A NEW TDMA-CR model for dynamic resource allocation in wireless networks

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Abstract

Wireless networks architecture contains mobile terminals randomly placed in cells managed by different APs (Access Points). Terminals are considered node generating different traffic types according to specific service classes. Supporting heterogeneous traffics over AP poses many questions about medium access and resource allocation. In this way, the present work study and analysis these constraints and proposes a novel technique for resources distribution. This technique, called TDMA-CR (Time Division Multiple Access-Compensation Reward) is designed at the mac layer of the AP. TDMA-based systems are considered the efficient access solution for resources allocation in wireless networks. A proposed TDMA/FDD-based mechanism is designed by a generic model in which time on the uplink and the downlink channels are divided into adjacent series of fixed-size TDMA frames. Each frame is further subdivided into a fixed number of slots to be dynamically allocated for different service classes (CBR, VBR). In this context, the solution may provide the ability to support multiple traffic types and to process them according to generic parameters. The basic idea is to provide slots reassignment, and to dynamically adjust connection parameters based on signalling information processing approach. This approach, based on resources compensation-reward, performs the WCAC (Wireless Call Admission Control) and gives solution to ameliorate link rate and traffic conditions. Simulation shows that it achieves optimal resources allocation, low connection reject probability, especially for CBR connections, and resources degradation avoidance for VBR and ABR connections, in comparable with TDMA technique.

Key words: *Wireless networks, TDMA, Resources allocation, performances evaluation.*

1. Introduction

TDMA (Time Division Multiple Access) allows multiple users to access on a single frequency channel without interference by allocating time slots to each user. TDMA shares the available bandwidth in the time domain. Each frequency band is divided into several time slots (channels). A set of such periodically repeating time slots is known as the TDMA frame. Each terminal is assigned in those slots. In addition to increasing the efficiency of transmission, TDMA offers the advantage to be easily adapted to the transmission of data as well as voice communication. There are different MAC schemes proposed in the literature to improve channel access based on TDMA mechanism. [3,9,11,13,17] give more details about different MAC frames structure and allocation strategies.

In this paper, we are interested to evaluate a frame reservation strategy allowing efficient transmission of multi-service traffic over TDMA/FDD channels in wireless networks. This scheme is based on a dynamic bandwidth allocation model for connections carrying different types of traffic. The model strategy is to reserve bandwidth (which changes dynamically) for each type of traffic during each frame-time. The distribution of bandwidth on the corresponding VCs depends on parameters of each traffic type. Compared to classic TDMA mechanism, the simulation results using TDMA based on a compensation-reward model (TDMA-CR) shows more efficient resources allocation.

Performances of TDMA-CR model are evaluated in terms of connection reject probability and traffic load, for various data traffic scenarios. The proposed MAC protocol uses fixed duration frames. It controls terminals according to traffic service class. The MAC mechanism requires negotiation of connections parameter. Unfortunately, the efficiency of such scheme can significantly decrease when the number of terminals to be served is large and/or their rates are high. Therefore, our principal goal, in this paper, is to increase the traffic load and ameliorate QoS. Even if the MAC protocol has no resources to satisfy connection request, it can compensate slots from others connections. These last can re-establish data transmit with their pic cell rate in next frames duration. This approach makes then priorities for different connections corresponding to service classes.

The paper is organised as follows. Section 2 presents the protocol aspect of TDMA scheme and invokes the WATM architecture. Section 3 gives details of the proposed algorithm and the experimental design. Regarding the impact of resource allocation procedure we present our simulation model and the derived performance results. Finally, we present some concluding remarks.

2. TDMA scheme Description

Typical dynamic TDMA protocol is always selected for resources allocation in wireless networks. It is suitable to provide QoS for real-time multimedia traffics [9]. With TDMA, the bandwidth is distributed using time-slot allocation according to the service classes and leads to link scheduling.

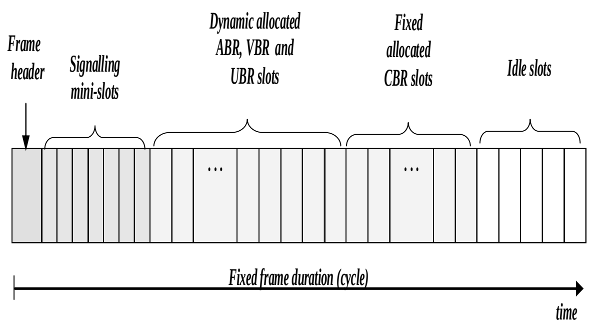

Fig. 1 Dynamic TDMAUPLINK access control frame format.

As shown in figure 1, the TDMA frame is fixed and divided into three sessions. They consist of a frame header, a signalling session, a data transmission session and an idle session. The header transport information for dynamic access control synchronisation. Data transmission session is variable because source terminal doesn't always have data to send. The number of data slots allocated for each connexion depends on the characteristics of the service class. Four service classes (CBR, VBR, ABR and UBR) are defined according to specific traffic and QoS parameters. In this paper, we assume that the slot size is equal to a WATM cell. When a signalling session achieved, the AP knows all the terminals that have data to transmit and calculate the slots number to be assigned for each connexion. Data transmission session is composed by dynamic allocated VBR, ABR and UBR slots and fixed allocated CBR slots. Finally, the idle session is proceeded when there are no data to send after that a new TDMA frame begins.

3. Target architecture

Asynchronous transfer mode (ATM) based technology can provide high speed wireless multimedia communications. In fact, the fine-grain multiplexing provided by ATM due to the fixed small cell size is well suited to slow-speed wireless links since it leads to lower delay jitter and queuing delays [1]. The wireless ATM protocol architecture incorporates wireless access and mobility related functions into the standard ATM stack. A high speed and low complexity wireless access technique is crucial for providing bandwidth-on-demand multimedia services to mobile terminals. Typical target bit rates for the radio physical layer of wireless ATM are around 25 Mbps. A modem must be able to support burst operation with relatively short preambles as well as short control packets and ATM cells [10].

For efficient sharing the available wireless bandwidth between multiple wireless terminals, a radio MAC layer is required. A novel TDMA approach is adopted for medium access control where several virtual circuits are multiplexed in a single radio channel. The TDMA frame structure supports constant bit rate (CBR), available bit rate (ABR), variable bit rate (VBR) and unspecified bit rate (UBR) services within each access point transmission cell area.

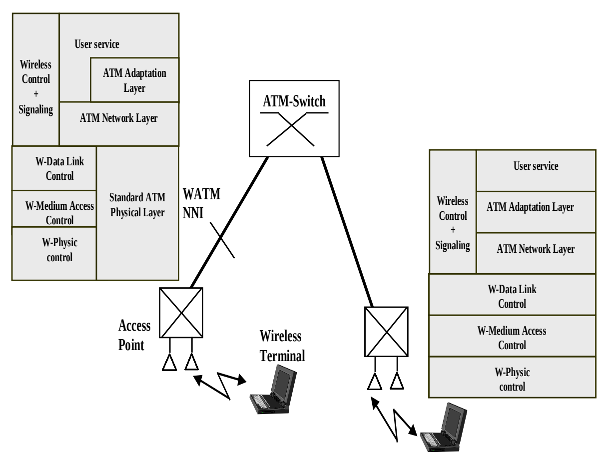

Fig. 2 WATM networks architecture.

4. Design model

4.1 Wireless Terminal MAC Model

The Wireless Terminals (WT) generates CBR, VBR, ABR and UBR traffic models. The ATMF's Traffic

Management specification defines four cell-based traffic parameters namely the Peak Cell Rate (PCR), Sustainable Cell Rate (SCR), Maximum Burst Size (MBS) and Minimum Cell Rate (MCR) [13]. The PCR is a maximum rate at which the user may transmit cells. Its inverse, the minimum cell inter arrival time (1/PCR), may be easier to measure in practice and it is useful to evaluate network performances. The SCR is a possible ‘‘average rate’’ for an ATM connection. The average rate is the number of transmitted cells divided by the connection's "duration". For ideal Constant Bit Rate (CBR) traffic, the PCR equals the SCR. For Variable Bite Rate (VBR) traffic, the SCR is typically less than the PCR.

For CBR VCs, slots are allocated according to their required bit rates. A CBR traffic convention includes the PCR and the Cell Delay Variation Tolerance (CDVT) factors. For VBR source model, we consider an "on-off" that transmits a number of cells at its SCR. Then, slots allocated to different sources depend on traffic parameters (Table 1).

Table 1: Service classes parameters

Service class	***Traffic parameters***	***QoS parameters***
CBR	PCR	CLR+CDV+CDT
VBR	PCR+SCR	CLR+CDT
ABR	PCR+MCR	
UBR		

4.2. Access Point MAC model

The crucial networking algorithm is placed at the AP. It includes receiving (data/signalling) packet, FCFSs queuing, resources managements, etc. Hence, signalling and data WATM cells are multiplexed and processed according to resources allocation scheme. The AP controls the uplink bandwidth allocation for WATM cells from each WT, taking into account the number and the type of active connections and their bandwidth requirements.

The medium bandwidth of WATM networks is divided into two separate channels: uplink and downlink. The uplink channel transfers information from WT to the AP. Each channel is further partitioned into several sub frames, carrying different classes of traffic. A set of buffer per-VC cell scheduling schemes are used as first-come first-served (FCFS) (figure 3). The FCFS cell-scheduling algorithm could be easily hardwired with low cost, however it is efficient only for homogeneous traffics. Consequently, in order to meet this weakness, several weighted FCFSs are allocated for different service classes queuing.

The radio resource manager, located at the AP, takes part in the connection admission control (CAC) process for a WATM terminal originated or terminated connection. It performs the wireless connection admission control (WCAC) and bandwidth allocation for ATM connection over the radio interface.
The scheduler meets problems related to the allocation of a limited amount of shared resources (buffer memory and output port bandwidth) to support all users, applications and service classes. It allows managing access to a fixed amount of output bandwidth by selecting the next cell which will be transmitted on a port [15]. CDV parameter can be controlled since queuing data cells is required at AP.

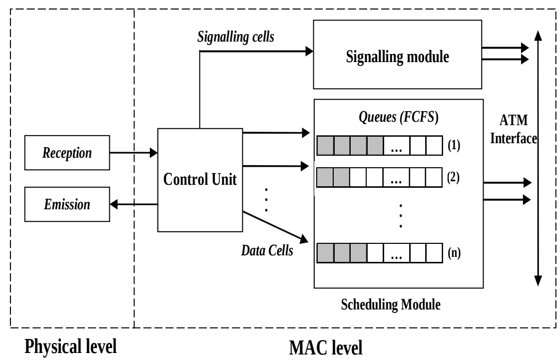

Fig. 3 AP radio medium architecture in WATM.

5. TDMA-CR proposal for dynamic resource allocation

In our proposal, radio spectrum is divided into time slots which are assigned to different connections. User applications can send data only in their dedicated slots. Due to the FDD duplexing technique, integrating the MAC protocol, two distinct carrier frequencies are used for the uplink and downlink channels. Results given here are performed with symmetric traffic in both directions (between AP and WT). The AP scheduler allocates the same number of slots for uplink and downlink channels. Uplink includes signalling mini-slots, followed by allocated CBR, ABR, VBR and UBR data slots. The signalling session allows the wireless terminals sending their bandwidth requirements to the access point. Terminals keep their radios on, since every signalling session of the TDMA frame.

In fact, a WT attempting to communicate with another, it sends firstly a connection request message to the AP. According to the required QoS, the AP assigns adequate number of time slots for this connection. Network parameters are manipulated with an algorithm based on characteristics typed ATM service. If there are not enough slots for the request, a connection can not be established with the required QoS guarantees. However, AP tries to adjust resources through a compensation-reward mechanism applied to all active connections. This mechanism, called TDMA-CR, attempt to avoid reject of new connections, especially CBR service class.

The proposal mechanism consists of rewarding time slots from active ABR and VBR connections, without degrading their performances, in order to serve a new connection to be established. This mechanism integrates computational steps in order to offer the desired resources in an optimal rewarding way distributed on all the active service classes. In other terms, ABR, UBR and VBR connections can reward some of theirs slots to satisfy requirements (or some of them) of new connections. Thereafter, time slots of liberated connections will be used to compensate time slots offered by those connections. Then, time slots of TDMA-CR frame are actualized whether a new event occurs (connection or disconnection). However, when requirements are not satisfied, connection request is rejected. Due to their strict requirements, reject probability for CBR class could be higher than the others classes. Moreover, ABR, UBR and VBR connections can start with a lower rate which may increase during next frames. Figure 4 shows a finite state machine of signalling process.

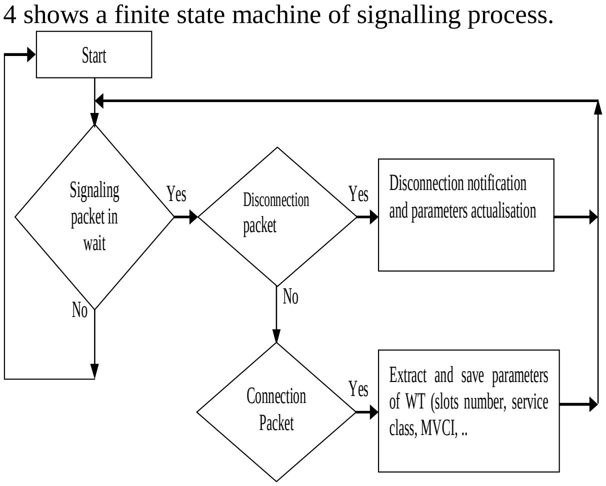

Fig. 4 Signaling process steps.

TDMA-CR approach starts to identify the type of request messages. Disconnection request allows actualizing available resources. However, a connection request requires activating the corresponding VCs, in the AP, and storing the reserved parameters. Second, the AP estimates the resource needed by WT in order to decide, over a calculation step, whether there are sufficient resources to establish this connection (Figure 5). Finally, The AP returns, to all the terminals, signalling cells describing them the time slots allocation (number and position in the frame). WT sends data to the AP within the allocated time slots. If it has no data to send, the terminal operates in idle mode.

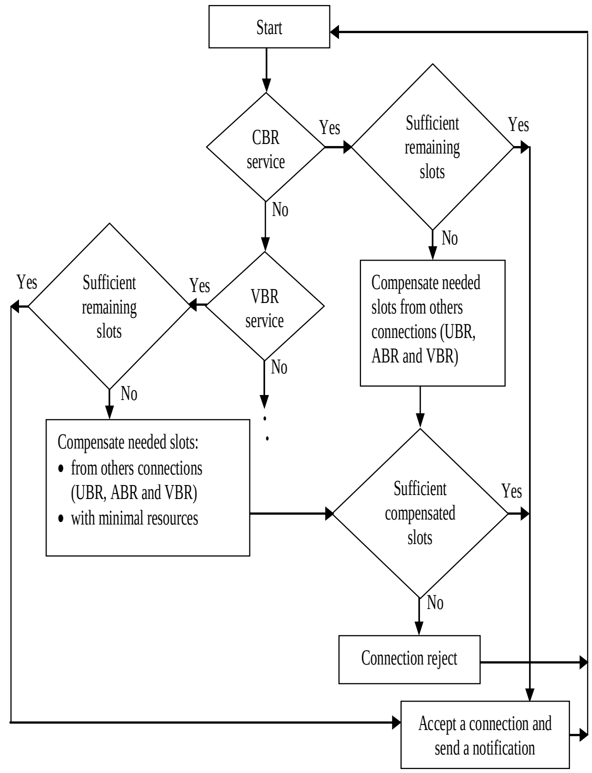

Fig. 5 Compensation-Reward protocol proposal.

6. Simulation results and performance analysis

Different extension schemes of TDMA are proposed in the literature for a fair and efficient operation of the MAC protocol. Research strategies focus on resolving difficulties to distribute carefully AP resources between WTs. Difficulties are related to various traffic conditions like buffer occupancy, connection parameter requirements, etc.. . Various solutions are proposed in the literature [6,9,11,13,17]. [11] proposes that the access point traits the average queue size. Then, information about wireless terminals queues must be sent in signalling packets over a special short control slots. It will be useful to distribute the suitable number of slots for each WT. We mention also that a scheduling technique, used for multiplexing terminals data, impacts the average buffer queue.

Another challenge studied in this context takes part to improve handoff performances. Then, buffer management and optimal reservation of radio resources allows ameliorating handoff efficiency. Many admission control strategies have been discussed in the literature to give priorities to handoff requests compared to the new connection requests as shown in [3,5]. When a mobile terminal moves from one area to another, the new AP area should provide sufficient resources to this handoff connection. Because, the premature termination of established connections, due to insufficient resources, is usually more objectionable than reject new connection request.

In this work, we consider frame duration of 2 ms with a rate of 25 Mbps. We evaluate the proposed protocol to ameliorate some traffic conditions. Figure 6 shows the proportionality between output and input flows for different channel utilization. Channel utilization is defined in [1] as the ratio of the number of slots allocated for WATM data cells to the total available slots. This figure depicts the influence of the service class on the output data rate. CBR traffic is particularly served with a higher flow ratio than VBR traffic. This is explained by a priority given by TDMA-CR to CBR sources. These lasts can support applications with strict temporal constraints (Real Time).

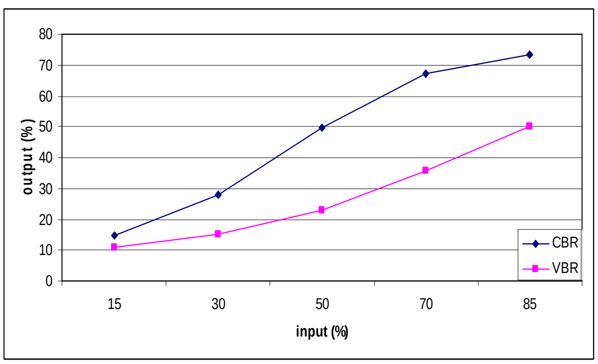

Fig. 6 Traffic Variation in function of service class.

Resource allocation protocol is useful to efficiently distribute available bandwidth to active connections. TDMA-CR performs to satisfy QoS parameters for each connection and to increase the percentage of resources utilisation as shown in figure 6. The resources utilisation improvement explains that compensation approach avoid wasting resources which allow increasing the number of served connections. Consequently, it decreases the reject probability, using the remainder and the compensated resources to be available for connecting new terminals.

TDMA-CR is, then, a resource allocation protocol witch affect the connection reject probability. Figure 7 compares, for the same considered traffic scenario, a reject probability between classical TDMA and TDMA-CR schemes. We mention that the large gap between curves during the first period explains the compensation efficiency introduced by TDMA-CR. This is due to the resource availability which could be compensated between connections. In the remained simulation time, the gap of reject probabilities becomes small. This means that resources become limited or a big number of terminals need to be served. However, the average reject probability is significantly lower for the TDMA-CR scheme compared with TDMA scheme.

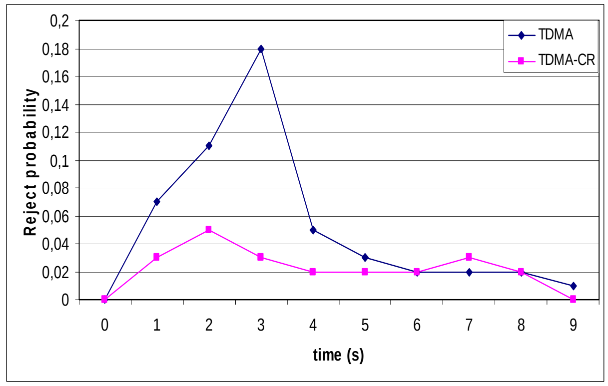

Fig. 7 Connection reject probability.

Presented results show that a compensation mechanism does not decrease a reject connections number only, but it also increase the percentage of resources utilisation as shown in figure 8. This figure outlines a traffic variation of 22 terminals equally distributed between CBR and VBR sources. Simulation results show that TDMA-CR schemes gives more than 25% of band regarding to TDMA. The improvement of resources utilisation explains that compensation approach avoid resources wasting and increase a number of served connections.

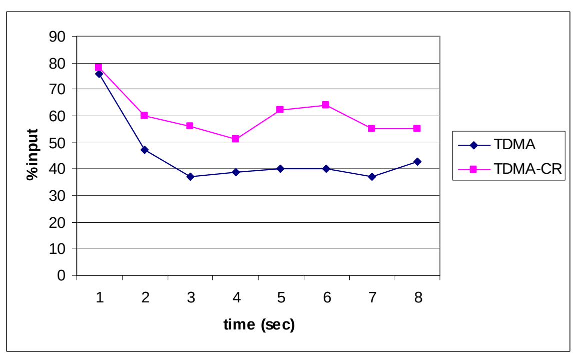

Fig. 8 Resources utilization percentage.

In this work, we have considered a priority aspect between HandOver connection and new connection and a priority according to a service class category (CBR, VBR). Figure 9 shows that reject probability depends on a proportion of CBR connections. CBR service class is a unique class that doesn't accept compensation of its resources. In consequence, connexion CBR requests must be served according to their traffic parameters or it is rejected. As shown in figure 9, CBR connections presents minimal reject probability when they are all established. In this case, it is possible to use resources compensation (minimal CBR traffic percentage). Otherwise, reject probability increase because when CBR traffic is dominant there will be little resources reserved for others classes to make compensation.

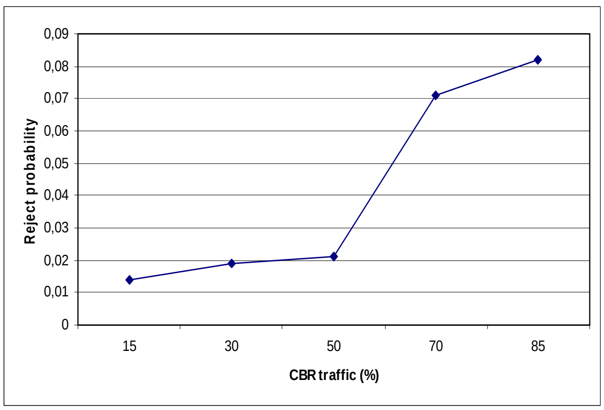

Fig. 9 CBR connection reject probability.

TDMA-CR is also designed to ameliorate HandOver performances maintained by a transparent transition between APs. In this way, it gives priority for HandOver requests compared to the new connection requests. As a result, the HandOver reject probability is notably decreased (figure 10). Moreover, disconnecting Handover terminal in order to serve a new connection is usually not preferred such as explained in [3,4,15].

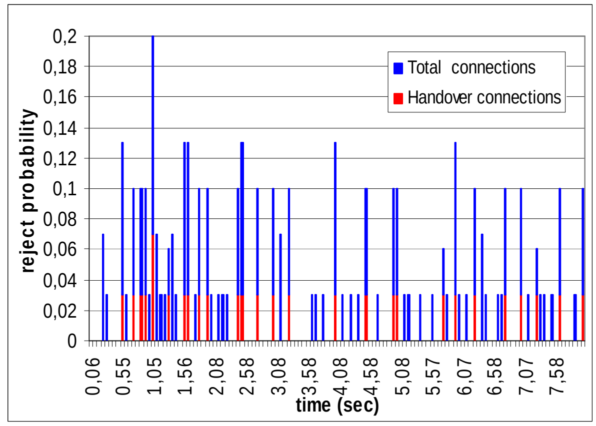

Fig. 10 Reject probability of HandOver connections.

The Cell Delay Variation (CDV) is a sensitive QoS parameter which depends on the type of service class. CDV should take on almost constant value especially for CBR classes. Figure 11 presents the CDV of CBR connections characterized respectively by PCR of 500 kbps and 1 Mbps. TDMA-CR minimizes CDV fluctuations which allow ameliorating QoS to be offered to mobile terminals and meets application delay constraints. It gives a sufficient resources distribution strategy that arranges fairly all the connections.

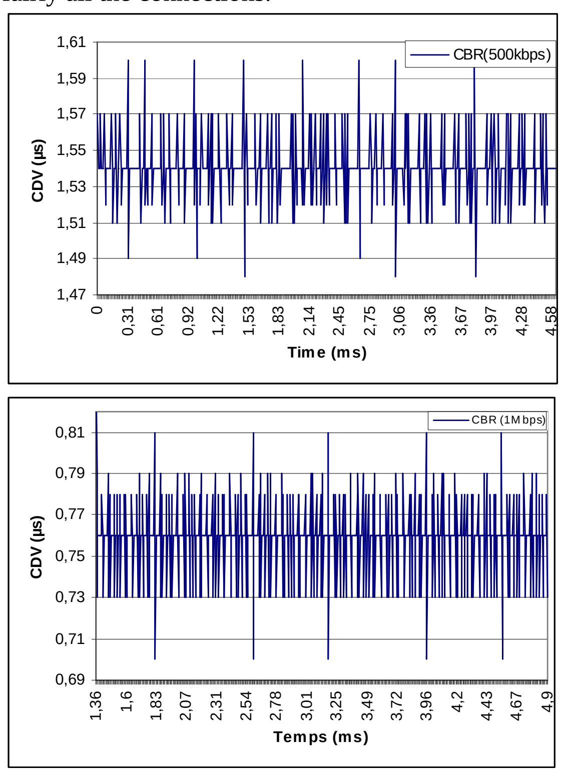

Fig. 11 CDV variation of CBR connections.

The overhead is defined by signalling messages introduced by TDMA-CR to insure compensation and negotiation of desired resources. Signalling messages are automatically and proportionally increased according to network traffic conditions and active terminals number (figure 12).

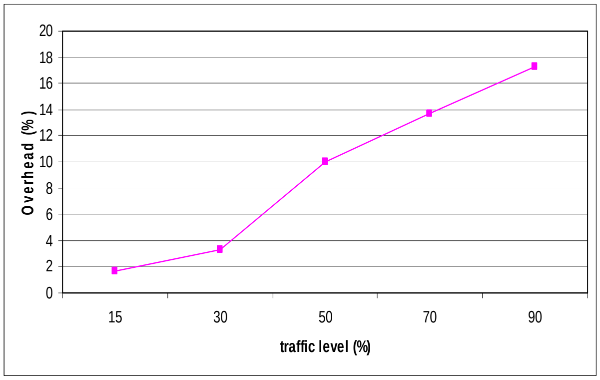

Fig. 12 Overhead variation in function of traffic percentage.

7. Synthesis results

7.1 Layout

Resource allocation process necessitates functions to the extraction and the manipulation of traffic parameters. It needs also functions to compute desired resources according to saved parameters. Complex models including arithmetic operators as addition, division and multiplication are, then, required to be employed in the resource allocation process.

Physical conception and verification present significant steps for integrated circuits conception procedure. Figure 13 shows a layout of the obtained resource allocation circuit. It indicates the complexity level of this circuit. Regarding to circuits complexity, some routine are applied to give *fan-out trees of* interconnections and generate *clock trees* for adequate distribution.

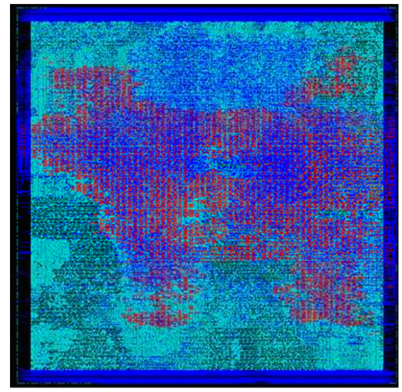

Fig. 13 Layout in silicon level.

7.2 Clock Distribution

The quality of the clock Distribution in a circuit plays a significant role in the performances of a synchronous circuit. The majority of numerical applications are implemented in synchronous logic, because the current tools for synthesis do not allow the automation for every design. These tools allow the automation for design with combinative or sequential descriptions which rest on one or more clock. It is vital for a certain implementation that clock must be known and fixed in all the physical circuit, and its geometrical propagation does not imply distortion and dephasing.

The solutions to guarantee a uniform clock distribution without skew dephasing are multiple. The best solution used today to reduce the clock dephasing is based on the concept of clock tree, it inserts on each level of hierarchy, buffer or reverser which rectifies the clock signal locally. This solution has the advantage of producing a geographically distributed and optimized consumption.
Figure 14 presents clock trees of resource allocation circuits designed to be integrated in the APs. Clock trees quality play an imported role to increase synchronous circuit performances.

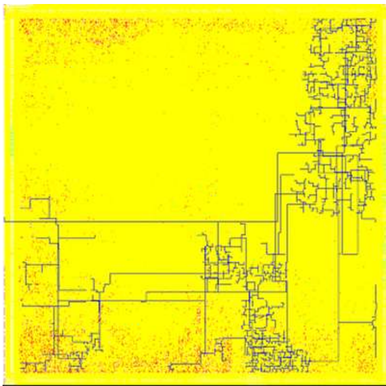

Fig. 14 Clock tree in silicon level.

8. Conclusions

The MAC level should provide QoS management based bandwidth allocation to multiple traffic classes. In fact, various applications such as voice, video and high quality multimedia services need QoS guarantees in order to ensure delay constraints, prescribed data rate and loss. In this paper we have evaluated an algorithm to distribute the resources provided by the access point (AP) at the MAC layer in wireless networks. We consider a classical TDMA/FDD mechanism. It is designed by a generic model in which time on the uplink and downlink channels are divided into a contiguous sequence of fixed-size TDMA frames. Each frame is further subdivided into a fixed number of slots to be dynamically allocated to different ATM traffic classes: CBR, VBR, ABR, and UBR.

This approach uses a compensation-reward process called TDMA-CR. It controls all signalling information of connected terminals in order to compute the suitable allocation of slots according to the service classes. Simulation results show the efficiency of such compensation-reward approach to improve traffic conditions.

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