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ITERATIVE MULTI-USER SCHEDULING ALGORITHM WITH JOINT RESOURCE ALLOCATION AND COOPERATIVE-LINK ADAPTATION

BY

MIHÁLY VARGA[*]

Technical University of Cluj-Napoca

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Abstract. A priority-based scheduling algorithm which exploits both the multi-user and cooperative diversity of a cell that uses cooperative-relaying is proposed and analysed. The proposed scheduling algorithm jointly performs resource allocation and link adaptation, trying to find the transmission scheme (cooperative or direct, coding rates and modulation orders) which would provide the required bit-rate, under a coded block error rate smaller than a target value, for a given user-terminal, using the minimum amount of radio resources. The analysis and simulation results presented in this paper show that the proposed joint scheduling and link adaptation algorithm provides greater spectral efficiency, while keeping the coded-block error rate below the target value, and smaller packet-delays than the “classical” non-cooperative approach.

Key words: wireless networks; radio resource management; spectral efficiency.

1. Introduction

Reliable coding and modulation techniques are required to combat the severe impairments of wireless channels, such as fading, interference and shadowing (Proakis, 2000). In addition, these schemes need to be constantly optimized and/or updated to cope with the increasing demand for higher data

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[*] *e-mail*: Mihaly.Varga@com.utcluj.ro

rate services and the well known cost and complexity constraints. Cooperative relaying techniques, which employ distributed coding and modulation algorithms, have been recognized as one of the most promising means for the improvement of the next generation wireless networks. The performance gains, in terms of reliability and spectral efficiency, provided by these techniques in multiple-access wireless networks, are significantly affected by the optimum radio resource management and medium access control schemes, which should be adapted to cooperative transmissions.

The main challenge of the medium access control (MAC) and radio resource management (RRM) techniques, used in cooperative transmissions, is how to dispatch the transmission resources between users of a network, while satisfying all requests at the highest possible degree, subject to the minimum complexity and efficient spectrum utilization constraints, and (optionally) a minimum power consumption,. The RRM entity of a relay-enhanced cell has to address in optimal ways, the problems of assigning to each user-terminal that best relay-node, the selection of the users that should be scheduled in each radio frame and the selection of the modulation and coding schemes that would provide the greatest spectral efficiency, while observing the reliability, *i.e.*, block error rate (BLER) requirements. Furthermore, the RRM issue of systems using cooperative relaying has to perform the resource allocation and modulation and coding selection for the three component links, *i.e.* source-destination, source-relay and relay-destination, in a joint manner in order to fulfill the global performance and reliability requirements.

2. System Model

The deployment scenario consists in a single cell with a central base-station (BS), six relay nodes (RNs) strategically placed in fixed positions (Fig. 1), and several user terminals (UTs) which, assisted or not by an RN, communicate with the BS. The BS manages *K* buffers containing heterogeneous data traffic destined to the user-applications (UT) running on the UTs (*e.g.* VoIP, HTTP, video, gaming, FTP). Typically, the different buffers at the BS have different QoS requirements, depending on the service type.

Transmissions are performed in the downlink direction. The cooperation strategy implies the assisting RN to transmit additional coded bits, such that, after the UT combines the soft bits received over both source–destination and relay – destination channels, the final code rate decreases and/or the reliability of the repeated bits increases (D3.3b Final Advanced PHY…). Note that not all transmissions are cooperative, *i.e.* only a part of the users requires cooperation.

For a given scheduled UT the transmitted coded block might occupy multiple RRUs, allowing the modulation order to differ from one used RRU to another. The BS does not use power control, such that the same power is allocated to each RRU.

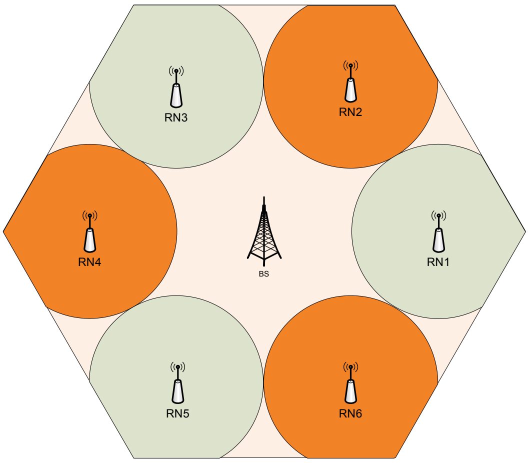

Fig. 1 – Positioning of the relay nodes in the cell, and resource reuse pattern for the relaying phase.

3. Iterative Multi-User Scheduling Algorithm with Joint Resource Allocation and Cooperative Link Adaptation

The proposed Iterative Multi-User Scheduling Algorithm with Joint Resource Allocation and Cooperative Link Adaptation has to perform the following main tasks:

a) Assumes a relay node assigned to each user terminal; this assignment is performed by Relay node assignment algorithm.

b) Selects from the input buffers the data mapped to the radio frame.

c) Based on the channel conditions experienced by the selected users, chooses for every user the cooperation scheme, transmission rate, the allocated radio resource units and the used modulation orders on the RRUs of the current transmission frame, in such a way to maximize the amount of average information bits carried by an elementary transport element.

d) The retransmissions in case of erroneous decoding of the coded block are managed by the associated cooperative H-ARQ algorithm.

The proposed algorithms are presented in the following sections.

3.1. Multi-User Scheduling Policy

The purpose of a scheduling algorithm is to allocate the RRUs of each frame in such a way that the different UTs’ QoS requirements are fulfilled in a spectral-efficient way.

The proposed scheduling algorithm is with priority-based and exploits both multi-user and cooperative diversity. The scheduler tries to allocate a user the best RRUs experienced on the BS–UT and RN–UT channels, conditioned by a correct decoding at RN, in a prioritized manner. User priorities are computed taking into account traffic type, queue lengths, long-term channel conditions, and packet delays.

It is assumed that the relay allocation was performed in advance, and the algorithm's result will only indicate if the relay of each scheduled UT is activated or not for the current frame. From the scheduler's point of view, cooperation is beneficial for the current frame if, for a given data block length, fewer resources (RRUs) are required to ensure a target coded BLER at the output of the UT's decoder.

For each frame, based on a set of user priorities, the outline of the scheduling algorithm is the following:

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1. Compute the running UTs' priorities.
2. While there are available RRUs.
    2.1. Select the user k with the highest priority, $(1 \le k \le K)$.
    2.2. If the user has not been scheduled for this frame (1st iteration for user k, i.e. i(k) = 1).
        2.2.1. Try to select the maximum transmission rate and allocate the minimum number of RRUs necessary to transmit a block of $I_{P,k}^{(1)}$ payload bits with a probability of error smaller than a target value: first, allocate the best available RRUs on the broadcast subframe, until there are enough resources to ensure a $\text{BLER}_{\text{RN}} < \text{BLER}_{\text{RN,target}}$ (the maximum acceptable probability that the RN is not able to correctly decode this block). Then, search to allocate the best available RRUs on both the broadcast and the relaying subframes, such that $\text{BLER}_{\text{UT}} < \text{BLER}_{\text{UT,target}}$. Note that after this step the modulation orders on each used RRU will be available.
        2.2.2. Recompute the priority of this user. Go to step 2.
    2.3. Else
        2.3.1. Try to allocate the minimum number of additional RRUs, available on the broadcast and relaying subframes, such that, together with the already allocated RRUs and the corresponding modulation orders, a payload block of greater length than the previous one ($I_{P,k}^{(i)} > I_{P,k}^{(i-1)}$) can be transmitted with $\text{BLER}_{\text{UT}} < \text{BLER}_{\text{UT,target}}$, where i denotes the i^th scheduling iteration for user k in the current frame. Note that the condition $\text{BLER}_{\text{RN}} < \text{BLER}_{\text{RN,target}}$ is also required for the new codeword.
    2.4. End If
End While
```

3.2. User Priority Computation

One of the issues that affect significantly the performances of the scheduling algorithm is the definition of the used rule to compute the UT's priority for the resource allocation. The UT priority should depend on a number of varying parameters, such as type of service, delay accumulated by the packet in buffer, the instantaneous and average qualities of the channels experienced by the user, the amount of the data in the queues, etc. To ensure the required QoS for all users and maximize the spectral efficiency at the cell level, the scheduler should find, in every frame period, a maximum on a multidimensional time-varying surface, while satisfying some fairness and other types of priority constraints. This problem is a non-deterministic polynomial-time hard one.

The priority of one user is computed with relation

$$Pr_i = \left(Pr\_\mathrm{ant}_i + Pr\_\mathrm{serv}_i + k_i \mathrm{max\_delay}_i + z_i\right)\mathrm{rap}_i, \tag{1}$$

where: Pr_ant_i denotes the priority of user i computed at the previous radio frame; Pr_serv_i represents the priority factor of user I; this coefficient contains the weights of the service-type and of the subscriber; it should ensure higher priorities for real time services; $\mathrm{max\_delay}_i$ denotes the time spent in the queue by the current packet (expressed in milliseconds); the weight of the delay term in the user's priority can be adjusted by varying the value of the k_i factor; z_i is the ratio between the instantaneous and imposed bitrates.

The value of the rap_i is expressed by

$$\mathrm{rap}_i = 1 - \frac{w_i}{W_{\mathrm{all}}}, \tag{2}$$

where w_i denotes the amount of radio resources assigned to user i in the current radio frame, and W_{all} represents the total amount of available radio resources on the radio frame, both expressed in RRUs.

This term reflects the qualities of the user's channels. If the user meets good channel conditions, the amount of resources needed to transmits a coded block is small, so the rap_i would have a great value (close to unity), but if user i experienced poor channel conditions, the amount of radio resources needed to transmit a coded block would be greater, so the value of this coefficient will decrease towards zero

If the scheduler assigned resources to i UT in the current radio frame, its rap_i factor would be smaller than one, thereby the UT's priority value would decrease, while for no assigned resources, the rap_i remains constant. Thus, the users who get resources on the current radio frame will have a lower Pr_ant_i priority on the following radio frames.

3.3. Joint Dynamic Resource Allocation, Link Adaptation and Relaying Phase Activation (JDRACLA) Algorithm

Within each iteration of the scheduling algorithm, the k UT with the highest priority is selected and a joint resource allocation and link adaptation is performed. The goal is to allocate from the pool of available resources the minimum number of RRUs on the Broadcast and Relaying subframes and select the appropriate transmission rates and modulation orders for each RRU, and the transmission rate for that coded block, such that, for a given payload size, $I_{P,k}^{(i)}$, the following conditions are fulfilled:

a) the probability that RN is not able to correctly decode and cooperate is less than a target value

$$\mathrm{BLER}_{\mathrm{RN}} < \mathrm{BLER}_{\mathrm{RN,target}}; \tag{3}$$

b) the probability that, after jointly processing the received messages, the UT's decoder provides an erroneous data block is less than a target value

$$\mathrm{BLER}_{\mathrm{UT}} < \mathrm{BLER}_{\mathrm{UT,target}}. \tag{4}$$

The above BLER values depend on the code rate, payload block size, and CSI and modulation orders of the occupied RRUs.

To satisfy the BLER targets, the algorithm needs to estimate the decoding performance provided by the multiple link configurations that are possible, and to select the most appropriate one. With that end in view the algorithm employs a BLER performance prediction method based on mutual information, its purpose being to estimate the instantaneous performance of a link, using current channel conditions and link parameters. There are several approaches in literature, among which the one proposed by Sayana *et al.* (2008), that uses mutual information metrics, is the most appropriate for our scenario. In the cited paper was shown that the BLER performance of CTC codes with coding rate, R_c, and information block length, $I_{P,k}$, over fading channels, can be estimated, with an arbitrary good precision, by using the mean mutual information per coded bit ($\overline{\mathrm{MI}}$) as quality metric to assess the AWGN performance of the CTC codes (Badiu *et al.*, 2010)

$$\mathrm{BLER}_{\mathrm{Fading}} \approx \psi\left(\overline{\mathrm{MI}}, R_c, I_{P,k}\right). \tag{5}$$

It is shown (Sayana *et al.*, 2008) that function $\psi(...)$ can be accurately approximated by

$$\psi\left(\overline{\mathrm{MI}}, R_c, I_{P,k}\right) = 0.5\left[1 - \mathrm{erf}\left(\frac{\overline{\mathrm{MI}} - b_{R_c, I_{P,k}}}{\sqrt{2}c_{R_c, I_{P,k}}}\right)\right], \tag{6}$$

where $\overline{\mathrm{MI}}$ is the mean mutual information per coded bit, and $b_{R_c, I_{P,k}}$

respectively $c_{R_c,I_{P,k}}$ are some coefficients whose values depend on R_c and $I_{P,k}$. The values of the $b_{R_c,I_{P,k}}$ and $c_{R_c,I_{P,k}}$ coefficients for different values of R_c and $I_{P,k}$ can be determined by computer simulations and curve fitting.

For the current frame, at the i^{th} iteration for the k UT, it would be required to check all the possibilities (combinations of available RRUs, coding rates and modulation orders) to arrive at the solution which uses the minimum number $L_B + L_R$ of resources to transmit $I_{p,k}^{(i)}$ informational bits and fulfill conditions (3) and (4). This approach is clearly impractical due to its exponential complexity; therefore, the solution described in the following is adopted.

It is assumed that the "individual" $\overline{\text{MI}}$ values ($\overline{\text{MI}}_{B,l}^{\text{UT}}$, $\overline{\text{MI}}_{B,l}^{\text{RN}}$, $\overline{\text{MI}}_{R,l}^{\text{UT}}$) are computed by the CSI acquisition and processing block at the beginning of each frame. Note that three values are stored for each RRU, corresponding to the QPSK, 16QAM and 64QAM modulations.

It is assumed also that every QAM-symbol data of one RRU uses the same modulation order, but the different RRUs selected to carry the coded block might use different modulation orders. We propose a search mechanism based on an associated trellis diagram as depicted in Fig. 2. The states of the trellis diagram are the possible modulation orders. The metric of the paths is defined as the number of information bits that could be mapped on that group of RRUs, so that the obtained BLER after decoding should be lower than a desired target value. Considering the three possible modulations (QPSK, 16QAM, 64QAM) there are three states in the trellis and three paths start from and arrive in each state, making up a full trellis.

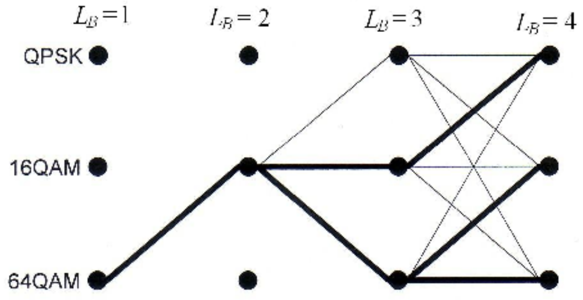

Fig. 2 – The associated trellis diagram.

S t a g e 1. *Resource allocation for the Broadcast subframe*.

a) Preprocessing.

From the available RRUs on the Broadcast subframe, choose the first $N_{B,\max}$ RRUs which have the highest $\text{MMIB}_{B,l}^{\text{UT}}$ values for a given modulation order, *e.g.*, $m_{B,l} = 2$, and sort them in descending order, generating a sorted list.

Step 1.

Set $L_B = 0$.

While $L_B \le N_{B,\max}$ and $\mathrm{BLER}_{\mathrm{RN}} \ge \mathrm{BLER}_{\mathrm{RN,target}}$ and $\mathrm{BLER}_{\mathrm{UT}} \ge \mathrm{BLER}_{\mathrm{UT,target}}$

Select the next 'best' RRU from the sorted list. Set $L_B = L_B + 1$.

For each modulation order, m_{B,L_B}, compute:

α) The total number of carried bits, $N_c^{B,m_{B-1}}$, which results if the current RRU that uses a modulation order m_{B,L_B} is appended to all previous surviving paths.

β) For each state, determine the "surviving path", *i.e.*, the path which gives the maximum value for $\overline{\mathrm{MI}}_{\mathrm{BS-UT}} \times N_c^B$, where $N_c^B = S_D \sum_{l=1}^{L_B} m_{B,l}$. This product balances the need to employ high order modulations to minimize the number of resources with the need of high $\overline{\mathrm{MI}}$ values to correctly decode.

γ) Compute $\mathrm{BLER}_{\mathrm{UT}}$ and $\mathrm{BLER}_{\mathrm{RN}}$ using (5).

End While

Save the parameters of the surviving path.

End Step 1.

Step 1 would be finished if at least one of the following conditions were fulfilled:

a) C1: $\mathrm{BLER}_{\mathrm{RN}} \le \mathrm{BLER}_{\mathrm{RN,target}}$; this means that the RN should correctly decode the coded block with high probability. This requirement must be fulfilled to activate the relaying phase.

b) C2: $\mathrm{BLER}_{\mathrm{UT}} \le \mathrm{BLER}_{\mathrm{UT,target}}$; in this case it is not necessary to use the second phase of cooperation, because the UT should decode the coded block with a probability greater than $1 - \mathrm{BLER}_{\mathrm{UT,target}}$, using the message received in the broadcast phase.

c) C3: $L_B > N_{B,\max}$; this means that there are not enough resources in the current broadcast subframe to transmit the coded block with a sufficiently small error probability.

Step 2.

IF $\mathrm{BLER}_{\mathrm{RN}} < \mathrm{BLER}_{\mathrm{RN,target}}$ (decodable at RN) and $\mathrm{BLER}_{\mathrm{UT}} \ge \mathrm{BLER}_{\mathrm{UT,target}}$.

From the available RRUs on both the Broadcast and Relay subframes, choose the first $N_{\max}$ RRUs which have the highest $\overline{\mathrm{MI}}_{B,l}^{\mathrm{UT}}$, respectively $\overline{\mathrm{MI}}_{R,l}^{\mathrm{UT}}$, values for a given modulation order, and sort them in descending order. $N_{\max}$ = = min(*available RRUs on both subframes*, $N_{B,\max}$). Basically in this case the algorithm continues in the same manner to search the best path on the trellis (as shows Fig. 3), taking also into account the RRUs from the relaying subframe.

$L_R = 0$.

While $L_B + L_R \le N_{\max}$ and $\mathrm{BLER}_{\mathrm{UT}} \ge \mathrm{BLER}_{\mathrm{UT,target}}$

Select the next 'best' RRU from the sorted list.

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        IF the RRU is from the Broadcast subframe $L_B = L_B + 1$, ELSE $L_R = L_R + 1$.
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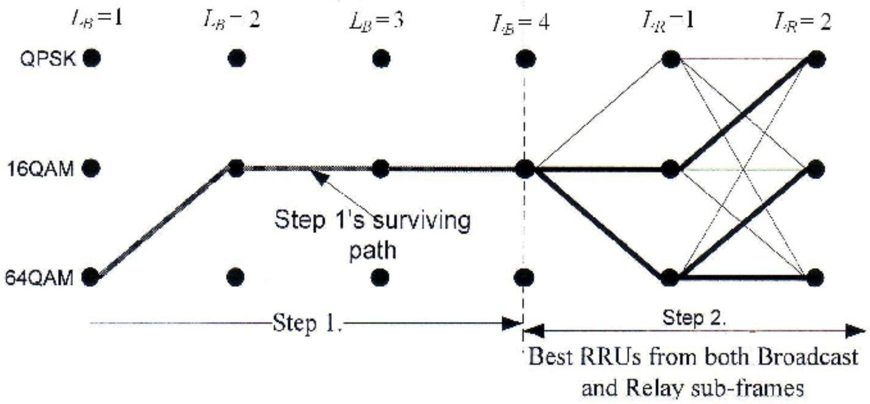

Fig. 3 – The trellis diagram during step 2.

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        For each modulation order $m_{B,L}$
        a) Determine the "surviving path", i.e., the path which gives the maximum value of $\overline{\mathrm{MI}} \times \left(N_c^B + N_c^R\right)$, where $N_c^B = S_D \sum_{l=1}^{L_B} m_{B,l}$ and $N_c^R = S_D \sum_{l=1}^{L_R} m_{R,l}$.
        b) Compute $\mathrm{BLER}_{\mathrm{UT}}$ using (5).
    End While
    If $L_R > 0$ activate the relaying phase. Else Direct transmission. End if
ELSE IF $\mathrm{BLER}_{\mathrm{UT}} < \mathrm{BLER}_{\mathrm{UT,target}}$
        STOP (the user will use a non-cooperative transmission)
ELSE IF $L_B > N_{B,\max}$
        not able to allocate resources for this user
END IF
```

Together with the scheduling algorithm, this algorithm has also to choose the length of the payload block (informational part of the coded block); an iterative selection of the payload length is performed. When the scheduling algorithm selects the UT for the first time, radio resources are assigned to carry the shortest possible payload length. After assigning the necessary resources to this data block, the priority factor of this UT decreases. If an UT is selected more than once during one radio frame, the payload length increases each time to the next possible level. At the increase of the data block length, the previously presented JDRACLA algorithm is repeated from step 1, but instead of the null initial conditions (L_R = 0), it starts from the surviving path of the previous iteration, as presented in Fig. 4.

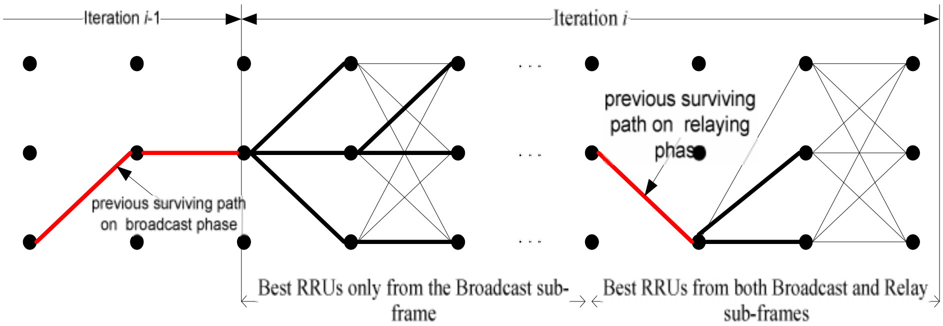


Fig. 4 – Increasing the codewords length.

In case of H-ARQ retransmissions (Byun & Kim, 2008; Wu & Jindal, 2010; Varga *et al.*, 2011), the algorithm has to assign more resources to the required additional bits, in order to decrease the block error rate below the imposed target. The payload length remains the same, but due to the changed value of the $\mathrm{BLER}_{\mathrm{UT,target}}$, since the block was decoded successfully by the RN. The step 1's survivor path is replaced by the survivor path of the previous transmission. Because during retransmissions, the additional messages are sent only by the RN in relaying phase, the $\overline{\mathrm{MI}}$ values of the broadcast phase are not considered (*e.g.*, they are set to zero); therefore, the algorithm will select only the RRUs in the relaying subframe.

4. Numerical Results

4.1. Simulation Scenario

The performance of the joint scheduling and link adaptation algorithm were evaluated in a single cell scenario with six fixed relays. The radius of the cell is set to R = 950 m and the RNs are located at a distance $d = 2R/3$. It is assumed that there are N_{UT} = 100 UTs in the cell. The UTs are uniformly distributed in the hexagonal cell, and they move according to the random-walk mobility model (IEEE 802.16m, 2009).

The channel models used for the three links of a cooperative transmission are presented in

Table 1. The model used to compute the path loss, L, of the radio signal between transmitter and receiver on one channel is the one proposed in IEEE 802.16m (2009) for vehicular environments. The BS-RN$_x$ channels are assumed to AWGN, because the two equipments are fixed and the antennae are supposed to be high enough to avoid any significant reflections. The effects of shadowing and interferences from other cells are not considered. Every link is assumed to use single-antenna transmitter and receiver.

Table 1
Channel Parameters of the Different Cooperative Links

Link	Path Loss	Multipath model	Speed km/h	Doppler Spectrum	Receiver antenna gain, [dB]
BS-RN	$L,\ [\text{dB}] = 130.18 + 37.6\log_{10}\left(\frac{R}{Km}\right)$	AWGN	0		10
BS-UT		ITU Veh. A	30	Jakes	0
RN-UT		ITU Veh. A	30	Jakes	0

The traffic mixture used is presented in Table 2 (NGMN, 2008; IEEE 802.16m, 2009). The different service types are modeled according to the definitions described (IEEE 802.16m, 2009).

Table 2
The Considered Traffic Mixture

Service type	% users	Average bitrate
Voice over IP (VoIP)	30	12.2 kbps
Near Real Time Video (Video)	20	64 kbps
Real Time Gaming	20	64 kbps
HTTP	20	10 Mbps
File Transfer Protocol FTP	10	10 Mbps

4.2. Simulation Results

A general performance metric of such a system would be the number of information (payload) bits correctly decoded within an elementary transport unit. A metric that is proportional to the spectral efficiency, but is not depending on the RRU's dimensions, is the number I_{SQ}, of correctly decoded information bits carried by a QAM symbol, which is considered as an elementary radio resource unit. The cumulative distribution function (cdf) and average value of the I_{SQ} should be used to indicate more completely its behavior.

The ISQ performances are presented by its cdf-s obtained by simulations in the scenario described above. Four cases were considered namely

a) the non-cooperative cell that doesn't use the HARQ, denoted by Direct and used as reference;

b) the non-cooperative cell that uses the HARQ, denoted by D-HARQ;

c) the cooperative cell that doesn't use the C-HARQ, denoted by Coop;

d) the cooperative cell that uses the C-HARQ, denoted by C-HARQ.

The cdf-s of ISQ ensured in the four cases described above are presented in Fig. 5 for the value of the average received SNR at the cells edge of 0 dB. The examination of the results from Fig. 5 shows that the cooperative approach with no HARQ uses up to 5 bits/QAM symbol with a smaller probability than the non-cooperative approach; this means that the probability to use 6 bits/QAM symbol is greater for the cooperative approach.

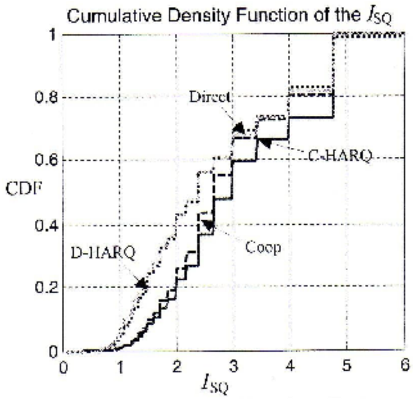
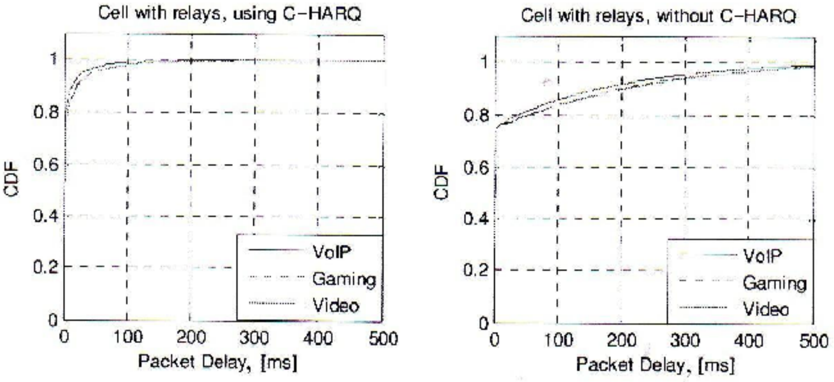
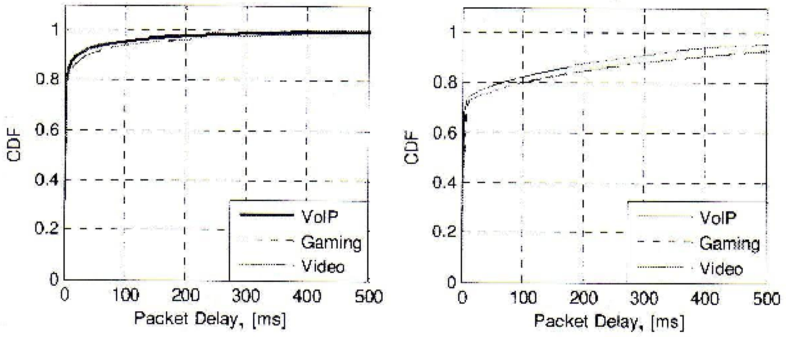


Fig. 5 – CDF(I_{SQ}) – 0 dB at the cell edge.



a *b*

Fig. 6 – CDF of Packet-delay for real-time services of the cooperative approach with HARQ (*a*) and without HARQ (*b*).



a *b*

Fig. 7 – CDF of Packet-delay for real-time services of the non-cooperative approach with HARQ (*a*) and without HARQ (*b*).

The delay inserted by cooperation and by the HARQ is expressed by the packet-delay, Del_P, measured at the destination's buffers for correctly decoded application-packets, for each type of application (service) considered. This metric is relevant for real-time applications, such as VoIP, video, gaming. The cdf-s of the four possible transmission approaches, are presented in Figs. 6 and 7, respectively.

The packet-delay is evaluated only for service-types that are sensitive to this parameter, *i.e.* VoIP, gaming and videostreaming. The employment of the HARQ algorithm in the cooperative approach brings a significant decrease of the delay inserted, compared to the cooperative transmissions that don't use the HARQ. This aspect could be explained by the fact that the HARQ requires less resources (in all its attempts) than the simple cooperative transmission, to transmit a coded block with the same BLER_t. This means that all coded blocks that compose the service-packet are transmitted, on average, in a smaller number of frames.

5. Conclusions

A scheduling and a link adaptation algorithm for relay enhanced cooperation are proposed. The results presented in this paper show that the cooperative transmissions, using the JDRACLA algorithm that jointly performs the link adaptation and resource allocation and the scheduling algorithm, ensure greater spectral efficiency and throughput, expressed by the I_{SQ}, than the non-cooperative transmission in the same scenario.

The utilization of the HARQ in cooperative transmissions brings increased spectral efficiencies and throughputs, compared to the corresponding transmissions that do not use HARQ algorithms.

The packet-delay inserted by cooperative transmissions is smaller than the one inserted by non-cooperative transmissions for the same real-time services, while the insertion of the HARQ algorithm lead to a decreased average packet-delay, compared to the corresponding non-HARQ transmission.

These preliminary results indicate that the cooperative approach, which uses adaptively cooperative distributed coding, might be beneficial for the cellular transmissions.

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ALGORITM ITERATIV DE PLANIFICARE A UTILIZATORILOR COMBINAT CU ALOCAREA RESURSELOR RADIO ŞI ADAPTAREA LEGĂTURII PRIN COOPERARE

(Rezumat)

Se propun şi se evaluează performanţele unui algoritm de planificare a utilizatorilor bazat pe priorităţi, care exploatează atât diversitatea prin cooperare cât şi diversitatea utilizatorilor. Algoritmul propus efectuează alocarea resurselor combinat cu adaptarea legăturii radio, încercând găsirea schemei de transmisie (transmisie prin cooperare sau transmisie directă, modalităţi şi ratele codurilor utilizate) care asigură recepţionarea datelor cu debitul mediu cerut de utilizator, respectând constrângerile legate de probabilitatea de eroare pe bloc, şi totodată utilizând numărul minim posibil de resurse radio. Analizele şi rezultatele simulărilor, prezentate în articol, arată că algoritmul de planificare a utilizatorilor propus, combinat cu algoritmul de adaptare a legăturii, asigură o eficienţă spectrală mai ridicată, şi întârzieri mai reduse ale pachetelor, decât în cazul transmisiei necooperative clasice, asigurând aceeaşi probabilitate de eroare pe bloc.