Air Interface Technologies and Performance*. Cambridge University Press, 2009.

[18] K. Pedersen, G. Monghal, I. Kovacs, T. Kolding, A. Pokhariyal, F. Frederiksen, and P. Mogensen, "Frequency domain scheduling for OFDMA with limited and noisy channel feedback," in *Proc. 2007 IEEE Veh. Technol. Conf.*, pp. 1792–1796.

[19] International Telecommunication Union, "Guidelines for evaluation of radio interface technologies for IMT-Advanced," ITU-R, Rep. M.2135- 1, 2010.

[20] TS36.101 Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) Radio Transmission and Reception, 3GPP Std., Rev. 11.0.0, Mar. 2012.

[21] T. Rappaport, *Wireless Communications: Principles and Practice*. Prentice Hall, 2002.

[22] M. Assaad, "Reduction of the feedback delay impact on the performance of scheduling in OFDMA systems," in *Proc. 2009 IEEE Veh. Technol. Conf.*, pp. 1–4.

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