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Advanced Access Schemes for Future Broadband Wireless Networks

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1. Introduction

Bandwidth allocation in next generation broadband wireless networks (4G systems) is a difficult issue. The scheduling shall support efficient multimedia transmission services which require managing users mobility with fairness while increasing system capacity together. The past decades have witnessed intense research efforts on wireless communications. In contrast with wired communications, wireless transmissions are subject to many channel impairments such as path loss, shadowing and multipath fading. These phenomena severely affect the transmission capabilities and in turn the QoS experienced by applications, in terms of data integrity but also in terms of the supplementary delays or packet losses which appear when the effective bit rate at the physical layer is low.

Among all candidate transmission techniques for broadband transmission, Orthogonal Frequency Division Multiplexing (OFDM) has emerged as the most promising physical layer technique for its capacity to efficiently reduce the harmful effects of multipath fading. This technique is already widely implemented in most recent wireless systems like 802.11a/g or 802.16. The basic principle of OFDM for fighting the effects of multipath propagation is to subdivide the available channel bandwidth in sub-frequency bands of width inferior to the coherence bandwidth of the channel (inverse of the delay spread). The transmission of a high speed signal on a broadband frequency selective channel is then substituted with the transmission on multiple subcarriers of slow speed signals which are very resistant to intersymbol interference and subject to flat fading. This subdivision of the overall bandwidth in multiple channels provides frequency diversity which added to time and multiuser diversity may result in a very spectrally efficient system subject to an adequate scheduling.

The MAC protocols currently used in wireless local area networks were originally and primarily designed in the wired local area network context. These conventional access methods like Round Robin (RR) and Random Access (RA) are not well adapted to the wireless environment and provide poor throughput. More recently intense research efforts have been given in order to propose efficient schedulers for OFDM based networks and especially opportunistic schedulers which preferably allocate the resources to the active mobile(s) with the most favourable channel conditions at a given time. These schedulers take benefit of multiuser and frequency diversity in order to maximize the system throughput. In fact, they highly rely on diversity for offering their good performances. The higher the diversity the more efficient are these schedulers, the less the multiuser diversity

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the more underachieved they are. However, in this context, the challenge is to avoid fairness deficiencies owing to unequal spatial positioning of the mobiles in order to guarantee QoS whatever the motion of the mobile in the cell. Indeed, since the farther mobiles have a lower spectral efficiency than the closer ones due to pathloss, the mobiles do not all benefit of an equal priority and average throughput which induces unequal delays and QoS (Fig. 1).

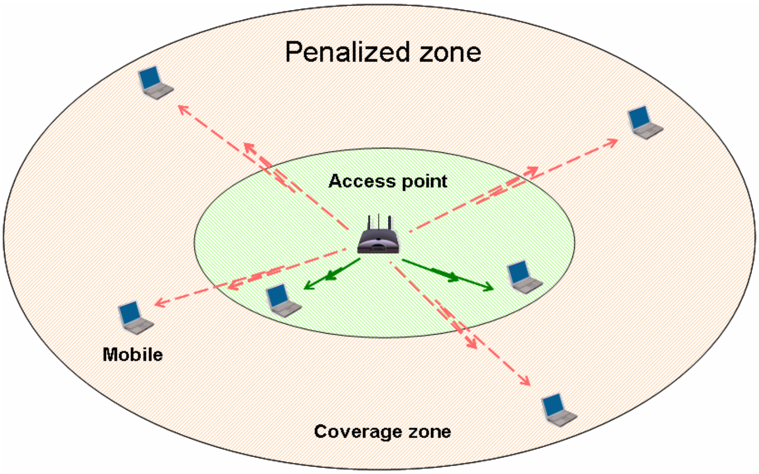


Fig. 1. Illustration of opportunistic scheduling fairness issue.

2. Multiuser OFDM system description

In this chapter, we focus on the proper allocation of radio resources among the set of mobiles situated in the coverage zone of an access point both in the uplink and in the downlink. The scheduling is performed in a centralized approach. The packets originating from the backhaul network are buffered in the access point which schedules the downlink transmissions. In the uplink, the mobiles signal their traffic backlog to the access point which builds the uplink resource mapping.

The physical layer is operated using an OFDM frame structure compliant to the OFDM mode of the IEEE 802.16-2004 (Hoymann, 2005). The total available bandwidth is divided in sub-frequency bands or subcarriers. The radio resource is further divided in the time domain in frames. Each frame is itself divided in time slots of constant duration. The time slot duration is an integer multiple of the OFDM symbol duration. The number of subcarriers is chosen so that the width of each sub-frequency band is inferior to the coherence bandwidth of the channel. Moreover, the frame duration is fixed to a value much smaller than the coherence time (inverse of the Doppler spread) of the channel. With these assumptions, the transmission on each subcarrier is subject to flat fading with a channel state that can be considered static during each frame.

The elementary resource unit (RU) is defined as any (subcarrier, time slot) pair. Each of these RUs may be allocated to any mobile with a specific modulation order. Transmissions performed on different RUs by different mobiles have independent channel state variations (Andrews et al., 2001). On each RU, the modulation scheme is QAM with a modulation order adapted to the channel state between the access point and the mobile to which it is allocated. This provides the flexible resource allocation framework required for opportunistic scheduling.

The frame structure supposed a perfect time and frequency synchronization between the mobiles and the access point as described in (Van de Beek et al., 1999). Additionally, perfect knowledge of the channel state is supposed to be available at the receiver (Li et al., 1999). The current channel attenuation on each subcarrier and for each mobile is estimated by the access node based on the SNR of the signal sent by each mobile during the uplink contention subframe. Assuming that the channel state is stable on a scale of 50 ms (Truman & Brodersen, 1997), and using a frame duration of 2 ms, the mobiles shall transmit their control information alternatively on each subcarrier so that the access node may refresh the channel state information once every 25 frames

3. Scheduling techniques in OFDM wireless networks

This chapter focuses on the two major scheduling techniques which have emerged in the litterature: Maximum Signal-to-Noise Ratio (MaxSNR), Proportional Fair (PF). Furthermore, it will present an improvement of PF scheduling which avoid fairness deficiencies: the Compensated Proportional Fair (CPF).

3.1 Classical scheduling: Round Robin

Before studying opportunistic schedulers, we bring to mind the characteristics of classical schedulers. Round Robin (RR) (Nagle, 1987; Kuurne & Miettinen, 2004) is a well-attested bandwidth allocation strategy in wireless networks. RR allocates an equal share of the bandwidth to each mobile in a ring fashion. However, it does not take in consideration that far mobiles have a much lower spectral efficiency than closer ones which does not provide full fairness. Moreover, the RR does not take benefit of multiuser diversity which results in a bad utilization of the bandwidth and in turn, poor system throughput.

3.2 Maximum Signal-to-Noise Ratio

Many schemes are derived from the Maximum Signal-to-Noise Ratio (MaxSNR) technique (also known as Maximum Carrier to Interference ratio (MaxC/I)) (Knopp & Humblet, 1995; Wong et al., 1999; Wang & Xiang, 2006). MaxSNR exploits the concept of opportunistic scheduling. Priority is given to the mobile which currently has the greatest signal-to-noise ratio (SNR). Profiting of the multiuser diversity and continuously allocating the radio resource to the mobile with the best spectral efficiency, MaxSNR strongly improves the system throughput. It dynamically adapts the modulation and coding to allow always making the most efficient use of the radio resource and coming closer to the Shannon limit. However, a negative side effect of this strategy is that the closest mobiles to the access point have disproportionate priorities over mobiles more distant since their path loss attenuation is much smaller. This results in a severe lack of fairness as illustrated in Fig. 1.

3.3 Proportional Fair

Proportional Fair (PF) algorithms have recently been proposed to incorporate a certain level of fairness while keeping the benefits of multiuser diversity (Viswanath et al., 2002; Kim et al., 2002; Anchun et al., 2003; Svedman et al., 2004; Kim et al., 2004). In PF based schemes, the basic principle is to allocate the bandwidth resources to a mobile when its channel conditions are the most favourable with respect to its time average. At a short time scale, path loss variations are negligible and channel state variations are mainly due to multipath fading, statistically similar for all mobiles. Thus, PF provides an equal sharing of the total available bandwidth among the mobiles as RR. Applying the opportunistic scheduling technique, system throughput maximization is also obtained as with MaxSNR. PF actually combines the advantages of the classical schemes and currently appears as the best bandwidth management scheme.

In PF-based schemes, fairness consists in guaranteeing an equal share of the total available bandwidth to each mobile, whatever its position or channel conditions. However, since the farther mobiles have a lower spectral efficiency than the closer ones due to pathloss, all mobiles do not all benefit of an equal average throughput despite they all obtain an equal share of bandwidth. This induces heterogeneous delays and unequal QoS. (Choi & Bahk, 2007; Gueguen & Baey, 2009; Holtzman, 2001) demonstrate that fairness issues persist in PF-based protocols when mobiles have unequal spatial positioning.

3.4 Compensated Proportional Fair

This QoS and fairness issues can be solved by an improvement of the PF called Compensated Proportional Fair (CPF). CPF introduces correction factors in the PF in order to compensate the path loss negative effect on fairness while keeping the PF system throughput maximization properties. With this compensation, CPF is aware of the path loss disastrous effect on fairness and adequate priorities between the mobiles are always adjusted in order to ensure them an equal throughput. This scheduling finely and simultaneously manages all mobiles. Keeping a maximum number of flows active across time but with relatively low traffic backlogs, CPF is designed for best profiting of the multi-user diversity taking advantage of the dynamics of the multiplexed traffics. Thus, preserving the multiuser diversity, CPF takes a maximal benefit of the opportunistic scheduling technique and maximizes the system capacity better than MaxSNR and PF access schemes. Well-combining the system capacity maximization and fairness objectives required for 4G OFDM wireless networks, an efficient support of multimedia services is provided.

At each scheduling epoch, the scheduler computes the maximum number of bits $B_{k,n}$ that can be transmitted in a time slot of subcarrier n if assigned to mobile k, for all k and all n. This number of bits is limited by two main factors: the data integrity requirement and the supported modulation orders.

The bit error probability is upper bounded by the symbol error probability (Wong & Cheng, 1999) and the time slot duration is assumed equal to the duration T_s of an OFDM symbol. The required received power $P_r(q)$ for transmitting q bits in a resource unit while keeping below the data integrity requirement BER_{target} is a function of the modulation type, its order and the single-sided power spectral density of noise N_0. For QAM and a modulation order M on a flat fading channel (Proakis, 1995):

$$P_r(q) = \frac{2N_0}{3Ts}\left[erfc^{-1}\left(\frac{BER_{t\arg et}}{2} \right) \right]^2 (M-1)\,, \tag{1}$$

where $M = 2^q$ and $erfc$ is the complementary error function. $P_r(q)$ may also be determined in practice based on BER history and updated according to information collected on experienced BER. Additionally, the transmit power $P_{k,n}$ of mobile k on subcarrier n is upper bounded to a value P_{max} which complies with the transmit Power Spectral Density regulation:

$$P_{k,n} \le P_{\max} \; . \tag{2}$$

Given the channel gain $a_{k,n}$ experienced by mobile k on subcarrier n (including path loss and multipath fading):

$$P_r(q) \le a_{k,n} P_{\max} \; . \tag{3}$$

The channel gain model on each subcarrier considers free space path loss a_k and multipath Rayleigh fading $\alpha_{k,n}^2$ (Parsons, 1992):

$$a_{k,n} = a_k \;\, \alpha_{k,n}^2 \; . \tag{4}$$

a_k is dependent on the distance between the access point and mobile k. $\alpha_{k,n}^2$ represents the flat fading experienced by mobile k on subcarrier n. $\alpha_{k,n}$ is Rayleigh distributed with an expectancy equal to unity. Consequently, the maximum number of bits $q_{k,n}$ of mobile k which can be transmitted on a time slot of subcarrier n while keeping below its BER target is:

$$q_{k,n} \le \left\lfloor \log_2 \left(1 + \frac{3P_{\max} \; T_s \; a_k \;\, \alpha_{k,n}^2}{2N_0 \left[erfc^{-1}\left(\frac{BER_{t\arg et}}{2} \right) \right]^2} \right) \right\rfloor . \tag{5}$$

We further assume that the supported QAM modulation orders are limited such as q belongs to the set $S = \{0, 2, 4, \ldots, q_{max}\}$. Hence, the maximum number of bits $B_{k,n}$ that will be transmitted on a time slot of subcarrier n if this resource unit is allocated to the mobile k is:

$$B_{k,n} = \max\left\{ q \in S, q \le q_{k,n} \right\} . \tag{6}$$

At each scheduling epoch and for each time slot, MaxSNR based schemes allocate the subcarrier n to the active mobile k which has the greatest $B_{k,n}$ value while the PF scheme consists in allocating the subcarrier n to the mobile k which has the greatest factor $F_{k,n}$ defined as:

$$F_{k,n} = \frac{B_{k,n}}{R_{k,n}} \, , \tag{7}$$

where $R_{k,n}$ is the time average of the $B_{k,n}$ values. However, considering rounded $B_{k,n}$ values in the allocation process have a negative discretization side effect on the PF performances. Several mobiles may actually have a same $F_{k,n}$ value with significantly different channel state with respect to their time average. More accuracy is needed in the subcarrier allocation process for prioritizing the mobiles. It is more profitable to allocate the subcarrier n to the mobile k which has the greatest $f_{k,n}$ value defined by:

$$f_{k,n} = \frac{b_{k,n}}{r_{k,n}} \, , \tag{8}$$

where:

$$b_{k,n} \leq \log_2\left(1+\frac{3P_{\max}\ T_s\ a_k\ \alpha_{k,n}^2}{2N_0\left[erfc^{-1}\left(\frac{BER_{t\arg et}}{2}\right)\right]^2}\right), \tag{9}$$

and $r_{k,n}$ is the $b_{k,n}$ average over a sliding time window.

PF outperforms MaxSNR providing an equal system capacity and partially improving the fairness (Gueguen & Baey, 2009). Based on the PF scheme, this chapter presents a new scheduler that achieves high fairness while preserving the system throughput maximization. It introduces a parameter called "Compensation Factor" *(CF_k)*, that takes into account the current path loss impact on the average achievable bit rate of the mobile *k*. It is defined by:

$$CF_k = \frac{b_{ref}}{b_k}. \tag{10}$$

b_{ref} is a reference number of bits that may be transmitted on a subcarrier considering a reference free space path loss a_{ref} for a reference distance d_{ref} to the access point and a multipath fading equal to unity:

$$b_{ref} \leq \log_2\left(1+\frac{3P_{\max}\ T_s\ a_{ref}}{2N_0\left[erfc^{-1}\left(\frac{BER_{t\arg et}}{2}\right)\right]^2}\right). \tag{11}$$

b_k represents the same quantity but considering a distance d_k to the access point:

$$b_k \leq \log_2\left(1+\frac{3P_{\max}\ T_s\ a_{ref}\left(\frac{d_{ref}}{d_k}\right)^{\beta}}{2N_0\left[erfc^{-1}\left(\frac{BER_{t\arg et}}{2}\right)\right]^2}\right), \tag{12}$$

with β the experienced path loss exponent.

The distance d_k of the mobile *k* to the access point is evaluated thanks to the channel state estimation time average (Jones & Raleigh, 1998). The CPF scheduling consists then in allocating a time slot of subcarrier *n* to the mobile *k* which has the greatest $CPF_{k,n}$ value:

$$CPF_{k,n} = f_{k,n}\ CF_k = \left(\frac{b_{k,n}}{r_{k,n}}\right) CF_k. \tag{13}$$

The CPF scheduling algorithm is detailed in Fig. 2. The distance correction factor CF_k adequately compensates the lower spectral efficiencies of far mobiles and the resulting

$CPF_{k,n}$ parameters bring high fairness in the allocation process. Far mobiles get access to the resource more often than close mobiles and inverse proportionally to their spectral efficiency. Thereby, an equal throughput is provided to each mobile. Moreover, CPF also keeps the PF opportunistic scheduling advantages thanks to the $f_{k,n}$ parameters which take into account the channel state. In contrast with MaxSNR and PF which satisfy much faster the mobiles which are close to the access point, the CPF keeps more mobiles active but with a relatively low traffic backlog. Satisfaction of delay constraints is more uniform and, preserving the multiuser diversity, a better usage of the bandwidth is made. This jointly ensures fairness and system throughput maximization.

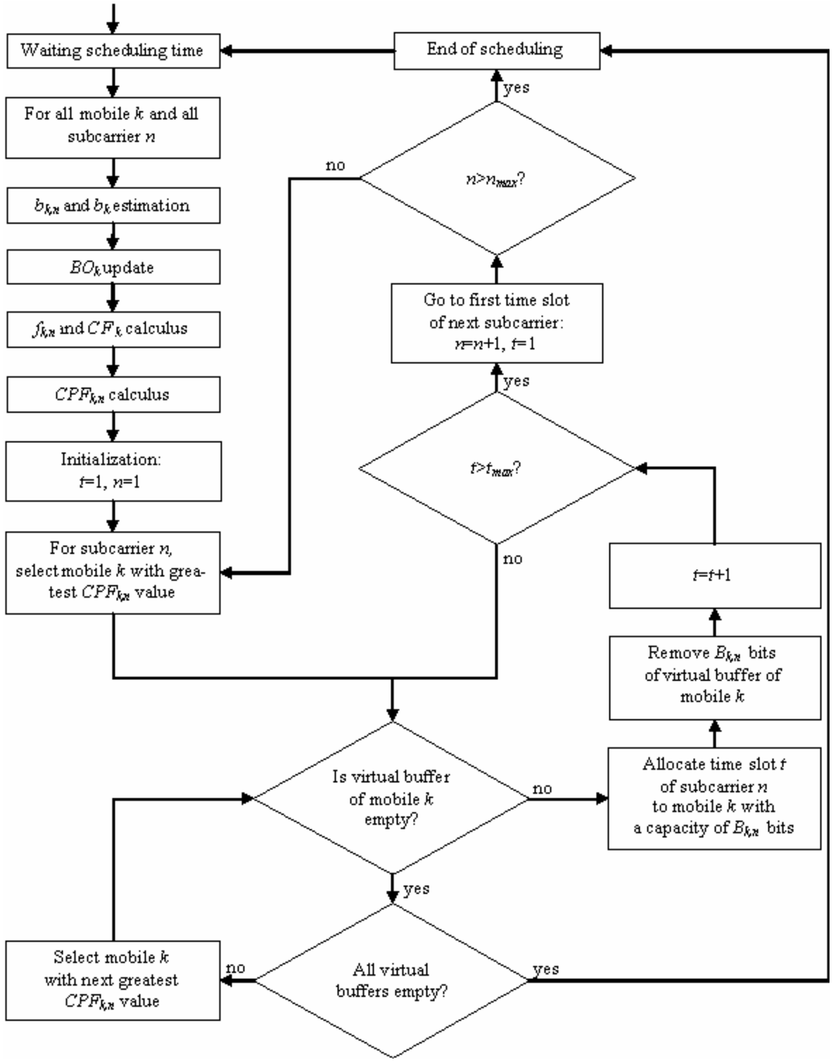


Fig. 2. CPF scheduling algorithm flow chart.

4. Performance evaluation

In this section an extend performance evaluation using OPNET discrete event simulations is proposed. We focus on two essential performance criteria: fairness and offered system capacity.

In the simulations, a frame is composed of 5 time slots and 128 subcarriers. β is assumed equal to 2 and the maximum transmit power satisfies:

$$10\log_{10}\left(\frac{P_{\max}T_s}{N_0}\times a_{ref}\right)=24\ dB\ . \tag{14}$$

All mobiles run a videoconference application. The traffic is composed of an MPEG-4 video stream (Baey, 2004) multiplexed with an AMR voice stream (Brady, 1969). This demanding type of application generates a high volume of data with high sporadicity and requires tight delay constraints which substantially complicates the task of the scheduler. The average bit rate of each source is 80 Kbps. The traffic load is set by varying the number of mobiles. This allows to study the ability of each scheduler to take advantage of the multiuser diversity.

A crucial objective for modern multiple access schemes is the full support of multimedia transmission services. Evaluating the QoS offered by a scheduling scheme should not only focus on the classical delay and jitter analysis. Indeed, a meaningful constraint regarding delay is the limitation of the occurrences of large values. In this aim, we define the concept of *delay outage* by analogy with the concept of outage used in system coverage planning. A mobile transmission is in delay outage when its packets experience a delay greater than a given threshold. The delay experienced by each mobile is tracked all along the lifetime of its connection. At each transmission of a packet of mobile k, the ratio of the total number of packets whose delay exceeded the threshold divided by the total number of packets transmitted since the beginning of the connection is computed. The result is called Packet Delay Outage Ratio (PDOR) of mobile k and is denoted $PDOR_k$. Fig. 3 illustrates an example cumulative distribution of the packet delay of a mobile at a given time instant.

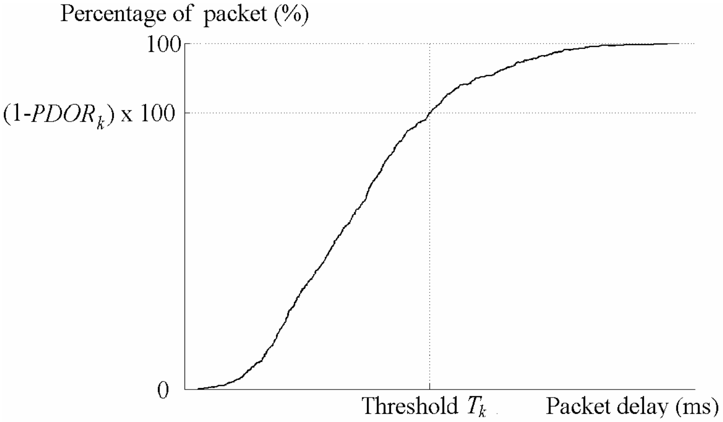


Fig. 3. Example packet delay CDF and experienced PDOR.

The PDOR target is defined as the maximum ratio of packets of mobile k that may be delivered after its delay threshold T_k. This characterizes the delay requirements of any mobile in a generic approach. In the following, the PDOR target is set to 5 % and the threshold time T_k is fixed to the value of 80 ms considering real time constraints. The BER_{target} value is taken equal to 10^{-3}.

Note that the problem we are studying in this chapter is quite different with the sum-rate maximization with water-filling for instance. The purpose of the schedulers presented in this chapter is to maximize the traffic load that can be admitted in the wireless access network while fulfilling delay constraints. This is achieved by both taking into account the radio conditions but also the variations in the incoming traffic. In this context, it cannot be assumed for instance that each mobile has some traffic to send at each scheduling epoch. Traffic overload is not realistic in a wireless access network because it corresponds to situations where the excess traffic experiences an unbounded delay. This is why, in the showed simulations, the traffic load (offered traffic) does not exceed the system capacity. In these conditions the offered traffic is strictly equal to the traffic carried over the wireless interface and all mobiles get served sooner or later. The bit rate sent by each mobile is equal to its incoming traffic. Fairness in terms of bit rate sent by each mobile is rigorously achieved. The purpose of the scheduler is to dynamically assign the resource units to the mobiles at the best time in order to meet the traffic delay constraints. This is why the PDOR is adopted as a measure of the fairness in terms of QoS level obtained by each mobile.

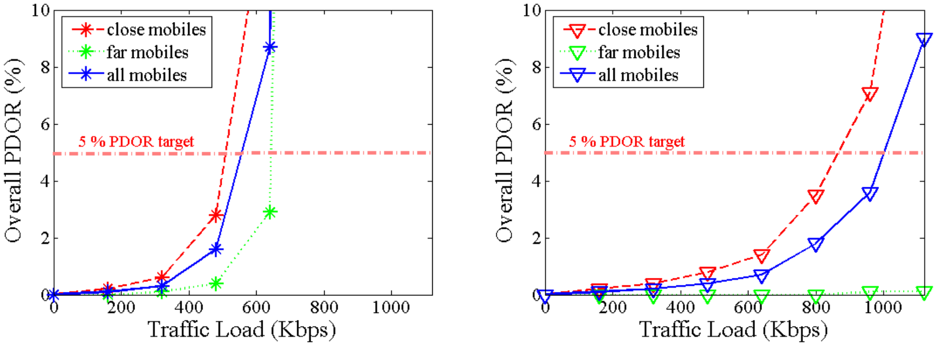
4.1 Static scenario

In order to study the influence of the distance on the scheduling performances, a first half of mobiles are positioned close to the access point at a distance of 1.5 d_{ref}. The second half of mobiles are twice over farther. With these settings, the values of $B_{k,n}$ for the two groups of mobiles are respectively 4 and 2 bits when $\alpha_{k,n}^2$ equals unity.

Fairness is the most difficult objective to reach. It consists in ensuring the same ratio of packets in delay outage to all mobiles, below the PDOR target. Fig. 4 displays the overall PDOR for various traffic loads. The influence of distance on the scheduling is also studied.

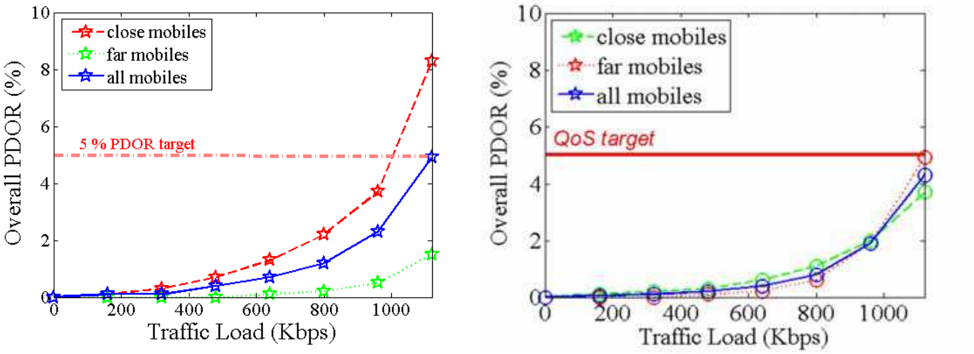
Classical RR yields bad results (Fig. 4a). Indeed, since multiuser diversity is not exploited, the overall spectral efficiency is small and system throughput is low. Consequently, the delay targets are exceeded as soon as the traffic load increases. Based on opportunistic scheduling, MaxSNR (Fig. 4b), PF (Fig. 4c) and CPF (Fig. 4d) provide better system performances. However, with MaxSNR and PF, close mobiles easily respect their delay requirement but the farther experience much higher delays and go beyond their PDOR target when the traffic load increases. This shows their difficulty to ensure fairness when the mobiles have heterogeneous positions. Indeed, with MaxSNR, unnecessary priorities are given to close mobiles who easily respect their QoS constraints while more attention should be given to the farther. These inadequate priority management dramatically increases the global mobile PDOR and mobile dissatisfaction. PF brings slightly more fairness and allocates more priority to far mobiles. The result on global overall PDOR indicates that some flows can be slightly delayed to the benefit of others without significantly affecting their QoS.

The CPF was built on this idea. The easy satisfaction of close mobiles (with better spectral efficiency) offers a degree of freedom which ideally should be exploited in order to help the farther ones. CPF dynamically adapts the priorities function of the mobile location. This results in allocating to each mobile the accurate share of bandwidth required for the



(a) With RR.

(b) With MaxSNR.



(c) With PF.

(d) With CPF.

Fig. 4. Measured QoS with respect to distance.

satisfaction of its QoS constraints, whatever its position. Like this, the problem of fairness is solved with CPF which provides comparable QoS levels to all mobiles whatever their respective location and allows to reach higher traffic loads with an acceptable PDOR (below the PDOR target). Additionally, observing the global PDOR value (for all mobiles), we can notice that, besides ensuring high fairness, CPF provides a better overall QoS level as well.

Fig. 5 shows the average number of bits carried per allocated Resource Unit by each tested scheduler under various traffic loads. Looking at the cost of this high fairness and mobile satisfaction in terms of system capacity, it appears that no system throughput reduction has been done with CPF. As expected, the non opportunistic Round Robin scheduling provides a constant spectral efficiency, i.e. an equal bit rate per subcarrier whatever the traffic load since it does not take advantage of the multiuser diversity. The three other tested schedulers show better results. In contrast with RR, with the opportunistic schedulers (MaxSNR, PF, CPF), we observe a characteristic inflection of the spectral efficiency curves when the traffic load increases. Exploiting the supplementary multiuser diversity, the system capacity is highly extended. This result also shows that the CPF scheduling has slightly better performances than the two other opportunistic schedulers. This improved multiplexing efficiency is obtained by processing all service flows jointly and opportunistically. Keeping more mobiles active but with a relatively lower traffic backlog, the CPF scheme preserves multiuser diversity and takes more advantage of it obtaining a slightly higher bit rate per subcarrier (cf. Fig. 5).

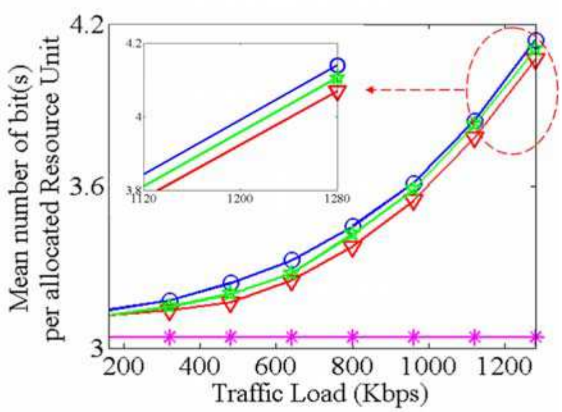


Fig. 5. Bandwidth usage efficiency.

The performance of the four schedulers can be further qualified by computing the theoretical maximal system throughput. Considering the Rayleigh distribution, it can be noticed that $\alpha_{k,n}^2$ is greater or equal to 8 with a probability of only 0.002. In these ideal situations, close mobiles can transmit/receive 6 bits per RU while far mobiles may transmit/receive 4 bits per RU. If the scheduler always allocated the RUs to the mobiles in these ideal situations, an overall efficiency of 5 bits per RU would be obtained which yields a theoretical maximal system throughput of 1600 Kbps. Comparing this value to the highest supported traffic load of 1280 Kbps (cf. Fig. 5) further demonstrates the good efficiency obtained with the opportunistic schedulers that nearly always serve the mobiles when their channel conditions are very good with near to 4.2 bits per allocated subcarrier.

4.2 Mobile scenario

In the above scenario, the mobiles are static, and positioned at two distinct locations. The objective was to demonstrate the opportunistic behaviour of the schedulers and also clearly exhibit their ability to provide fairness whatever the respective position of the mobiles. This second scenario brings additional results in a more general context that includes mobility. We constituted two groups of 7 mobiles that both move straight across the cell, following the pattern described in Fig. 6 and Fig.7. Each mobile has a speed of 3 km/h and the cell radius is taken equal to 5 km (3 d_{ref}). When a group of mobiles comes closer to the access point, the other group simultaneously goes farther away.

Considering the path loss, the Rayleigh fading and this mobility model, we have computed in Fig. 8 the evolution of the mean number of bits that may be transmitted per Resource Unit for each group of mobiles, averaging over all the Resource Units of a frame. This shows the impact of the mobile position on the mean $m_{k,n}$ values. Fig. 9 reports the mean number of bit(s) per “allocated” Resource Unit for each group of mobiles (RR performances are not presented here since RR is not able to support such a high traffic load.). The results underline the ability of opportunistic schedulers to take advantage of the multiuser diversity in order to maximize the spectral efficiency. With opportunistic scheduling, a Resource Unit is allocated only when the associated channel state is good and the number of bits that may be transmitted is greater than the mean. This provides high system throughput with a mean number of bits per allocated Resource Unit varying between 3 and 5 (Fig. 9) while the average Resource Unit capacity ranges between only 1.8 and 3.5 (Fig. 8). This also further confirms the results of Fig.5: CPF offers slightly better results than MaxSNR and PF in terms of spectral efficiency.

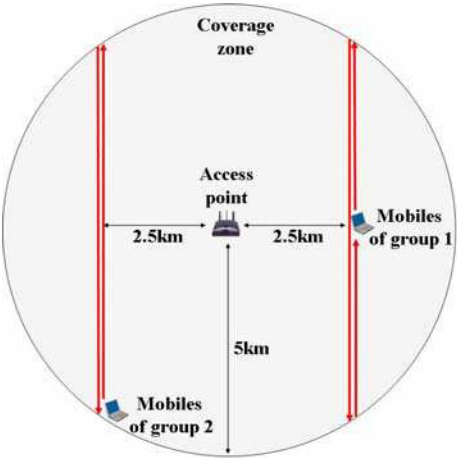


Fig. 6. Mobility pattern.

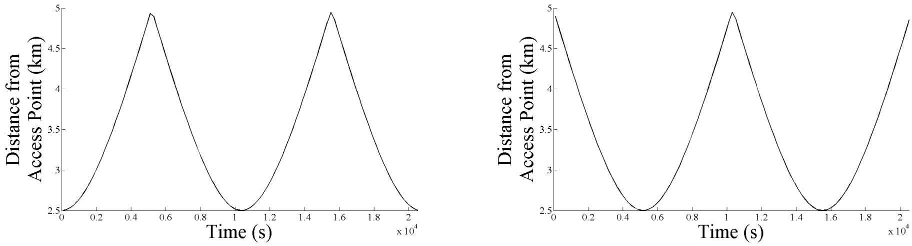


Fig. 7. Position of the mobiles across time (for mobiles of group 1 on the left and for mobiles of group 2 on the right).

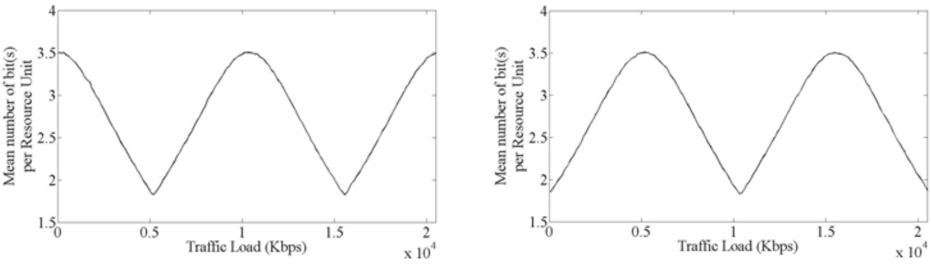


Fig. 8. Mean number of bit(s) per Resource Unit for each group of mobiles (for mobiles of group 1 on the left and for mobiles of group 2 on the right).

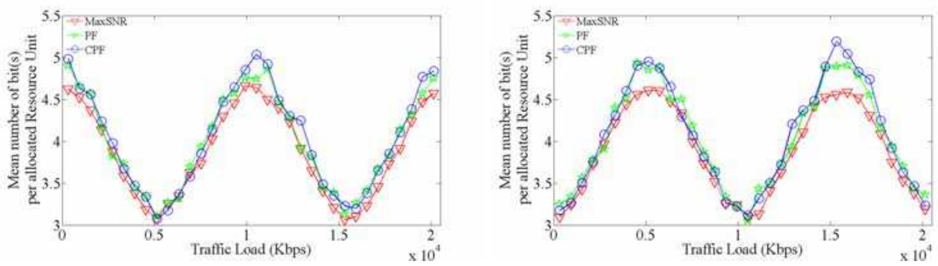


Fig. 9. Mean number of bit(s) per allocated Resource Unit for each group of mobiles (for mobiles of group 1 on the left and for mobiles of group 2 on the right).

Regarding fairness, Fig. 10 reports the mean delay experienced by the transmitted packets of each group of mobiles across time. MaxSNR is highly unfair. Indeed, as soon as the mobiles move away from the access point, they experience a very high delay. PF offers better results. It brings more fairness and globally attenuates the delay peaks. However, we observe that

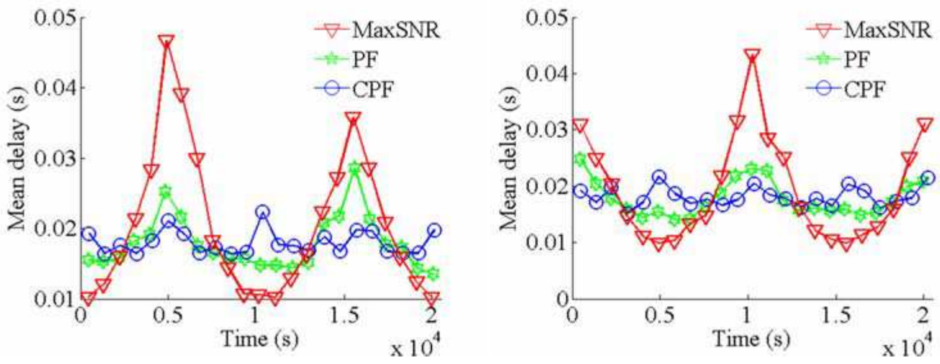


Fig. 10. Mean delay experienced by each group of mobiles (for mobiles of group 1 on the left and for mobiles of group 2 on the right).

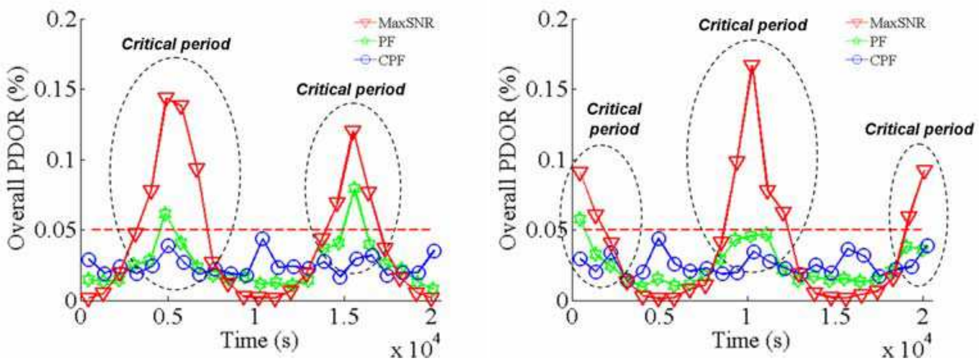


Fig. 11. PDOR fluctuations experienced by each group of mobiles (for mobiles of group 1 on the left and for mobiles of group 2 on the right).

CPF is the one that most smoothes the delay peaks. CPF continuously allocates the adequate priorities between the mobiles considering their relative movement across the cell. Providing a totally fair allocation of the bandwidth resources, CPF smoothes the delay experienced by each mobile across time.

Fig. 11 shows the mean PDOR experienced by each group of mobiles across the time. As we can see in Fig. 10 and Fig. 11, there is a very high correlation between the mean packet delay and the mean ratio of packets delivered after the delay threshold (mean PDOR). Reducing the magnitude of the delay peaks, PF greatly improves the mobile satisfaction with a greater reactivity than MaxSNR in critical periods. CPF further enhances the PF performances. It dynamically adjusts the priority of the mobile considering its position so that the PDOR values are further decreased. This results in a very fair resource allocation that fully satisfies the delay constraints whatever the motion of the mobile.

5. Conclusion

In the literature, several scheduling schemes have been proposed for maximizing the system throughput. However, guaranteeing a high fairness appeared as unfeasible without sacrificing system capacity. In this chapter, we have presented an improvement of the PF scheduling scheme yet acknowledged as the most promising so far. This scheme, called "Compensated Proportional Fair (CPF)", allows to avoid the tradeoff between fairness and system capacity. It has a low complexity and is easily implementable on all OFDM based networks like 802.11a/g and 802.16 networks. CPF sparingly delays the flows of close mobiles with good spectral efficiency in order to favor the flows of the farther mobiles which need more attention for fulfilling their delay constraints. Performance results show that CPF provides both high fairness and system throughput maximization making a better usage of multiuser diversity.

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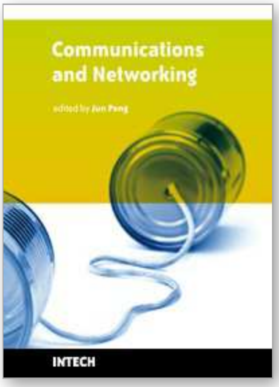

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This book "Communications and Networking" focuses on the issues at the lowest two layers of communications and networking and provides recent research results on some of these issues. In particular, it first introduces recent research results on many important issues at the physical layer and data link layer of communications and networking and then briefly shows some results on some other important topics such as security and the application of wireless networks. In summary, this book covers a wide range of interesting topics of communications and networking. The introductions, data, and references in this book will help the readers know more abut this topic and help them explore this exciting and fast-evolving field.

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