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Coverage Extension Based on Incentive Scheduler for Mobile Relaying Nodes in Wireless Networks

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Abstract—In this paper, we propose a new protocol able to extend the wireless coverage by using an incentive approach for potential mobile relaying nodes. Indeed, the cost of cooperation can be expensive in terms of QoS and energy consumption which do not motivate the nodes to cooperate. We introduce an incentive approach in the scheduling algorithm in order to reward the cooperative nodes. The percentage of cooperation is considered in the QoS management in order to incite the border nodes to cooperate and then to extend the wireless area. Moreover, the monitoring mechanism is proposed to correctly evaluate the cooperation rate of each node. The proposed solution is not limited to incite the nodes to cooperate but also to enhance the QoS by increasing the average throughput and decreasing the delay. The simulation results show that not only the proposed solution called CEI allows the border nodes to cooperate without the negative impact but also enhance the QoS parameters. Particularly, with this new resource allocation strategy, the cooperative mobiles can increase their own throughput around 114% and the total amount of data transmitted out of the cell in order to extend the coverage can be increased around 59% compared to the acknowledged scheduling algorithm MaxSNR.

Index Terms—Incentive Scheduling, Coverage extension, Cooperation, Quality of Service, Multipath fading, opportunistic scheduling.

I. INTRODUCTION

The basic idea of the coverage extension area in wireless networks is to increase the network connectivity without increasing the infrastructure. This is one of the main applications of the cooperative communications in wireless networks. The coverage extension issue requires the cooperation of border mobile nodes to relay the packets of neighbouring nodes which are located outside of the base-station area. For instance, the nodes located at two hops from the Access Point (AP) can access the services offered by AP through the relayed nodes like Internet as illustrated in figure 1. Many researchers dealt with the strategies to find the optimal placement for the relayed nodes in order to guarantee the Quality of Services (QoS) [1]. Other works dealt with the optimal number of hops of relayed nodes in wireless networks [2][3]. However, they assume that the relayed nodes by definition are fixed and cooperative which is not interesting in the case of a dynamic wireless network where the nodes freely move and potentially selfish.

The mobility of the relayed node has to be taken into account in order to be close to the reality. Other works consider the mobile relayed nodes to extend the wireless coverage with throughput enhancement [4]. However, no incentive approach is considered in these works. The relayed nodes must share

their throughput with other neighbouring nodes which can impact their own packets transmission. In addition, the energy consumption of the relayed nodes is more important than the one of other classical nodes. They do not only transmit their own packets but also the packets of other neighbouring nodes. Therefore, the user of the potential relayed node can disable the cooperative functionality in order to keep the performance in terms of QoS only for its own transmission. In this paper, we consider that the mobile relayed nodes are not part of the fixed wireless infrastructure. That is why the incentive strategy for potential mobile relay nodes is very important to consider in the design of the cooperation protocol. The main incentive models in literature are based on the game theory [5][6]. However, it is hard to implant these models because of many assumptions and because no implementation or performance evaluations are given.

In this paper, we propose a cooperative protocol based on an incentive approach with QoS consideration for the mobile relayed nodes in order to extend the coverage area. This approach consists in increasing the priorities of the relayed nodes according to their cooperation rate. The idea is to reward the relayed nodes for their cooperation instead of penalized them by the cost of the cooperation. Consequently, the nodes do not have the benefits to select and act as selfish behaviour using their throughput only to transmit their own packets. Our proposed solution called “Coverage Extension based on Incentive scheduling” (CEI) is also build in a cross layer approach. Moreover incentive nodes to cooperate, the physical layer informations are used in order to take advantage of the time, frequency and multiuser diversity and maximize the system capacity close to the Shannon limit. Unlike the existing models, our solution can be widely implemented, evaluated and compared to the existing ressource allocation strategies like classical Round-Robin (RR) [7] and acknowledged MaxSNR [8][9].

This paper is organized as follows: in Section 2, we present the existing works related to coverage extension by cooperation in wireless networks, incentive models and scheduling algorithms. Section 3 provides a detailed description of the system under study and describes the proposed coverage extension protocol based on the incentive approach. The fourth Section presents the obtained simulation results and their analysis. Finally, Section 5 concludes the paper and presents our future works.

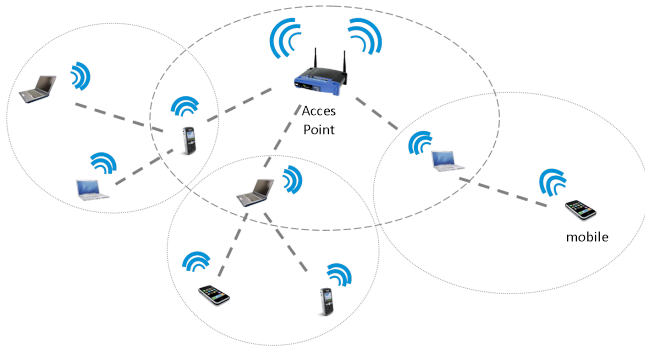


Fig. 1. Coverage extension in wireless network.

II. RELATED WORK

In this section, we present the existing works related to coverage extension protocols, cooperation incentives models and scheduling algorithms.

A. Coverage extension Protocols

The wireless coverage extension is one application of the cooperation communications system. Many existing works dealt with the coverage extension by analysing the different strategies to find the optimal placement for the relayed nodes in order to guarantee the Quality of Services (QoS). Sadek et al. proposed two distributed relay-assignment protocols in order to reduce the outage and increase the network connectivity [1]. The first protocol selects the relayed node with the best performance in terms of placement while taking into account the quality of SNR and the distance between nodes. The second protocol gives the optimal placement of the fixed relayed to help the existing users. Other works dealt with the optimal number of hops of relayed nodes in multi-hop wireless networks. Florea and Yanikomeroglu have shown that the optimal number of relayed nodes can be determined for multi-hop link under assumption that all links have the same path loss exponent and the relays are located at equal intervals [2]. Few works consider the mobile relayed nodes to extend the wireless coverage with throughput enhancement. Xiao et al. proposed quantitative studies of benefits offered by mobile relayed nodes for potential coverage area extension [4]. The mobile node relays offer substantial coverage extension benefits. However, no incentive approach is considered in these works and they assume that the relayed nodes are all cooperative.

B. Cooperation Incentives Models

In literature, two main solutions were proposed to overcome the problem of selfish nodes.

The first one is based on the reputation mechanisms which consist in assessing a nodes' contribution like forwarding and routing functionality [10], [11], [12], [13]. The reputation model called CONFIDANT is proposed to share the reputation metric and alarms messages in order to detect and punish the misbehaving nodes [12]. Another model called CORE is proposed to implement the reputation function by using

the monitoring technique. Each node computes the reputation value for every neighbour and refuses to provide services to misbehaving nodes when their reputation is lower than a certain threshold [10]. However, all these solutions did not consider the problems of the false observation related to the collision and the performance of the potential relayed nodes.

The second one is based on the economics mechanisms like price-based and game theory [5]. In these models the nodes are paid for offering message forwarding service and pay for receiving forwarding service. The proposed incentive models based on the price and game theory have introduced the concept of virtual cash. The nodes are rewarded for packets forwarding through trading virtual cash with source and next hop nodes [5]. Buttyan and Hubeaux [14] proposed nuglets as credits for managing forwarding transactions. The source node pays relay intermediate nodes by storing nuglet in the packet head. The intermediate nodes acquire the nuglets when forwarding the packets. In [15] a hybrid model used the reputation and the price-based mechanism was proposed to overcome the issue of selfish nodes. However, these contributions stay conceptual with no performance evaluations, their implementations in resources allocation schedulers are not easy and the models assumptions must be adapted.

C. Scheduling Algorithms in Wireless Networks

The conventional access methods like Round Robin (RR) [7] and Random Access (RA) are not well adapted to the wireless environment and provide poor throughput. More recently intensive research efforts have been made in order to propose more efficient schedulers: the opportunistic schedulers. They 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. All these schemes strongly rely on diversity for offering their good performances. One major scheduling algorithm has emerged and appeared in literature as the reference: Maximum Signal-to-Noise Ratio (MaxSNR).

In MaxSNR, priority is given at every scheduling event to the mobiles which have the greatest signal-to-noise ratio (SNR). It allocates the resource at a given time to the active mobile with the greatest SNR [8][9]. Taking profit of multiuser and frequency diversity, MaxSNR scheduling continuously allocates the radio resource to the mobile with the best spectral efficiency. Consequently, MaxSNR strongly increases the system throughput. Dynamically adapting the modulation and coding allows one to always make the most efficient use of the radio resource and come closer to the Shannon limit.

However MaxSNR does not take into consideration other aspect than throughput and particularly MaxSNR scheduling does not manage priority in order to favour cooperative mobiles. Consequently, no reward is guaranteed to cooperative mobiles. Their supplementary energy consumption and the personal throughput loss are not compensated. These results in a severe penalty for them which do not encouraged cooperative networks and coverage extension.

III. COVERAGE EXTENSION PROTOCOL

A. Preliminary

In this subsection, we give some definitions and the wireless network context. We focus on the coverage extension of the Wireless Local Area (WLAN) and particularly of the access point area using the allocation of radio resources with cooperative behaviour consideration. We consider a centralized approach based on access point in WLAN or on cluster-head in Mobile Ad hoc Networks (MANETs). Indeed, maximize the system capacity is one of the most crucial issues of wireless network and a centralized approach is needed to allow opportunistic scheduling which provides significant system throughput gain comparing to decentralized resources allocation. The packets originating from the backhaul network are buffered in the AP which schedules the downlink transmissions. In the uplink, the mobiles signal their traffic backlog to the access point which builds the uplink resource mapping.

We assume that the physical layer is operating using the structure described in Fig. 2. 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. 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.

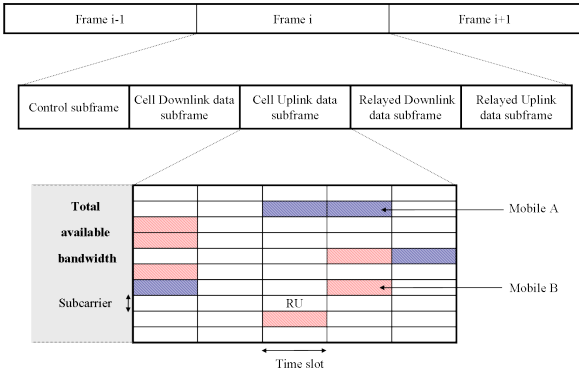


Fig. 2. Frame structure in TDD mode.

The elementary resource unit (RU) is defined as any (sub-carrier, 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 [16]. 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 system is operating using time division duplexing with five subframes: the *control subframe*, the *cell downlink data subframe*, the *cell uplink data subframe*, the *relayed downlink*

data subframe and the *relayed uplink data subframe*. The cell uplink and downlink data subframes are used for transmission of intra-cellular user data while the relayed uplink and downlink data subframes are used for transmission by the relaying nodes of extra-cellular user data. During the control subframe, the access point sends control information towards its mobiles. This control information is used for signalling to each mobile which RU(s) it has been allocated in the next cell uplink and downlink data subframes, the modulation order selected for each of these RUs and the recommended emission power in the uplink. In addition, during this subframe, the active mobiles send their current traffic backlog and information elements such as transmit power. This subframe is also used by the mobiles for establishing their connections. This frame structure supposes a perfect time and frequency synchronization between the mobiles and the access point as described in [17]. Therefore, each frame starts with a long preamble used for synchronisation purposes. Additional preambles may also be used in the frame.

B. The Incentive Scheduler Algorithm

The main element of the proposed protocol is its scheduling algorithm called CEI. The scheduler, located in the central node like access point or cluster-head node, grants RUs to each mobile as a function of:

- its channel state;
- its currently cooperation ratio;
- its network confidence percentage;
- its traffic backlog.

The knowledge of the channel state is supposed to be available at the receiver [18]. The current channel attenuation on each subcarrier and for each mobile node 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 [19], 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.

The CEI scheduling algorithm relies on weights that set the dynamic priorities for allocating the resource. These weights are built in order to satisfy two major objectives: to maximise system throughput and to encourage nodes to cooperate.

1) *System Throughput Maximization Parameter*: The CEI scheduler maximizes the system throughput in a MAC/PHY opportunistic approach. Data integrity requirements of the mobiles are enforced adapting the modulation scheme and the transmission power to the mobile specific channel state. At each scheduling epoch, the scheduler computes the maximum number of bits $m_{k,n}$ that can be transmitted in a time slot of subcarrier n if assigned to a 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 and the time slot duration is assumed to be equal to the duration T_s of an OFDM symbol [8]. The required received power $P_r(q, k)$ for transmitting q bits in a RU while keeping below the data integrity requirement $BER_{target,k}$ of the service flow of mobile k 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 [20]:

$$P_r(q, k) = \frac{2N_0}{3T_s} \left[\operatorname{erfc}^{-1} \left(\frac{BER_{target,k}}{2} \right) \right]^2 (M - 1), \quad (1)$$

where $M = 2^q$ and erfc is the complementary error function. $P_r(q, k)$ may also be determined in practice based on BER history and updated according to information collected on experienced BER.

The transmission power $P_{k,n}$ of mobile k on subcarrier n is upper bounded to a value P_{max} which complies with the transmission Power Spectral Density regulation:

$$P_{k,n} \leq P_{max}. \quad (2)$$

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

$$P_r(q, k) \leq a_{k,n} P_{max}. \quad (3)$$

Hence, 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:

$$q_{k,n} \leq \left\lfloor \log_2 \left(1 + \frac{3P_{max} \times T_s \times a_{k,n}}{2N_0 \left[\operatorname{erfc}^{-1} \left(\frac{BER_{target,k}}{2} \right) \right]^2} \right) \right\rfloor. \quad (4)$$

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

$$m_{k,n} = \max \{q \in S, q \leq q_{k,n}\}. \quad (5)$$

Opportunistic schedulers like MaxSNR based schemes allocate the resources to the mobiles which have the greatest $m_{k,n}$ values. This bandwidth allocation strategy maximizes the bandwidth usage efficiency but do not encourage nodes cooperation. In order to extend coverage area while preserving the system throughput maximization, a new parameter is added on $m_{k,n}$ which modulates these pure opportunistic resource allocation.

2) *Incentive Parameter*: The second major objective of the CEI is to incite nodes to participate to frame relay in order to extend the network coverage zone. This is achieved by extending the above cross-layer design to other layers. A new "Incentive Parameter" (IP_k) is introduced based on the current estimation of the cooperation ratio:

$$IP_k = \frac{R_k}{D_k} = \frac{D_k + \sum_{i=0 \dots i=K} D_{ki}}{D_k}, \quad (6)$$

where R_k is the global amount of data transmitted by the mobile k . It is the sum between D_k , the amount of data transmitted to the mobile k for its own requirement and D_{ki} , the amount of data transmit to the mobile k for a mobile i (then these data will be relayed to mobile i by mobile k in the relaying subframe). This information could be directly monitored by the access point, or signalled by each mobile to access point.

We also define the cooperation ratio C_k as the number of packets that the mobile k is ready to relay for other mobiles when it receives 100 packets for its own consumption, for example:

- when the mobile k relay no traffic out of the cell, C_k equal 0%;
- when it is ready to relay 50 packet out of the cell since it receive 100 packets for its own consumption, C_k equal 50%;
- when the mobile relay as much packet out of the cell that its own received for its own consumption, C_k equal 100%.

Supposing that there are always packets to relay out of the cell, the IP_k will be respectively for these three cases equal to 1, 1.5 and 2. Consequently, based on the ressource allocation on IP_k allows to give more priority on mobiles which cooperate to extend coverage zone with frame relaying.

3) *Confidence Parameter*: We assume that each mobile signals its R_k and D_k to the access point. Thanks to this information, the CEI scheduler will make the adequate resource allocation rewarding the mobile for its cooperation degree. However in order to block malicious mobiles which could lie on this information, we introduced the last paramater called confidence parameter. The confidence parameter T_k depends on the correspondence between the announced cooperative ratio and the observed forwarding ratio. This control is done by a monitor node (in our case the AP or cluser-head). Each T_k is varies between 0 and 1 included. When the access point watching on R_k and D_k correspond to the announced cooperative ratio, T_k is set to 1. On the contrary, when the mobile does not relay the announced amount of data for which it had previously received more priority, its T_k is set to 0 for one round of scheduling in order to punish it. This assures a deterrent threat for mobile which would try to mislead the system.

4) *Global CEI Algorithm Description*: The WFO scheduling algorithm is detailed in Fig. 3. The scheduling is run subcarrier by subcarrier and on a time slot basis for improved granularity. In the allocation process of a given time slot, the priority of a mobile with respect to another is determined by the magnitude of its CEI parameter :

$$CEI_{k,n} = m_{k,n} \times \frac{R_k}{D_k} \times T_k. \quad (7)$$

Based on the $m_{k,n}$ and IP_k factor, the $CEI_{k,n}$ directly takes into account the channel states and the mobile behavior.

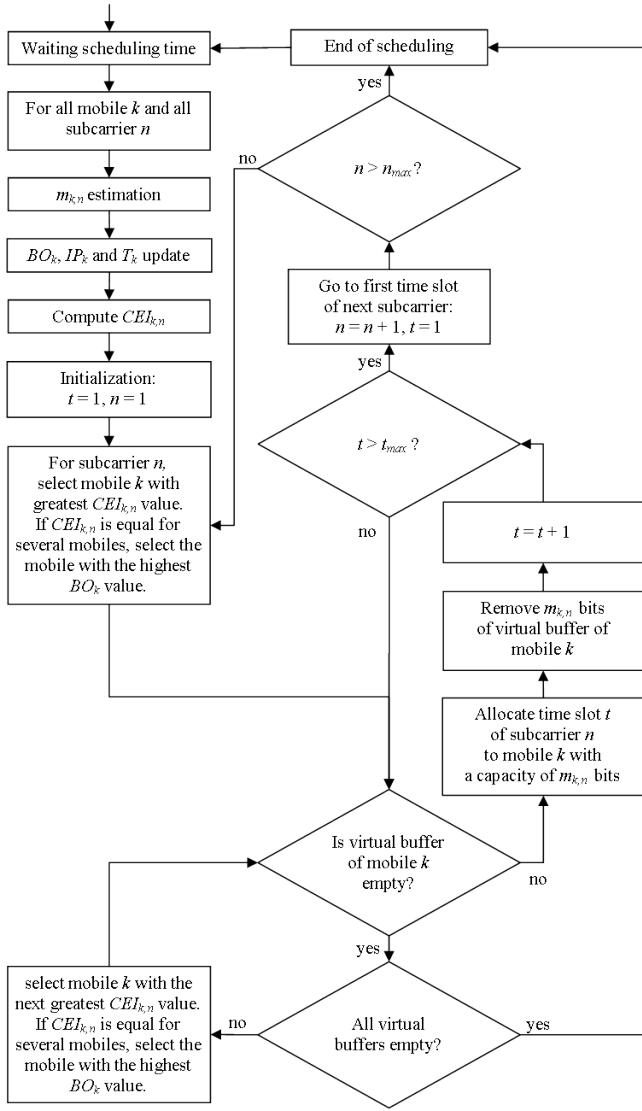


Fig. 3. CEI scheduling algorithm flow chart.

Physical layer information is used with $m_{k,n}$ in order to take advantage of the time, frequency and multiuser diversity and maximize the system capacity. Cooperation information is exploited in a weighted system with IP_k parameter that introduces dynamic priorities between mobiles for ensuring good awards to mobiles which help to extend the coverage zone. This results in an efficient scheme which guarantees a better network connectivity while avoiding tradeoff with the system capacity.

The T_k parameter is an additional factor which allows to temperate $CEI_{k,n}$ value function of network confidence. Include T_k parameter allows to be resistant to malicious nodes which would lie on its $\sum_{i=0}^i D_{ki}$. Thanks to this control parameter, no malicious mobiles will retransmit the packets which they have previously received supplementary priorities will be penalised and the good behavior are stimulate.

The CEI scheduling algorithm is detailed in Fig. 3. The scheduling is performed subcarrier by subcarrier and on a

time slot basis for improved granularity. In the allocation process of a given time slot, the priority of a mobile with respect to another is determined by the magnitude of its CEI parameter. In the following, we describe the proposed scheduling algorithm step by step.

- Step 0: The scheduler refreshes the current $m_{k,n}$ and update cooperation ratio IP_k , confidence ratio T_k and buffer occupancy BO_k values. Then, it computes the $CEI_{k,n}$ parameter for each mobile and each subcarrier. Then, n and t are initialized to 1.
- Step 1: For subcarrier n , the scheduler selects the mobile k with the greatest $CEI_{k,n}$ value. If $CEI_{k,n}$ is equal for several mobiles, the scheduler chooses the mobile with the highest BO_k value.
 - Sub-step 1-1: If the virtual buffer occupancy¹ of mobile k is positive, the scheduler goes to Sub-step 1-2. Else, if all virtual buffers are null or negative, the scheduler goes to Step 2. Otherwise, the scheduler selects the next mobile k with the greatest $CEI_{k,n}$ value and restarts Sub-step 1-1 (if $CEI_{k,n}$ is equal for several mobiles, the scheduler chooses the mobile with the highest BO_k value).
 - Sub-step 1-2: The scheduler allocates time slot t of subcarrier n to mobile k with a capacity of $m_{k,n}$ bits, removes $m_{k,n}$ bits of its virtual buffer and increments the value of t . If t is smaller than the maximum number t_{max} of time slots by subcarrier, go to Sub-step 1-1 for allocating the next time slot. Else, go to next sub-step.
 - Sub-step 1-3: Increment the value of n . If n is smaller than the maximum number n_{max} of subcarriers, go to Step 1 for allocating the time slots of the next subcarrier. Otherwise, go to Step 2.
- Step 2: All buffers are empty or all time slots of all subcarriers are allocated and the scheduling ends.

5) *Discussion*: We propose to limit IP_k values to a maximum of 2 which correspond to a cooperation ratio of 100%. Indeed, we assume that a mobile with a C_k value more higher than 100% could be considered as irrational. Indeed, it could be not desirable that a mobile relay more packets than it receive for its own consumption. We consider that it could be not profitable for it and also for the system since a mobile with a disproportionate cooperation ratio could quickly used its battery and could obtain all resources in the cell which will excessively penalize other mobile even with good cooperation ratio.

IV. PERFORMANCE ANALYSIS

In this section we evaluate the performance of the proposed CEI scheduling and we compare it with the classical Round Robin allocation and the well acknowledged MaxSNR scheduler. We consider four kinds of nodes: the first kind of

¹We define the virtual buffer occupancy as the current buffer occupancy of mobile k minus the number of bits already allocated to this mobile.

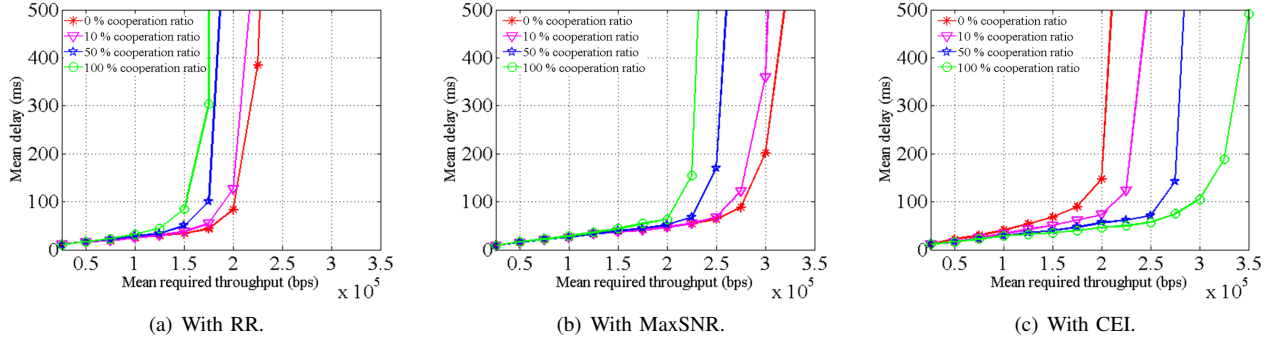


Fig. 4. Measured mobile mean delay with respect to their cooperation ratio.

nodes are selfish and do not relay packets ($C_k = 0\%$), the second kind relay a few packets with $C_k = 10\%$, the third kind is more cooperative with $C_k = 50\%$ and the last kind of nodes is really network friendly with a high cooperative ratio of 100%. We focus on two main performance metrics: the mean packet delay and the mean throughput provided at each mobile. Performance evaluation results are obtained using OPNET discrete event simulations with simulation parameters presented in the next subsection.

A. Simulation setup

We assume that each frame is formed by 128 subcarriers and 5 time slots. The channel gain model on each subcarrier considers free space Path Loss a_k and multipath Rayleigh fading $\alpha_{k,n}^2$ [21]:

$$a_{k,n} = a_k \times \alpha_{k,n}^2. \quad (8)$$

where a_k is dependent on the distance between the access point and mobile k and $\alpha_{k,n}^2$ represents the flat fading experienced by mobile k on subcarrier n . $\alpha_{k,n}$ is Rayleigh distributed with an expectancy equal to unity. Additionally, the maximum transmission power satisfies:

$$10 \log_{10} \left(\frac{P_{max} T_s}{N_0} \times a_{ref} \right) = 31 \text{ dB} \quad (9)$$

and the BER target is equal to 10^{-3} . With this setting, the value of $m_{k,n}$ is 3 bits when $\alpha_{k,n}^2$ equals one.

In order to be close to the reality, we consider that all mobiles run the same videoconference application. This demanding type of application generates a high volume of data with a high sporadicity and requires tight delay constraints which substantially complicate the task of the scheduler. Each traffic is composed of an MPEG-4 video stream [22] and an AMR voice stream [23]. The traffic load variation is done through increasing the mobile bit rate requirement of each mobile all together.

B. Delay impact

First we focus on the mean mobile packet delay provided by each scheduler function of different traffic loads keeping a special attention on their ability to encourage mobile cooperation with a low guaranteed delay. The obtained results are

plotted in figure Fig. 4 with the mean throughput required by each mobile of the cell represented on the abscissa.

Figure 4(a) shows the case of RR with different cooperation ratios of nodes. We remark that the classical RR fails to promote cooperation activities. The RR fairly allocates the RUs to the mobiles without taking into account the effort of the cooperative mobile nodes which share their allocated resources with other nodes located out of the primary access point cell. Consequently, the more cooperative the nodes are, the less resources for their own transmission they have. 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. Consequently, unacceptable packet delay is experienced even with relatively low traffic loads.

Figure 4(b) illustrates the obtained results in the case of MaxSNR with different cooperation ratios of nodes. We point out that even if a higher traffic load is supported with an acceptable packet delay, the cooperative nodes are not rewarded and their performance in terms of QoS are less compared to the non-cooperative nodes.

Figure 4(c) shows the obtained results in the case of the proposed CEI scheduler. We remark that CEI not only encourages the nodes to cooperate but also to enhance the performance in terms of delay. When the nodes increase their cooperation ratio, the enhancement of their delay is more important. For example, the nodes with 100 % as cooperative ratio, have a delay inferior to 100ms when the mean required throughput is less than 3×10^5 bps which is not possible with other schedulers. The CEI dynamically and gradually adjusts the relative priorities of the mobiles in order to fairly and adequately reward them according to their relative cooperation ratio. With this approach, sparingly delaying the selfish mobiles, the CEI helps the others and whatever the traffic load, the mobile which provides the best cooperative ratio experiences the lowest packet delay.

C. Throughput impact

We now have a look on the mean mobile throughput provided by each scheduler function of different traffic loads keeping a special attention on their ability to encourage mobile cooperation with a high guaranteed throughput. The obtained results are plotted in figure 5. The first parts of these three

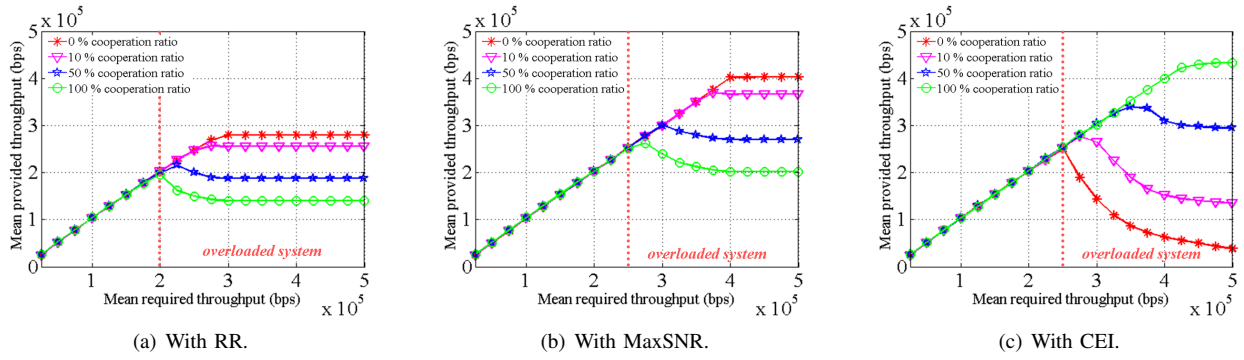


Fig. 5. Measured mobile throughput with respect to their cooperation ratio.

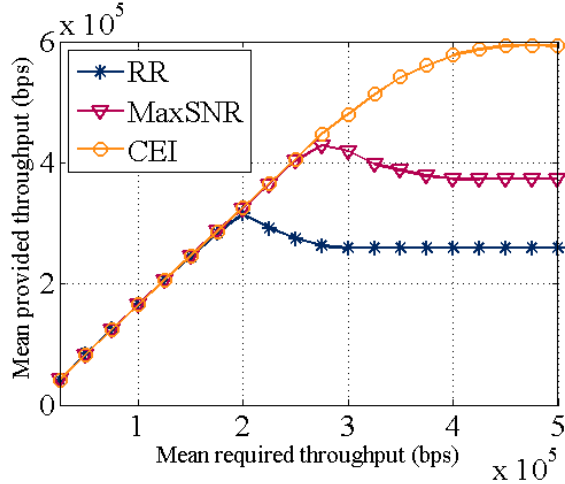


Fig. 6. Relay efficiency.

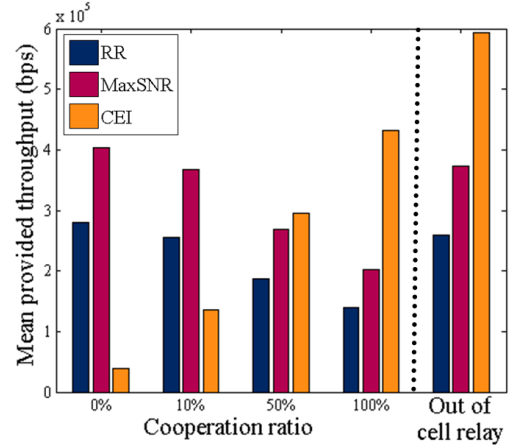


Fig. 7. Provided throughput function of cooperation ratio in overload system.

figures, where all the curves are superimposed, correspond to an unoverloaded system. Each mobile can be served and each scheduler is able to provide the required throughput.

In the second parts of these figures, the system capacity is exceeded and the scheduler must make a choice. With RR the system capacity goes past its limit when each source requires $200Kbps$. With MaxSNR and CEI which provide an efficient spectral efficiency thanks to their opportunistic approaches, this limit is moved to $250Kbps$.

In an overloaded context, clearly, RR and MaxSNR give advantage to the selfish mobile nodes as illustrated in figures 5(a) and 5(b). Indeed, with these schedulers, each mobile of the primary access point coverage receives the same mean number of RUs. However a mobile with a cooperation ratio of 100% keeps only the half of its allocated RUs for its own consumption while a selfish mobile with a C_k of 0% keeps all its allocated RUs only for its own requirement. Consequently, the friendly mobile with C_k equal to 100% has a personal provided throughput half less higher than the one of the selfish mobile. This result is a really disheartening situation for cooperative mobiles which are finally penalized².

²The penalizing is proportional to the C_k magnitude. For example, when C_k equals 50%, the mobile forwards 50 packets when it receives 100 packets for its own consumption. Consequently, its personal provided throughput is a third less higher than the one of the selfish mobile.

In an overloaded context, the CEI does not deploy the same strategy while reaching the overloaded limit with the same traffic load as MaxSNR as illustrated in figure 5(c). The more network friendly a mobile is and relays packets in order to help primary access point coverage extension, the more the CEI increases its priority. Consequently, when the CEI can not serve all mobiles, it first sacrifices the selfish mobiles, then the next less friendly mobile. The result of this new scheduling strategy is that mobiles are stimulated to cooperate to keep a high throughput.

D. Relay efficiency impact

Figure 6 illustrates the relay efficiency in terms of the total mean throughput that each scheduling algorithm has allowed to provide out of the cell³. We remark that RR provides the worst performances compared to MaxSNR and CEI. MaxSNR allows to relay more packets but it is the CEI which gives the best number of provided throughputs out of the cell. The RR and MaxSNR curves decrease after the peaks due to the best cooperative mobile penalizing when the system capacity is reached. The CEI, according more priority to friendly mobiles, continues to increase the total amount of forwarding

³The cell can be assimilated to the primary access point coverage zone, without assuming relaying.

throughputs until a high traffic load which corresponds to a high network extension capacity. With this new resource allocation strategy, when the mean required throughput of each mobile is equal to 500 Kbps, the total amount of data transmitted out of the cell in order to extend the coverage area can be increased around 59% compared to the well acknowledged MaxSNR and around 129% compared to the classical scheduling algorithm RR.

E. Results summarization

Figure 7 concludes these performance evaluations. It notices, for a high traffic load of 500Kbps for each mobile, the scheduler behaviour showing the mean cell mobile provided throughput according to their cooperation ratio and the total mean provided throughput out of the cell (at the right). These last results clearly corroborate the previous results. With RR and MaxSNR scheduling, there is no interest for a mobile to cooperate. To be friendly induces to increase its mean packet delay as illustrated in figures 4(a) and 4(b), but also to reduce its potential throughput particularly in an overloaded context (Fig. 5(a) and 5(b)). On the contrary, with CEI, there is a significant interest for a mobile to cooperate. To be friendly induces to decrease its mean packet delay whatever the traffic load on the system (Fig. 4(c)) but also allow to increase its potential throughput in an overloaded context (Fig. 5(c)). Thanks to this new resource allocation strategy, mobiles are no more penalized to cooperate but receive high rewards in terms of QoS which could easily compensate cooperative energy cost. The cooperative mobiles can increase their own throughput around 114% compared to MaxSNR and around 209% compared to resources allocation strategy RR (Fig. 7). Therefore, this allows significant coverage extension which was not realizable with RR and MaxSNR strategies and free mobiles.

V. CONCLUSION

In this paper we have proposed a new incentive approach which encourages nodes to relay neighbors frame. With our proposition, the mobile stays free to cooperate or not but the proposed scheduler CEI sparingly awards participative nodes so that it is more interesting for them to actively contribute to a good network connectivity. This result is a well-balanced resource allocation which allows to increase the network coverage area while never reducing the global system throughput thanks to a combined opportunistic approach. A minimum throughput is guaranteed to all mobiles of the cell and, thanks to its high spectral efficiency, the mean packet delay provided to the selfish mobiles by CEI is close to the best RR performance. These CEI interesting performance results are all the more interesting that a significant priority is given to mobiles which help the network providing a low packet delay and a high personal throughput. In the future work, we plan to introduce services differentiation in our proposed solution.

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