Dynamic Channel Assignment with Delay and Loss Considerations for Wireless TDMA LANs

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ABSTRACT

The scarce available bandwidth and the unpredictable, variable bit rate traffic in modern packet-switched wireless LANs, require an efficient channel allocation scheme. In this paper we make an overview of traditional call-by-call Dynamic Channel Assignment (DCA) methods and propose a novel DCA method that aims at assigning channels in a more dynamic way, based on the quality-of-service (QoS) required by different connections. Although the method can be applied in different wireless environments, here it is used in a wireless ATM LAN, in conjunction with a TDMA/TDD medium access control protocol. Simulation results at the end of the paper show that this kind of methods can improve significantly the performance of the system.

1. INTRODUCTION

The radio resource allocation problem in a cellular radio system is, in principal, a complex problem to handle. Modern wireless LANs are expected to offer data rates per cell in the range of 10Mbps. For such rates, and if FDMA/TDMA techniques are used, a bandwidth of several MHz is required [1]. Since radio spectrum is expensive, efficient strategies for reusing frequencies, while adequately maintaining co-channel interference as a means to provide enough network capacity, is critically important. One approach to solve this resource allocation problem is to divide the available radio spectrum in orthogonal “channels” (for example frequency channels, time slots, or time slots into different frequency channels) which are used simultaneously by base stations that are sufficiently apart [2]. This is called Fixed Channel Assignment (FCA) and it was used in the first generation of narrowband cellular wireless LANs, where the main or only service offered was telephony.

But in modern cellular networks, broadband communications are needed to offer services like accessing the World Wide Web efficiently, providing data rates comparable to fixed local area networks, even providing multimedia services such as image and video. For this reason, these networks must re-use bandwidth very aggressively, ideally reusing the same frequency band in every cell. This is where Dynamic Channel Allocation (DCA) techniques have effect. DCA’s aim in a FDMA/TDMA network, is to dynamically assign bandwidth resources (i.e., the time slots in different frequencies) to transmitters, in such a way in order to guarantee a given signal-to-interference ratio (SIR).

Most of the previous DCA studies focused on circuit-switched voice communications [3]. This lead to methods that are used on a call-by-call basis to achieve time-varying frequency reuse patterns that dynamically attempt to minimize mutual interference among all active calls (for example, [4], [5], [6]). This approach is good for uniform, in terms of input traffic and requirements, connections (e.g., voice), but can have low performance for multimedia, broadband communications. [3] was one of the first, as far as the authors of this paper know, proposals for DCA that dynamically allocates channels in a burst-by-burst basis (i.e., data packets within an ON-period). This was an attempt to compromise statistical multiplexing and DCA efficiency. To achieve maximum spectrum efficiency and system capacity in a packet-switched wireless network, it is most desirable to perform independent channel assignment for every packet. However, this would require a very fast DCA scheme and a consequent increase of the signaling overhead. Accordingly, the compromise of packet bursts was selected.

A proportional compromise is also proposed in this paper. Having in mind a FDMA/TDMA/TDD scheme with variable time-frame length, we propose a method that assigns channels (i.e., time slots in different frequencies) in a frame-by-frame basis. The novelty of the specific proposal is an attempt to introduce a metric of the QoS required by every connection into the decision process of the DCA algorithm. More specifically, in this paper a centralized DCA method for wireless ATM systems is presented, designed around an entity in the core network. It is based on an earlier proposal, called IADCA, a frame-by-frame DCA method presented in [7], and tries to improve its performance. The most important contribution of the proposed method is that it assigns resources (i.e., time in carriers), based on the traffic needs of the base-stations (BSs) responsible for each cell, taking into account not only interference constraints, but also the QoS required by active connections, expressed through delay and loss constraints. In this way, time- or loss-sensitive traffic has higher priority for transmission, while traffic with loose constraints is postponed, resulting in lower loss ratio and mean delay.

The paper is organized as follows. Section 2 introduces a centralized DCA system architecture and provides the basic system assumptions. In Section 3, the proposed method is described in detail. Section 4 describes the simulation model and discusses the obtained simulation results. Finally, Section 5 contains our conclusions.

2. SYSTEM ARCHITECTURE

Our reference model is a wireless ATM LAN like the one shown in Figure 1. The radio resources consist of a set of available frequency channels, referred to as "carriers", each one represented by a distinct integer. A carrier is organized in variable length time frames, which are further subdivided in time slots. Time slot duration is equal to the time needed to transmit an ATM cell. The multiplexing of uplink and downlink traffic is based on time division duplex (TDD). Slot allocation is performed in a dynamic and adaptive manner so that bit rates can readily match current user needs, by allocating more or fewer time slots per time frame. This is critical in servicing ATM connections, especially those with variable bit rate, because bandwidth can be allocated dynamically, and the resulting statistical multiplexing gain yields high resource utilization. This TDMA/TDD protocol can be MASCARA [8], the MAC protocol proposed in the context of ACTS project "Magic WAND" [9]. MASCARA uses an advanced scheduling algorithm, called PRADOS [10], to decide on the allocation of available wireless resources (i.e., time slots in a frame).

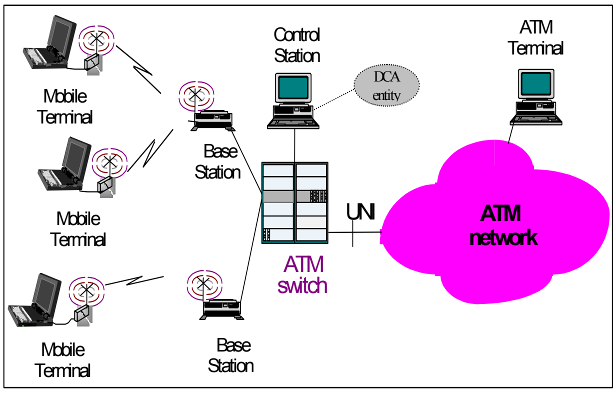

Figure 1: A wireless ATM LAN

Let us assume N BSs using M carriers, where N>M, and mutual interference restrictions exist among BSs. In this case, a central functional entity is required, which exchanges information with BSs, and dynamically assigns resources (time and carriers), i.e., performs the DCA. The DCA entity can be located in the Control Station attached to the switch, and decides which carrier can be reserved by a BS, as well as the start time and the duration of this reservation. The system parameters that the DCA entity takes into account are based on mutual interference restrictions. Potential interferences come from three possible sources: another source within some range using the same channel (a *co-channel* interference); another source in an adjacent region using an adjacent channel in the frequency domain (an *adjacent channel* interference); and another source within the same region using another channel within some range (a *cosite* interference) [5].

These interference restrictions can be expressed by an appropriately defined *"compatibility matrix"* [11],[12]. This matrix defines the minimum distance between the carriers allowed to be used simultaneously for each pair of BSs. The compatibility matrix, characterizing a typical wireless ATM installation, is a NxN symmetric matrix with elements (i,j)≥0, 0≤i≤N, 0≤j≤N. For example, under the compatibility matrix shown in Table 1, BS#1 and BS#3 cannot use the same carrier simultaneously (distance is at least 1) but they can use adjacent carriers. On the other hand, BS#2 and BS#5 do not interfere with each other (reuse distance 0) and can use the same carrier at the same time. For the purposes of this paper we assume that (i,i)=0 for 0≤i≤N; i.e., no cosite interference. However, the proposed DCA method applies in cases where cosite interference is present (e.g., on sectorized cells), as well.

Table 1: A compatibility matrix

	BS1	**BS2**	**BS3**	**BS4**	**BS5**
BS1	0	2	1	2	1
BS2	2	0	3	1	0
BS3	1	3	0	2	1
BS4	2	1	2	0	1
BS5	1	0	1	1	0

Although the compatibility matrix is assumed static here, the proposed DCA method is also applicable in the case where the elements of the compatibility matrix are dynamically updated to reflect changes in the system.

3. THE PROPOSED METHOD

The method proposed here is an improvement of the method already proposed in [7]. According to that method, referred to as IntrAdomain-DCA (IADCA), a lookup table of resource allocation is maintained (an example is shown in Figure 2), containing the current committed resource assignment. At the end of a frame, each BS constructs the next frame (according to PRADOS or any other scheduling algorithm), and sends to IADCA entity a request, asking i) which carrier to use for that frame, and ii) the start time of the allocation. The IADCA has to decide immediately and send the response back to the BS before the end of the current frame. This is important to let the BS inform its MTs in which carrier to synchronize, in order to listen for the next frame header. To minimize response time, the communication between IADCA and BSs can be performed in permanent VP/VC connections with high priority. The IADCA decisions are based on the compatibility matrix constraints and on the resource lookup table. The main objective of IADCA is to make a carrier allocation as close to the time it gets a request from a BS as possible, without violating the compatibility matrix constraints. The IADCA entity maintains Check Points (CPs) in the resource lookup table. A CP is defined as a time instance at which the carrier reservation status can change. In other words, a CP is the end of a BS's time frame. Each time a request for carrier reservation arrives from a BS, the IADCA examines these CPs and decides when to schedule the new time frame. Since at the end of each time frame, the BS will request time on a carrier from IADCA, the decision time will coincide with one CP.

For example, assume that a structured wireless ATM LAN consists of five BSs (BS1,…,BS5), and can use three available carriers (f1,…,f3). At time Td (decision time), a request arrives to IADCA from BS1. IADCA determines from the lookup table that there are five CPs. Note that CP1 coincides with time Td. The rest of the CPs correspond to instances where the carrier occupation is changed, that is the end of time frames belonging to other BSs. Starting from the closest (CP1), IADCA will check all CPs, until it will find one where BS1 can start transmitting without interfering, to accommodate the request. Figure 2 illustrates a possible lookup table for this case. Assuming the compatibility matrix of Table 1, BS1 cannot transmit neither on CP1 nor on CP2 because other BSs have allocated all frequencies and (1,j)>0 for all j≠1. It cannot even transmit on CP3 at frequency f2 because it interferes with BS4 ((1,4)=2). The next available time is CP4 where it can transmit at f3 without interference.

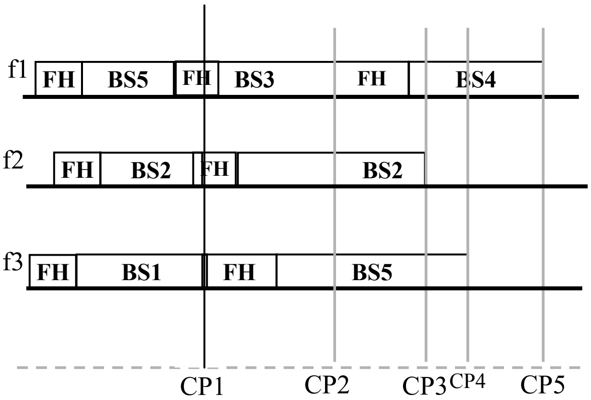

Figure 2: A lookup table used by IADCA

In IADCA, two main drawbacks can be identified. The first is that the response of IADCA to a request from a BS has to be very fast, to let it inform its MTs about where to synchronize in order to listen for the next frame header. The Control Station, where the IADCA is most probably located, is a heavy-duty component of the system, performing many other operations, including mobility control, signaling, authentication, etc. But even if fast response can be guaranteed, IADCA cannot do anything to handle the second and most important drawback; that is the questionable fairness. As already mentioned, IADCA bases its decision on interference conditions, described in the compatibility matrix. This means it does not take under consideration QoS guarantees of the connections transmitting ATM cells in each time frame. For example, assuming the previous situation where a decision for the next transmission of BS1 had to be taken, IADCA decided at CP1 to allocate frequency f3 starting at time instance CP4, where no interfere conditions exist. This decision could not change even if other BSs with more "urgent" time frames requested transmission during the time period [CP1, CP4].

Trying to solve this problem in [13], we introduced CSDCA (Central Scheduler for DCA), a scheduler that is based on IADCA, but also takes under consideration the QoS guarantees, expressed through the mean deadline of each frame. The mean deadline of each time frame is calculated by the BS that generated it, and transmitted together with the request to CSDCA. It is the mean value of the deadlines of the real-time ATM cells included in the time frame. Simulation results presented in [13] show that CSDCA actually manages to improve the performance of IADCA both in terms of delay and loss.

Here, we try to improve even more the performance of CSDCA, by introducing a different way of considering QoS guaranties. The operation of the proposed method, referred to as CSDCA+, can be divided in two parts. The first part is at a CP when a request from a BS arrives. At that time, it decides, just like IADCA, on the next available frequency and time instance, according to information provided by the resource lookup table, and the compatibility matrix. The difference with IADCA is that here the decision does not necessarily mean "real allocation" of the selected frequency; it actually means "possible allocation". The objective of the scheduler is to delay the real allocation as much as possible, in order to pick the most "urgent" time frame for transmission. This lets CSDCA+ to possibly make the same decision for other requests from other BSs, and actually "lead" a number of requests to the same CP. This is where the second part of the scheduler is enabled. Assume that a number of time frames are waiting to be transmitted in a specific CP. CSDCA+ selects the most "urgent" timeframe for immediate transmission and postpones the transmission of others to the next available CP.

"Most urgent" means the time frame with the highest priority. The priority of each time frame is calculated by the BS that generated it, and transmitted together with the request to the CSDCA+ entity. For every frame j, let $\{C1, C2, \ldots, Ck_j\}$ be the real-time connections (CBR and rt-VBR) having ATM cells to transmit within this frame. Only in the special case of a frame without real-time ATM cells, non-real-time connections are considered. The priority Pj is expressed as:

$$P_j = 0.5\frac{\sum_{i=1}^{k_j}\frac{D_i}{D_i^{\max}}}{k_j} + 0.5\frac{\sum_{i=1}^{k_j}\frac{L_i}{L_i^{\max}}}{k_j}$$

where for every connection Ci, D_i is the mean delay experienced so far in the wireless link, D_i^{max} the acceptable mean delay for the wireless link, L_i the cell loss ratio experienced so far in the wireless link, and L_i^{max} the acceptable cell loss ratio for the wireless link. At this state, delay and loss have equal contributions in the final priority, that is why equal weights (0.5) are used. Different weights can be used in next versions of the priority.

The objective behind this priority is to also consider loss constraints, besides delay constraints considered in CSDCA, in order to improve overall performance. The reason for considering only real-time connections is that early simulations showed that non-real-time ATM cells, with very loose delay constraints, can descrease the priority of a time frame in unacceptable values, causing expiration and discard of real-time ATM cells. Considering only real-time ATM cells does not exclude non-real-time ATM cells from being transmitted, since they both belong to the same time frames.

4. SIMULATION MODEL AND RESULTS

In this section we give simulation results on the performance of CSDCA+. We also compare it with the old version, IADCA, in which no QoS consideration was taken into account, and also with the CSDCA presented in [13], where only delay constraints are considered.

The simulation models were built using the OPNET tool [14]. In these models we considered two available frequencies, with channel capacity of 20Mbps each, and three base stations. The reuse ratio was set to 1 for every couple (BSi, BSj) i≠j. The total traffic consisted of constant bit rate (CBR), real-time variable bit rate (rt-VBR) and non-real-time variable bit rate (nrt-VBR) connections, arbitrarily distributed among BSs and uplink/downlink, as shown in Table 2. To model the traffic for VBR connections, we used independent discrete-time batch Markov arrival processes (D-BMAP). D-BMAP, proposed in [15], is the discrete-time analogue of the batch Markov arrival process, introduced by Lucantoni in [16]. We gradually increased the total input traffic in the system, and we measured the ATM cell loss ratio and mean delay on the wireless link, both for the old and the new method. The wireless hop CDT was set to 300 time slots (6.18 msec) for CBR and rt-VBR, and 10,000 slots (206 msec) for nrt-VBR connections.

Table 2: Distribution of connections

	BS1	**BS2**	**BS3**
Downlink CBR	5	0	3
Uplink CBR	5	5	6
Downlink rt-VBR	4	3	6
Uplink rt-VBR	7	1	1
Downlink nrt-VBR	0	4	5
Uplink nrt-VBR	2	0	2

Figure 3 plots the cell loss ratio of CBR connections versus the mean input traffic per BS (in Kbps) both for the three methods. As it can be seen, there is a considerable improvement obtained with the new method for light and medium traffic loads, while for heavy traffic the obtained improvement is not so impressive. Note that the Y axis is in logarithmic scale and the improvement in some cases is more that 50%, compared to IADCA. Figure 4 gives the CBR mean wireless hop delay (in slots) versus the total input traffic (in Kbps) for all methods. The values for light and medium loads are similar in all methods. This means that the new method manages to improve the cell loss ratio without increasing the mean delay. Also, for heavy traffic loads, where CSDCA is slightly worse than IADCA, CSDCA+ improves the delay slightly, even though this is not important, since at these cases the system is already overloaded (for example, at 10Mbps per BS the cell loss ratio is more that 30% in both methods).

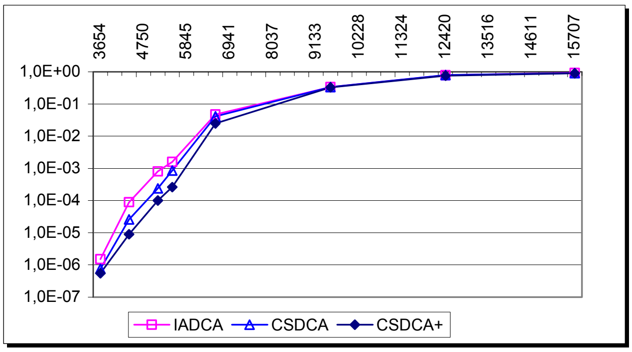

Figure 3: Cell loss ratio for CBR connections

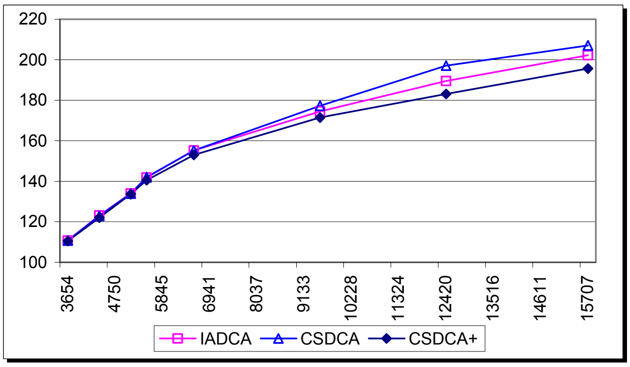

Figure 4: Mean wireless hop delay for CBR connections

Figures 5 and 6 plot the same metrics for rt-VBR connections. As for CBR, the new method has a good cell loss ratio performance for light and medium traffic loads, while for heavy loads it is close to the old methods, although always better.

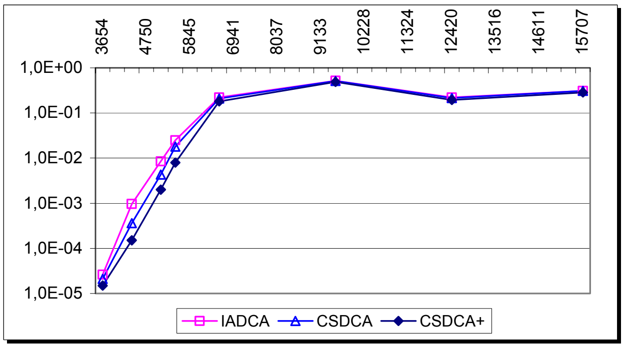

Figure 5: Cell loss ratio for rt-VBR connections

Finally, as shown in Figure 7, the mean delay for nrt-VBR connections is slightly improved, while no ATM cells expire with all methods. This means that the new method does not favor real time against non-real time connections.

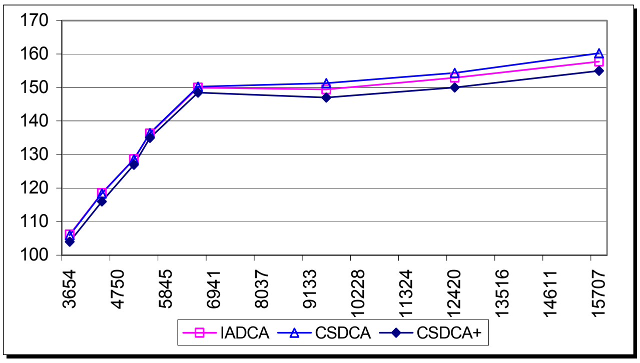

Figure 6: Mean wireless hop delay for rt-VBR connections

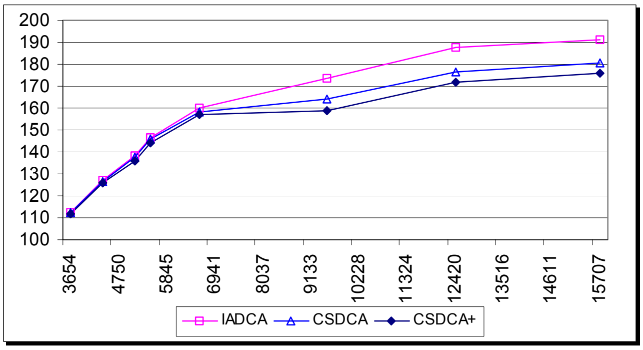

Figure 7: Mean wireless hop delay for nrt-VBR connections

5. CONCLUSIONS

In this paper, we made a short review on the DCA methods available, and proposed a centralized method for dynamic assignment of resources among the BSs of a structured wireless ATM LAN, referred to as CSDCA+. The innovation of the method is that, besides mutual interference constraints and current resource usage, it also considers QoS guarantees of active connections, expressed in terms of delay and loss constraints.

To evaluate the performance of the proposed method, we have compared it with an older one (IADCA) that does not take into account QoS constraints, as well as an earlier version (CSDCA) that only considers delay constraints. The obtained simulation results show that cell loss ratio for real time connections, attained with the new method, is even better than CSDCA, especially for low and medium traffic loads. The mean delay on the other hand, is similar for all methods, resulting in better performance at the end user. Finally, mean wireless hop delay for nrt-VBR connections is improved with the new method.

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