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SITUATION-AWARE RADIO RESOURCE MANAGEMENT FOR MULTI-RATE MC-CDMA WIRELESS NETWORKS TARGETED AT MULTIMEDIA DATA EXCHANGES IN LOCAL AREAS

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ABSTRACT

In this report, a novel methodology for radio resource management is considered for multi-rate MC-CDMA WLAN indoor networking. The proposed strategy is based on resource reallocation and rate adaptation depending on the network situation, monitored in terms of achieved QoS by an intelligent access-point (AP). As they access the medium, all users send bit-rate requests on the basis of their application requirements. Then, the AP monitors the QoS in terms of frame-error-rate (FER) and decides a) to reallocate the radio resources (in terms of number of orthogonal subchannels) and b) to reduce the data rate, in order to improve throughput performances for those users penalized by heavy FER. The "rate downshift" process is continued until the FER measured by the AP allows data transfer with an acceptable QoS. The intelligent AP can also issue a "rate upshift" for users previously downshifted, or in presence of explicit requests, when the channel situation improves. Simulation results underline a general improvement of the aggregated throughput deriving from adaptively manage the QoS requirements with respect to the network situation, thus enabling good resource usage with the WLAN cell.

I. INTRODUCTION

In recent literature, some applications of the innovative concepts of location and situation awareness in broadband wireless networking have been shown. The basic idea of *location awareness* is to adaptively modify network settings, user interface and function according to their location. *Situation awareness* is invoked in order to provide wireless networks with the capability of self-organizing in an intelligent way by dynamically reacting to external perturbations (due to traffic, congestion, propagation impairments, etc.), which imply a decrease of the user-perceived QoS [1]. It is intuitive that location and situation awareness could be jointly exploited in order to reconfigure in an adaptive way all network layers in order to improve global performances for mobile connecting users independently from the provided services.

In this paper, the information about network situation is employed in order to design an adaptive medium access control strategy for multi-rate multi-carrier CDMA WLAN networks using TCP transport protocol. The adopted strategy is substantially a joint MAC-PHY layer approach derived by the one shown in [2] which relies on the variable-bit-rate (VBR) MC-CDMA physical layer design proposed in [3]. The overall transmitting users are partitioned into different VBR classes, each one characterized by a set of PHY-layer parameters consisting of: a) a variable-cardinality subcarrier set and b) a variable-length spreading code, each one depending on the bit-rate class. An intelligent access-point (AP) monitors the performances in terms of frame-error-rate (FER) of each transmitting user. From the MAC layer perspective; this task clearly represents monitoring of the network situation in terms of achieved FER performance. In fact, TCP-based connections rely on packet retransmission in case of detected channel errors [4]. As a consequence, the connection throughput inversely depends on the FER, as shown in [5]. When user performances in terms of FER are not satisfactory, the AP issues a “class downshift” for users penalized by heavy FERs. Such a downshift mechanism, introduced in [2], substantially consists in a decrease of the data rate, with a consequential increase of the processing gain and transmission SNR, achieved in the context of the VBR MC-CDMA PHY-layer design detailed in [3]. The effectiveness of the class downshift mechanism has been already proven in [2]. In fact, such procedure allows improving the aggregated throughput of a VBR MC-CDMA network, raising throughput curves of most penalized users from a cumbersome “zero-floor”. In this work, we intend to complete the joint MAC-PHY layer approach of [2], considering also the possibility of a “class upshift” for those users previously downshifted or “on request” by users not yet downshifted. The “class upshift” is issued by the intelligent AP for previously downshifted users, only when the network situation allows it. Moreover, the intelligent AP establishes a priority scale in the management of the upshift requests coming from other users by privileging the slower users' requests with respect to fastest users' ones.

The paper is structured as follows: Section II presents a state-of-the-art overview with some related works cited. Section III will detail the proposed radio resource management strategy. Section V aims at showing selected experimental results. Finally, paper conclusions are drawn in Section VI.

II. RELATED WORKS

Standard concepts about radio resource management in WLAN networks are being currently revised considering the recent diffusion of emerging PHY-layer techniques based on multicarrier modulations [11]. Orthogonal Frequency Division Multiplexing (OFDM) found one of its first commercial applications in the IEEE 802.11a standard. IEEE 802.11a employs the same MAC protocol used by legacy IEEE 802.11 (and IEEE 802.11b), but the physical level is designed for OFDM modulation (allowing a data rate of 50Mb/s [11]). MC-CDMA techniques are regarded as the "natural" spread spectrum extension of OFDM. MC-CDMA is robust against multipath fading distortions and exhibits a natural inclination to variable-bit-rate (VBR) transmission as shown in [3]. The provision of efficient and asynchronous multiple access at different data rates guaranteed by MC-CDMA is a very interesting feature, especially if applications like multimedia data exchange in local areas, characterized by different QoS requests coming from connecting users, are considered (see e.g. [12], dealing with coding techniques for rate-controlled TCP-based MPEG-4 streaming). Recent works on radio resource management in multicarrier CDMA systems include [6], which presents the main issues regarding broadband WLAN (B-WLAN) systems, focusing on a scheme based on OFDM-CDMA technique. The MAC protocol proposed in [6] includes a centralized base-station (BS) and several mobile terminals. The algorithm employed for capacity allocation is the fair sharing algorithm (FSA). Other relevant references on the topic of MAC for MC-CDMA are just a few: [7], where a MAC protocol is presented for supporting QoS in synchronous frame transmission employing an IntServ/RSVP approach; and [8], where access is granted through a token-passing approach. In the specific variable-bit-rate context, the authors of the present paper previously proposed a reservation-based approach [9] that exploits the flexibility in terms of available bitrate and interference control enabled by VBR MC-CDMA, demonstrating the possibility of achieving service differentiation in a multi-user WLAN scenario. Transmitting users have been partitioned into two main QoS classes: "Best-Effort" (BE) and "QoS-guaranteed" (QG). QG users must send a reservation request to a "resource arbiter", whereas BE traffic is transmitted on a separate channel without the need of reservation. Then, the resource arbiter decides on the basis of the number of requests and pre-definite channel conditions to allocate the radio resources and hence to enable the data exchange. The MAC protocol presented in [9] provides a good efficiency in the use of the shared wireless medium, but, as drawback, BE users and highest-rate QG users are severely penalized by the heavy impact of multiple-access interference (MUI) on PHY-layer performances. The joint MAC-PHY approach proposed in [2] can be regarded as the natural evolution of [9] and the starting point for the novel MAC approach detailed in Section III. The "class downshift" discussed in [2] mechanism is a sort of "PHY-layer fostering" provided to "colliding" users, in order to make them more robust with respect to the MUI effects. Differently from [9], users do not wait for a guaranteed QoS level, but they can access in real-time the shared medium. If the VBR channels initially attributed to them are saturated by MUI, these users will achieve a very low QoS, but they will succeed to transmit in any case.

III. THE PROPOSED SITUATION-AWARE RADIO RESOURCE MANAGEMENT STRATEGY

Despite to its indubitable advantages, the approach shown in [2], based only on user downshift, is too conservative and needs some improvement. In fact, throughput performance of downshifted users can be severely limited also when network situation is changed and theoretically allows them at transmitting at higher data rates. In the present paper, the analysis of the network situation performed by the intelligent AP is employed in order to improve the flexibility and the "situation awareness" of the joint MAC-PHY approach proposed in [2]. This is the matter of the following of this section.

A. *VBR MC-CDMA radio resources*

The pictorial scheme of the VBR MC-CDMA networking system is shown in Fig. 1. Users are partitioned in different VBR classes each one characterized by the following PHY-layer resources:

- Fixed transmission bandwidth for the multi-user and multi-rate MC-CDMA signal;

- Fixed transmission power for all user classes. In such a way, the received SNR is higher for those users transmitting at lower data rates;
- Number of orthogonal subcarriers depending on the data rate of the class. The subcarrier assignment rule is the one chosen in [3] and already used in [2] and [9];
- Spreading codes for CDMA multiple access belonging to the orthogonal variable spreading factor (OVSF) set of sequences, employed as channelization codes for UMTS.

More in details, K transmitting users are subdivided into C rate classes, following the given rule:

$$r_j = 2^{C-j} r \quad j = 1,..,C \tag{1}$$

where r is the symbol-rate of the "slowest" user class (i.e.: class C). The sub-carrier allocation strategy for the j-th VBR users class is given as follows [3]:

$$f[n, j] = f_c + \frac{F}{2}\left(2^{j-1} - 1\right)r + nFr_j \quad n = 0,.., N_j - 1 \tag{2}$$

F is the sub-carrier spacing factor [11], generally chosen equal to 1 or 2, whereas f_c is the carrier frequency. In such a way, the total number of users equals: $K = K_1 + K_2 + .. + K_C$ where K_j is the number of users belonging to the j-th class. A pictorial diagram describing the subcarrier allocation in a VBR MC-CDMA system is shown in Fig.2. From such a figure, it is intuitive to understand that the performances of such kind of CDMA multiple access is limited by two different kind of multi-user interference: a) the inter-class interference internally generated by users belonging to the class j, and b) the intra-class interference, generated by users belonging to other classes (this last kind of interference is not present in case of fixed-rate MC-CDMA transmission). Experimental results shown in [2], [3] and [9] evidenced that the users with reduced number of subcarriers (and therefore transmitting at higher data rate) are penalized by inter-class and intra-class MUI more severely than "slower" users having increased frequency diversity.

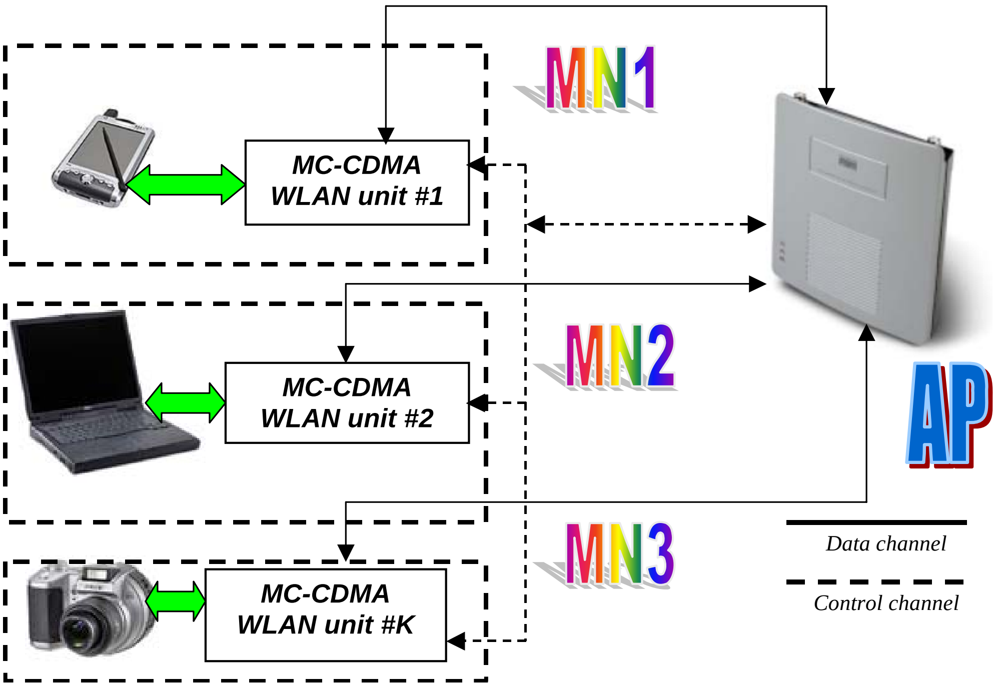

Figure 1. *Block diagram of the VBR MC-CDMA WLAN networking system*

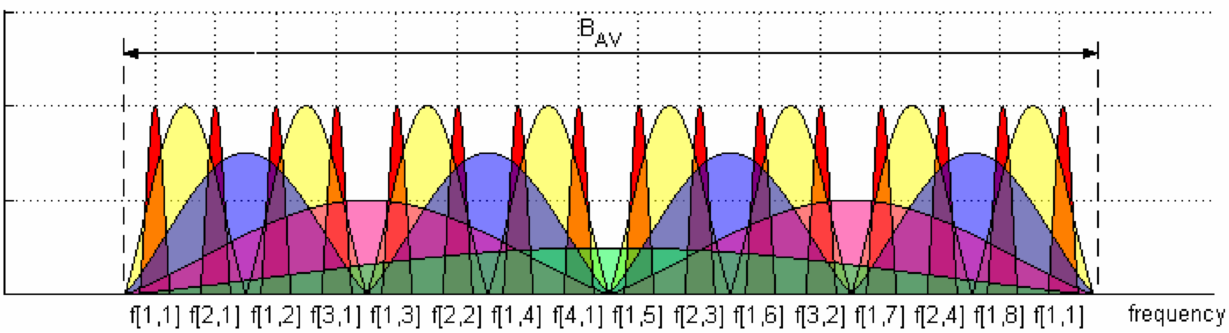

Figure 2. *Pictorial scheme of the subcarrier allocation in VBR MC-CDMA*

B. *Detail of the radio resource management strategy*

As described in the introductory section, the proposed radio resource management strategy is designed in such a way to dynamically adapt to the changing requirements of the users as well as to the network situation, monitored by the intelligent AP. This is possible by exploiting the VBR MC-CDMA physical layer multi-user capability jointly appropriate signal processing techniques (see [2] and [3] for more details).

Dynamic resource management is performed through the employment of two procedures:

- *class downshift*, consisting in a decrease of the data rate, with a consequential increase of the processing gain and transmission SNR; such procedure enables to provide more protection to noise and interference to users subject to low performance;
- *class upshift*, allowing users to increase data rate in case network situation supports it.

The philosophy of the approach is (1) to adapt to the changing requests and traffic patterns generated by the users; (2) to self-optimize resource allocation.

The basic flowchart of the resource management strategy is detailed in Fig.3. The mechanism is based on two thresholds (TH1 and TH2, with TH2>TH1) on the FER, which are used in order to decide whether the achieved performance of a given user is not satisfactory or not. As a rule of thumb, a FER higher than TH2 is associated to a penalized user, while FER lower than TH1 represents an indication that the user could probably access to a higher data rate, experiencing very good transmission performance. As an example, experimental results are achieved for $TH2=10^{-2}$ and $TH1=10^{-3}$.

More in detail, each user starts with a set of PHY parameters set on the basis of his rate requests and starts transmitting frames on the wireless medium. In case the achieved FER with such configuration is higher than TH2, the AP starts issuing class downshifts to such user and continuously monitors the corresponding performance until FER remains below TH2. Once such goal is achieved, in case FER drops lower than TH1 then the AP can issue a class upshift in order to enable higher bitrate.

Moreover, the AP maintains a list of upshift requests from the users in order to selectively enable class upshift in case the network situation improves (see Fig.3). The policy chosen for the upshift request management considers the following priority scale (1: high priority – 3: low priority):

1) Users that have been previously downshifted;

2) Users not downshifted belonging to lower data-rate classes;

3) Users not downshifted belonging to higher data-rate classes.

Such a policy is reasonable, because it privileges users that may really need a bandwidth increase: users that previously subjected to a bandwidth decrease, and/or requesting higher data rates on the basis of updated application requirements.

IV. EXPERIMENTAL RESULTS

In order to illustrate and test the situation-aware radio resource management technique described in Section III, some intensive simulation trials have been performed in MATLAB SIMULINK V7.0.1 environment. In practice, we simulated the procedure depicted in the flowchart of Fig. 3, considering the uplink connection of mobile terminals with the intelligent AP. Downlink transmission can be directly managed and optimized by the AP – being completely under its control. The simulator dynamically evolves, starting from an initial VBR configuration. Synchronous uplink transmission in fixed-size 3000-bit-length frames and measures "on the fly" the resulting frame-error-rate are performed. On the basis of the criteria discussed in Section III, the simulated intelligent AP makes its decisions (class downshift or upshift) and reassigns the PHY-layer parameters to the transmitting users that are subject to poor performance. The output of the simulation substantially consists of a sequence of events (connection, disconnection, class upshift and downshift) and the corresponding time sequence of FER values measured for each users by the intelligent AP. Afterwards, the FER values are mapped into throughput values by using the well known analytical formula derived by Padhye and Kurose in [5] and shown in eq.3:

$$B(p) = \min\left\{ \frac{W_m}{RTT}, \frac{1}{RTT\sqrt{\frac{2bp}{3}} + T_O \min\left\{1, 3\sqrt{\frac{2bp}{8}}\right\} p\left(1+32p^2\right)} \right\} \qquad (3)$$

where p is the measured FER, RTT is the measured round-trip-time, W_m the maximum congestion window size, b is the number of packets that are acknowledged by a received ACK and T_o the time-out value. In the considered scenario of a data transfer through TCP among terminals in the WLAN picocell, we have the following parameters: b=2, W_m=16, T_o=0.700 s. These parameters are typical values found in several works, like [9]. The RTT has been set to twice the time of frame transmission (depending on the data rate of the user class) plus an overhead time of 128 μs - being usual IFS in IEEE 802.11 WLAN transmission.

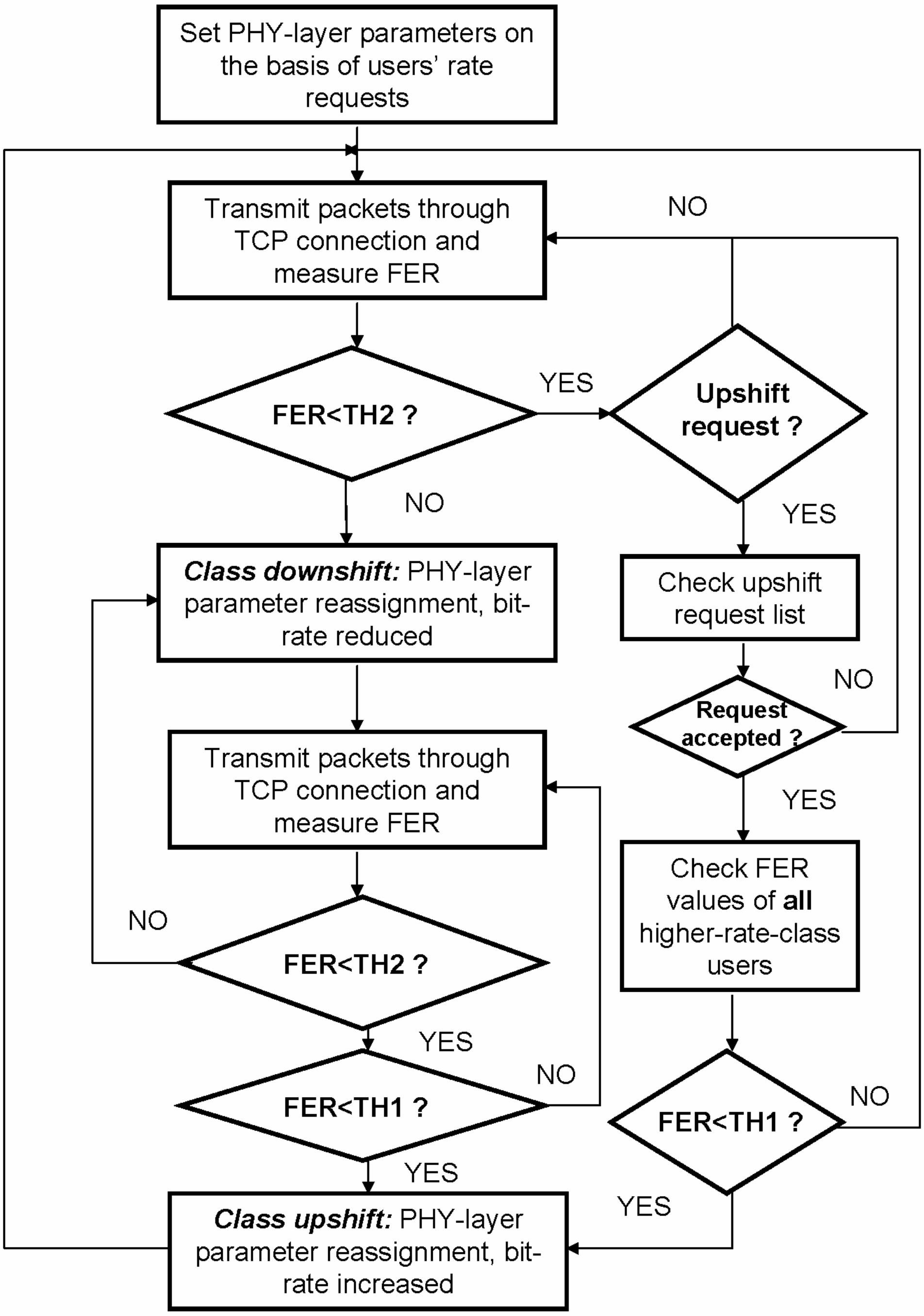

Figure 3. *Flowchart of the proposed resource management algorithm*

The indoor multipath channel at 2.4 GHz has been simulated by a tapped delay line model, parameterized by using the experimental data about delay profile shown in [10]. The digital modulation employed for all the users is a BPSK and a conventional Equal-Gain-Combining (EGC) detector [11] is employed inside the AP. In such a result section, we have considered the initial VBR configuration of Tab.1. The number of users K has been fixed equal to 7. The users are mapped into C=3 bit-rate classes.

TABLE I. INITIAL VBR CONFIGURATION

User	**Class**	**Bit rate (Kbit/s)**	**Subcarrier number**	**Transmission Eb/N_0 (dB)**
U1	1	4096	16	Eb/N_0
U2	1	4096	16	Eb/N_0
U3	3	1024	64	Eb/N_0+6
U4	3	1024	64	Eb/N_0+6
U5	4	512	128	Eb/N_0+9
U6	4	512	128	Eb/N_0+9
U7	4	512	128	Eb/N_0+9

A first simulation has been done by setting Eb/N_0=12.5dB. The FER sequence vs. time produced by the simulator is shown in Fig.4. Note that the measured FER for user U3, U4, U5, U6 and U7 are identically 0 during the overall simulation time. On the other hand, the initial FER values for user U1 and U2 are too high to guarantee a satisfactory QoS. As a consequence, the intelligent AP issues a downshift for user U1 and for user U2. After the two downshift events, the measured FER values for U1 and U2 consistently decrease. Before the end of simulation, a low-rate user (U7) is disconnected and the network situation for U1 and U2 improves, decreasing their FER. Nevertheless, such FER values are still over the threshold TH1 and an upshift cannot be issued at the present time. In Fig. 5, the related results about estimated throughput are shown for users U1 and U2, together with the aggregated throughput obtained by summing the capacity achieved by the overall connecting users. It is interesting to note that the curve of the aggregated throughput is monotonically increasing, whereas both throughput curves of user U1 and U2 progressively lift up. As a result, the two mobile devices of class 1 can exploit a limited, however acceptable QoS, to upload their data. It is worth noting that performances of the devices of the other classes are not affected by the downshift events issued.

Another series of simulation results is shown in Fig.6, where we considered the same VBR configuration of Tab.1, but a higher E_b/N_0 value - equal to 25dB. Initial FER measurements report FER=0 for all users. No class downshift is needed, but we suppose that all users require increasing their data rates one after another. In particular, we considered the case that *all* users gradually want to reach the bit-rate class #1 (4096Kb/s). This is not very realistic in real-world multimedia exchange applications, but it is useful for our analysis in order to verify the effectiveness of the management of the upshift requests. We simulated this situation, considering a sequence of successive upshift requests, first coming from low-rate users U5, U6 and U7. Such requests are approved and such users can successively reach one-o-one the class 3. Afterwards, all users of class 3 (U3, U4, U5, U6, U7) request an upshift to the class 2 (2048 Kb/s). All these requests are approved too, and all users of class 3 successively reach the class 2. At this point, we supposed that all users of class 2 (U3 .. U7) want to usphift to the class 1. In case of success, we should have K=7 users transmitting at the fixed rate of 4096 Kb/s. The curve of Fig. 6 shows us that the class upshift is allowed for all users, but the last upshift of the user U7 involve a decrease of the aggregated throughput, because some FER values are approaching the critical threshold TH2 (this is true for user U5 and U7 measuring a FER equal to 0.004 and 0.007, so the estimated throughput values achieved equal 2810 Kb/s and 1291 Kb/s respectively).

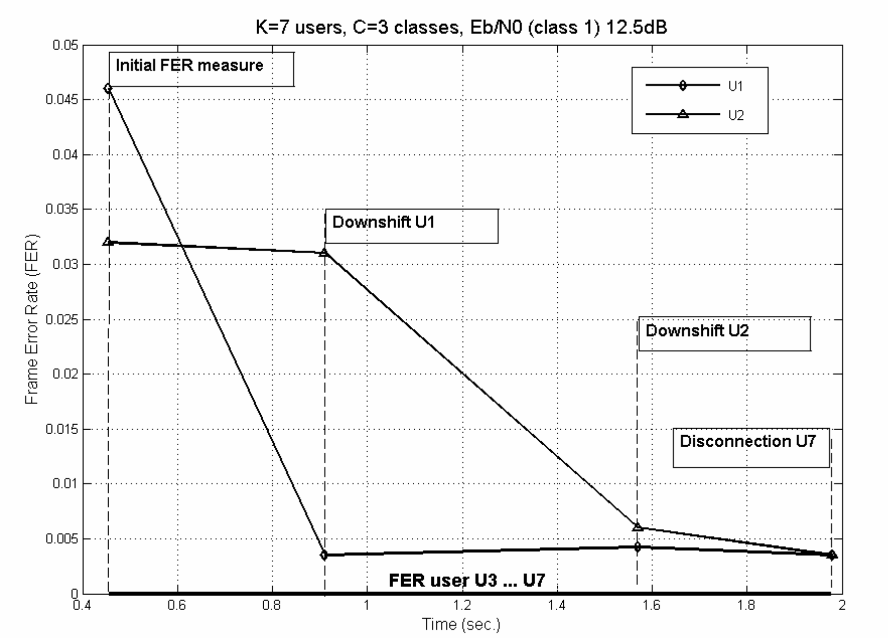

Figure 4. *Frame error rate vs. time measured by the intelligent AP, Eb/N$_0$ (class 1)=12.5dB (events: user downshift and user disconnection)*

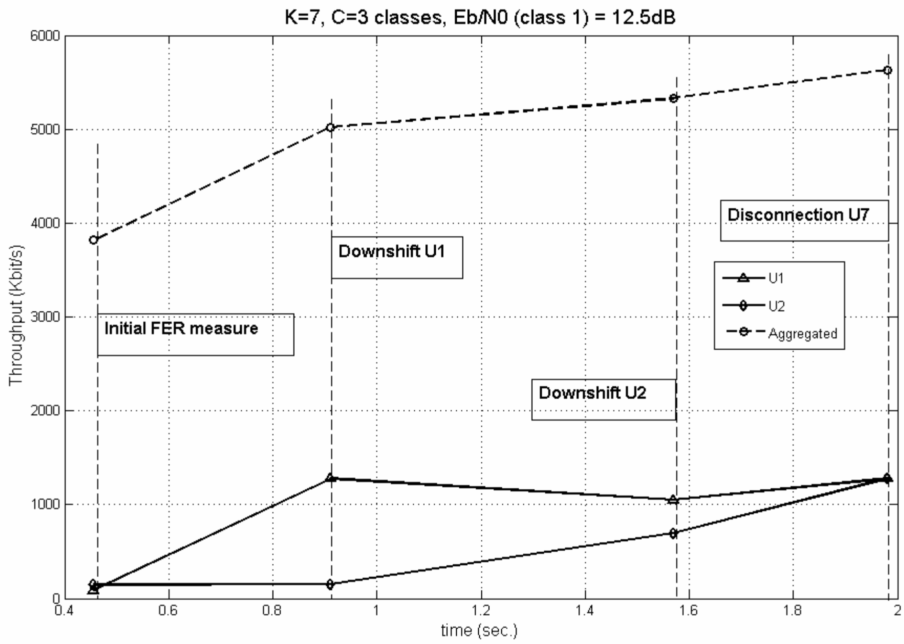

Figure 5. *Estimated aggregated throughput vs. time for, Eb/N_0 (class 1)=12.5dB (events: user downshift and user disconnection)*

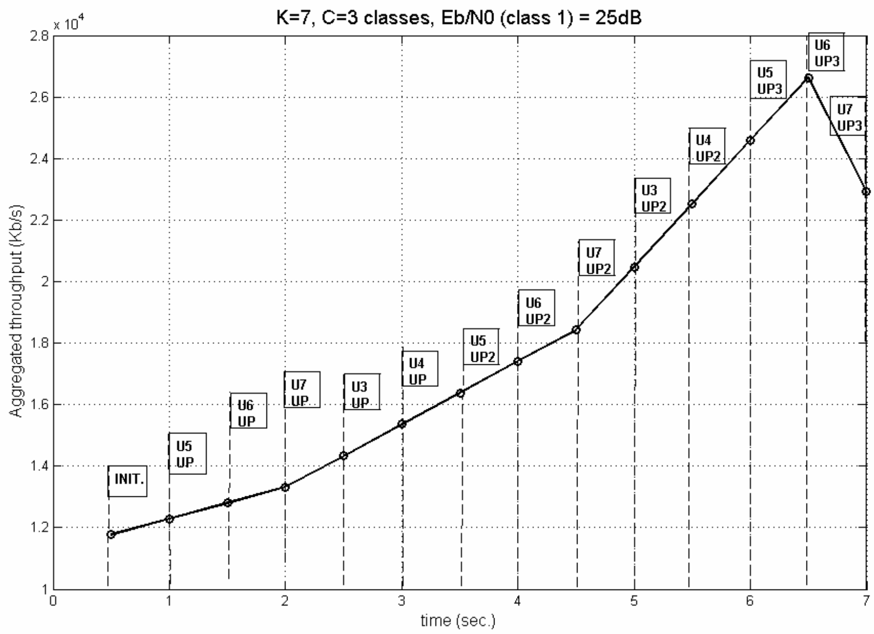

Figure 6. *Estimated aggregated throughput vs. time, Eb/N_0 (class 1)=25dB (events: upshift requests satisfied)*

V. CONCLUSION

In this paper, a novel radio resource management strategy has been proposed in order to implement adaptation of PHY parameters in the case of a variable-bit-rate multicarrier CDMA WLAN system. The key concept of the considered approach is represented by the “situation awareness". In fact, the WLAN system starts to transmit data with a fixed configuration of users and bit-rates. The "intelligent" AP is able to continuously monitor the network situation in terms of connection of new users, disconnection of old users and FER performance of all users. If some users exhibit unsatisfactory performances in terms of FER, the AP issues a "class downshift", so to improve their robustness against channel distortion and MUI. The protocol also allows the "class upshift", both to users previously downshifted and to users that explicitly request it. The management of the upshift requests is done on the basis of a priority policy and the rate upshift is enabled only when network situation allows it. The proposed radio resource management strategy underlined an improved degree of flexibility and provides good results in terms of aggregate throughput and stability of performance.

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