A Bandwidth Management Scheme based on Time Multiplexing for Wireless Networks with Predictive Services

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Abstract—**Nowadays, in wireless computing, guaranteeing a certain grade of Quality of Service (QoS) during wireless sessions is an important issue, especially when non-tolerant applications are running into the system. Mobility and channel quality often affect system performance, depending on the grade of mobility of hosts. In this paper, providing QoS to mobile hosts belonging to a certain service class (Mobility Independent Predictive - MIP) is the main issue and a statistical multiplexing algorithm is proposed, in order to save an enormous amount of resources; it is based on the Cell Stay Time (CST) distribution analysis for a 2-dimensional (2D) wireless environment under the Smooth Random Mobility Model (SRMM). There are many works in literature about resource pre-reservation: they offer good QoS guarantees, but a very low system utilization, because they do not care about the fact that a passive reservation can remain unused for long time. With the help of the CST statistical multiplexing introduced in this paper, better results are obtained in terms of system utilization, while the Quality of Service and prediction error are maintained at acceptable levels. The proposed idea has been validated through many simulation campaigns, with a good performance analysis in terms of some interesting parameters, like bandwidth system utilization or prediction errors.**

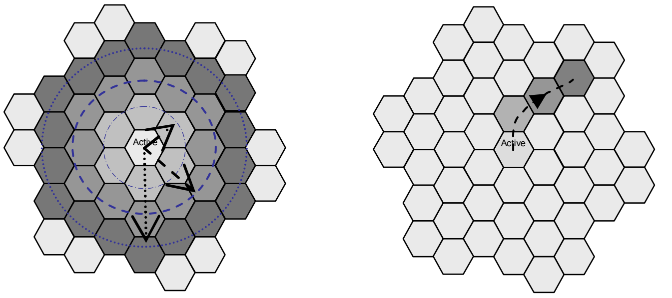
Keywords — WLAN; MIP; Smooth Random Mobility Model; Predictive Reservation; Statistical Multiplexing;

I. INTRODUCTION

Recently, mobile computing has observed a rapid growth of QoS services request and the demand for wireless communications has rapidly increased [1,2,3]. Unfortunately, in wireless scenario, the congestion level that a mobile host can suffer is often different from a coverage area to another one, because the bandwidth management of each Access Point (AP) of the system is always independent from the neighbouring AP conditions. Thus, when a mobile host executes a hand-off procedure, it may find scarce resource availability in the new location and the active connection can be dropped (or seriously degraded if discrete bandwidth levels are allowed). In order to offer an adaptive QoS to mobile hosts an architecture, capable to reserve bandwidth levels and to offer guaranteed services: it is the Integrated Services Packet Networks (ISPNs) with mobile hosts, while Mobile ReSerVation Protocol (MRSVP) is applied for exchanging state information of wireless networks [4]. The only way to ensure a certain grade of QoS and service continuity to mobile users is the employment of the passive reservation policy: that is to say reserving bandwidth for a mobile host not only in the cell when the call has originated, but making it over all the cells that the mobile host will visit during the active connection. The MRSVP is based on active and passive reservations and it is capable to pre-reserve a certain amount of bandwidth for Mobile Independent Predictive (MIP) (for tolerant real-time applications, that can allow some bounded data packet delay variations) flows in the current cell and in the future ones, guaranteeing the desired QoS during hand-off events, while serving Mobile Dependent Predictive (MDP) requests (for applications that can suffer continuous QoS degradations or connection droppings); in this way, the effects of mobility for MIP connections are minimized. More details on QoS service classes can be found in [1]. The main contribution of this paper is the enhancement of the pre-reservation phase: the basic idea is the multiplexing of the pre-reserved passive bandwidth, in order to avoid to leave it unused until the mobile host enters the considered cell. In this way, system utilization is seriously improved. By an analysis of users' mobility, a statistical treatment about CST distribution can be made and the multiplexing for the MIP reservation can be introduced; thus, in this paper the contribution is focused on the bandwidth multiplexing among pre-reserved resources considering the different bandwidth occupancy during the call holding time. In ISPNs, each flow can receive a different QoS, which must be negotiated at the beginning of sessions, between flows and network, by the RSVP protocol or the Mobile-RSVP/Dynamic-RSVP protocol in mobile scenarios [5]. Since mobility and resource management are critical to provide QoS in wireless networks, it is very important to describe accurately movement patterns of mobile users in wireless cells. In [6] some studies on the Call Holding Time (CHT) and Cell Residence Time (CRT) of the novel PCS networks were carried out. The authors show how the classical assumptions of exponentially distributed CHT and CRT is not appropriate in a real context. They propose some more realistic distributions that describe the CHT and CRT trend of mobile users. In [7], a hierarchical user mobility model based on an appropriate pattern matching and Kalman filtering is presented. It allows to get the necessary information for advance resource reservation in wireless ATM networks. In [8] two innovative and powerful resource prediction schemes are proposed, in order to evaluate the required amount of bandwidth during hand-off events through the employment of the Wiener prediction theory and the time series analysis. In [9] a resource reservation protocol and a call admission control based on location estimation of the mobile user, on the instantaneous variation of the speed and the direction of mobile stations is also proposed. However, all these approaches are based on local reservation on the next-hop cells. This can determine a problem when more QoS guarantees need to be offered under different user mobility speeds. Our previous works addressed the issue of mobile adaptive wireless networks. In particular in [13], the management of predictive independent (MIP) and dependent services (MDP) from mobility in adaptive multimedia networking is considered. In order to offer an adaptive QoS (soft QoS) increasing the total wireless system utilization, a utility-based rate adaptation algorithm is considered. In [13-15] a prediction technique based on the cell stay time (CST) evaluation of a mobile user under a Random Way Point mobility model is proposed. In [11] a formula that binds speed, cell radius and variation around the average speed is calculated and resource reservation techniques have been proposed in a mono-dimensional mobility model. An extension to a 2D model and an improvement of the reservation schemes accounting also the mobile hosts movement direction is presented in this contribution. In [10], a prediction technique based on the cell stay time (CST) evaluation of a mobile user under the Smooth Random Mobility Model (SRMM) is proposed. The work illustrated in this paper is based on the same prediction schemes of [10] but the innovative multiplexing scheme is introduced, in order to solve the main problem of low system utilization when heavy MIP traffic percentage is present in the system. In this way, if the proposed algorithm is used, the problem of bandwidth wastage due to the presence of unused bandwidth is avoided, giving to the system a higher bandwidth availability for active and passive reservations, as explained in next section. This paper is organized as follows: next section presents a brief overview of the Mobile RSVP protocol (applied in our work in order to make passive reservations) and the concept of passive reservations are given; the multiplexing scheme is then presented in section III and simulation results with the conclusions are respectively summarized in the last two sections.

II. MOBILE-RSVP AND PASSIVE RESERVATIONS IN BANDWIDTH MANAGEMENT POLICIES

The Internet best-effort service does not offer any guarantee about available bandwidth, network propagation delays, jitter and packet delivery. In ISPN networks there are three provided service classes [1]: Mobility Independent Guaranteed (MIG, for hard and intolerant applications, that need absolute guarantees on packet delays), Mobility Independent Predictive (MIP, for tolerant real-time applications, that can suffer limited bounds on packet delays) and Mobility Dependent Predictive (MDP, for applications that can suffer continuous QoS degradations or connection droppings). In this paper only MDP and MIP classes are considered. MIP services use a pre-reservation phase to reserve bandwidth for a mobile host in the current cells and in the cells that mobile host will probably visit (passive and active reservations) and MDP services, instead, can reserve the bandwidth only on the current cell. According to adaptive multimedia wireless framework, MIP and MDP can reserve a bandwidth level that can change during call holding time. This behavior can guarantee a more flexible resource management, increasing the system utilization. With the MRSVP, hand-off events can be managed in an adequate manner and mobile users can make reservation requests over more than one cell, by their proxy agents: there are local proxy agents (which handle the active reservations) and remote proxy agents (which deal with passive reservations). An active reservation is made by a user only on the current access point (for MDP class, as will be seen later), while passive reservations are made only on the remote cells that the user will visit during its connection (users belonging to MIP class request passive reservations). Fig.1 illustrates a typical 2D wireless scenario: each wireless cell is covered by an access point that is wired connected to the sender node through a Switching Subnet (SS) (not illustrated); a mobile host makes a service request in a certain coverage area (that is user's home region) through a RESV message; the reservation request is then routed to the sender node by an appropriate set of MRSVP messages. Passive reservation are obtained from one of the algorithms of [11], that use a circular reservation policy (Fig.1a) or a directional one (Fig.1b).



a) Circular reservation

b) Directional reservation

Figure 1. A typical 2D scenario with active cell reservation and passive (darker colour) reservations for MIP users.

A MRSVP connection starts with a proxy-discovery protocol phase, with which the user can know the addresses of its remote agents (for details [5]). Before making the real reservation request, the mobile host must ensure itself that there is enough bandwidth availability on the current cell (and on the passive ones if it belongs to MIP class), so it sends the Pre_Reservation (Pre_Resv) message to the local access point (and to the remote ones through its local access point and the switching subnet if it belongs to MIP class); the involved access points answer with a positive acknowledgement if possible. If the mobile host does not receive all the positive acknowledgements, then it will try the connection later; on the contrary, it will perform its reservation request by sending the Resv message, that can be an active_Resv if the request is made only to the local access point or a SPEC if it must reach some remote access points for passive in-advance reservations. Finally, the access points answer with a positive confirmation if the request can be accepted. Details about the adopted Call Admission Control (CAC) scheme can be found in [11].

III. BANDWIDTH MANAGEMENT AND STATISTICAL MULTIPLEXING

The important issue of the proposed work is the statistical passive bandwidth multiplexing: when a MIP users pre-reserves a certain amount of passive bandwidth in the remote Access Points it may be considered as available resource when other incoming calls request the admission into the system. So, the CAC module of the whole Access Points constellation have to implement a time-based bandwidth multiplexing. Let now introduce some definitions and the new idea. Let C be set of cells that compose the considered system (in our case, we considered a simulation map of 7 clusters with 7 cells each one, so 49 cells in total); for simplicity each cell is identified by a unique identifier $i \in N$, so $C \subset N$. As discussed in early works ([10], [11]), the average Cell Stay Time distribution (CST – the time spent by a user in a certain coverage area) can be well approached by a Gaussian distribution; so:

$$pdf_{CST} \cong N(\mu,\sigma) \;\Rightarrow\; pdf_{CSTi} \cong N_i(\mu_i,\sigma_i) \;\; \forall i \in C, \quad (1)$$

where *pdf* indicates the probability density function. In our case, $pdf_{CSTi}=pdf_{CSTj} \;\forall\, i,j \in C$. So, a desired value of CST, indicated with *cst*, can be obtained from its distribution by inverting the *pdf* function:

$$cst_i = N^{-1}(\mu_i,\sigma_i). \quad (2)$$

Let $t_{in}(k)$ and $t_{out}(k)$ indicate the predicted times of arrival and departure to/from a cell for the *k-th* hand-off event respectively. The identification of the correct cell (with a low error probability) is possible through the employment of a prediction scheme like the one proposed in [10]. Then, it can be written that:

$$t_{in}(k+1) = t_{out}(k) = t_{in}(k) + cst_i(k), \quad (3)$$

$$t_{in}(k+1) = t_{in}(k) + cst_i(k) + t_{in}(k-1) + cst_j(k-1), \quad (4)$$

where i is the predicted identifier of the cell that will be probably visited on the *(k+1)-th* hand-off (j has the same meaning for the *k-th* hand-off). The following equation is also valid, so eq. (3) and (4) can be generalized as in eq. (5):

$$t_{in}(k+1) = \sum_{m=0}^{k}\left[t_{in}(m) + cst_{i_m}(m)\right], \quad (5)$$

where i_m is the predicted cell identifier for the *m-th* hand-off and $t_{in}(0)$ is assumed to be the time when the call has originated. It must be noticed that $t_{in}(.)$ becomes a new random variable and recalling that if X is a random variable then $pdf_X=pdf(X)=pdf(a+X)$ with $a \in R$, it can be written that $pdf_{tin(k+1)}=pdf_{tin(k)}=\ldots=pdf_{tin(1)}$, so:

$$pdf_{\sum_{m=1}^{j+1} tin(m)} = N(\mu_{TOT},\sigma_{TOT}),$$
$$where \;\; \mu_{TOT} = \sum_{m=1}^{j+1}\mu_{cst_m} \;\; and \;\; \sigma_{TOT} = \frac{\sqrt{\sum_{m=1}^{j+1}\sigma^2_{cst_m}}}{j+1}. \quad (6)$$

Now, let us consider the arrival of passive service requests, as illustrated in Fig.2. If B_l is the total available capacity of the Access Point (AP) l then, assuming that each flow has the same Passive Bandwidth Reservation Level (PBRL – for example the admitted maximum value), a set of Passive Bandwidth Slots $PBS=\{b_1, b_2, \ldots, b_{nl}\}$ for AP l can be defined, with: $n_l=B_l/PBRL$. In our work, for sake of simplicity, $B_1=B_2=\ldots=B_{49}=B \Rightarrow n_1=n_2=\ldots=n_{49}=n$. In fig.2 an example of the usage of the n slots in function of time is illustrated.

Each call (service request) has a predicted hand-in time and a predicted hand-out time, as derived in eq. (3)(4) and (5), indicated with $t_{in\text{-}m}(k)$ and $t_{out\text{-}m}(k)$ respectively, where k indicates that the bandwidth reservation of duration $t_{out\text{-}m}(k)-t_{in\text{-}m}(k)$ is made for the *k-th* hand-off of the *m-th* call.

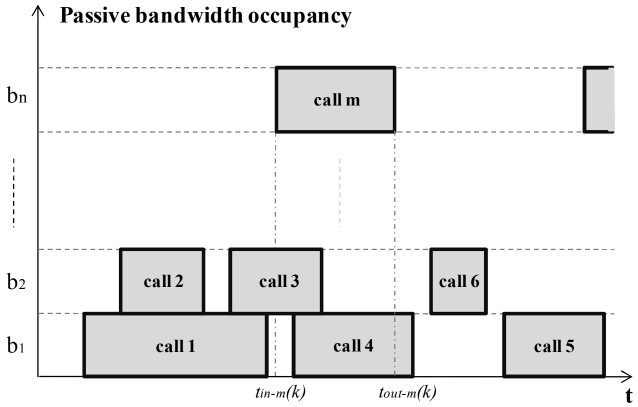


Figure 2. Typical AP passive bandwidth management with multiplexing scheme.

If call_x and call_y have no time intersections between their passive reservations in the considered AP, then the same slot can be used, so $call_x \cap call_y = \varnothing$ if:

$$(t_{out\text{-}x}(j) < t_{in\text{-}y}(k)) \,||\, (t_{in\text{-}x}(j) > t_{out\text{-}y}(k)), \quad (7)$$

where j,k are the hand-off indexes for x and y respectively. In other words, $call_x \cap call_y = \varnothing$ if call_x's reservation ends before call_y's one starts or after call_y has finished in the current AP. The main goal of the multiplexing scheme is the efficient passive bandwidth utilization, so an appropriate "slot-allocation" policy must be considered. Let define the following index, called "time-gap":

$$u(b_i) = \frac{\sum_x \Delta t_{xb_i}}{T_{b_i}}, \quad (8)$$

where $\Delta t_{xbi} = t_{out\text{-}x}(.)-t_{in\text{-}x}(.)$ is a passive reservation of *call_x* belonging to slot b_i and $T_{bi}=max_x(t_{out\text{-}x}(.))-min_x(t_{in\text{-}x}(.))$ is the total predicted period of reservation for slot b_i. It gives an idea of the percentage of time that the considered slot will be occupied. The proposed algorithm tries to obtain $u(b_i) \cong u(b_j)$, introducing the needed fairness condition. So the algorithm works as follows:

1) *When a new passive request from call_x arrives to the AP l, candidate slots are sorted in increasing order of time-gap.*

2) *Let* b_i *be the first element of the list (with the lowest time-gap): if* $!\exists y \in b_i$ */ the condition of eq. (7) is not satisfied then the request of call_x can be accommodated in the slot* b_i*; otherwise the next element of the sorted list is considered and step 2 is fully repeated.*

If also the *n-th* slot (the last one) is full, the passive request will be not accepted.

IV. SIMULATION RESULTS

Our network consists of 7 clusters of wireless cells (only one cluster is illustrated in Fig. 3, but the general network structure is the same of Fig. 1); users move thoroidally, according to the SRMM, with the same mobility parameters of [12]. An exponentially distributed CHT with mean λ=180*s* has been considered.

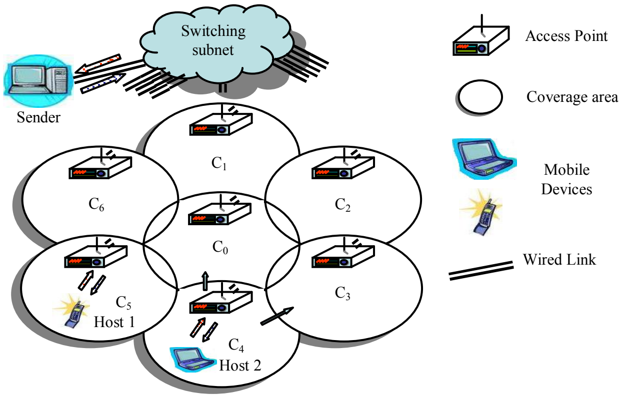


Figure 3. One of the 7 simulated clusters.

Many campaigns of simulations have been carried out, in order to appreciate the correctness of the proposed multiplexing algorithm in terms of received bandwidth, system utilization and number of admitted/dropped MIP flows. All the figures have on the x-axis the percentage of MIP traffic, from 100% (only MIP traffic), to 0 (only MDP traffic). MDP performance is not considered, since flows belonging to that class are not affected by multiplexing scheme. All the curves are obtained either if the multiplexing scheme is applied (MUX) or it is not (NO-M), by varying the number of service requests per second (req/s).

Fig. 4 shows the average system utilization with or without the proposed multiplexing scheme; as it can be seen, system utilization goes increasing, in both cases, when the MDP percentage increases (because passive reservations go decreasing); when the percentage of MDP traffic is 100%, no differences are visible because the system is not affected by multiplexing; the introduction of the proposed scheme leads to a performance enhancement (with a maximum gain of 40%). In this way, system under-utilization of previous schemes [10] is avoided.

Fig. 5 shows the trend of the average received bandwidth from MIP and MDP flows: the introduction of the multiplexing scheme causes a reduction of the obtained values; that is because a higher number of MIP users are admitted into the system, so there is a lower bandwidth availability than in the no-multiplexing case. In addition, the slight increasing trend for higher MDP traffic percentage is due to the reduction of passive reservations with a higher bandwidth availability.

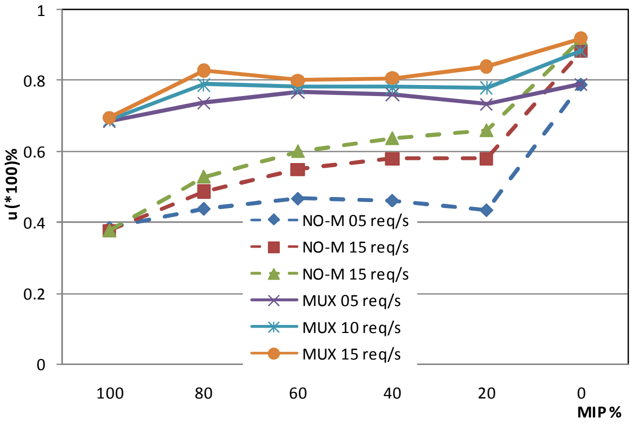


Figure 4. Average system utilization vs MIP traffic percentage.

Fig. 6 and Fig. 7 show the performance of the system in terms of admitted and dropped MIP flows: MIP service interruptions are negligible in both cases (the mean of dropped flows is always under 1), while in terms of admitted flows there is a visible difference if the multiplexing scheme is introduced: if MIP requests are present, there is a gain at least of 40-50 unities.

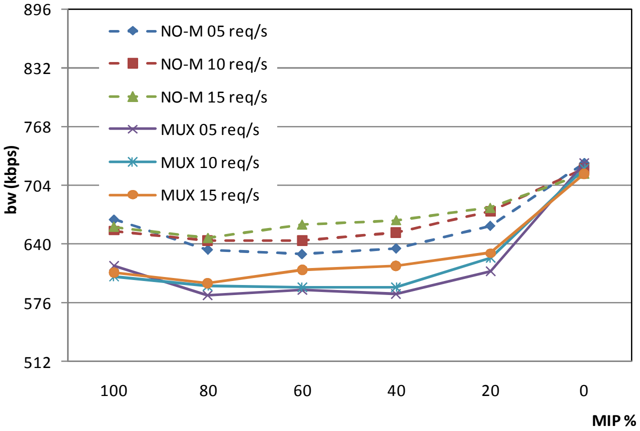


Figure 5. Average received bandwidth from MIP and MDP flows.

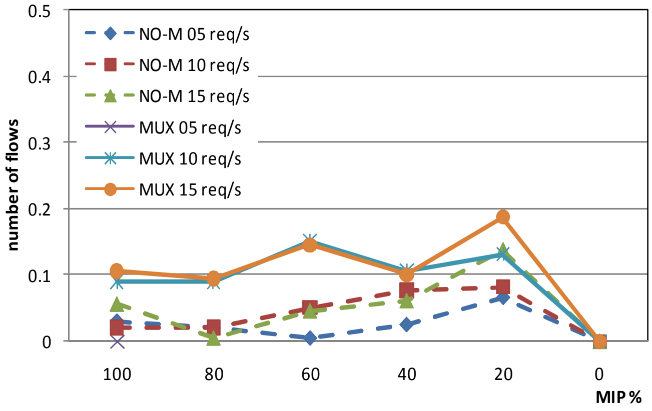


Figure 6. Average number of dropped MIP flows.

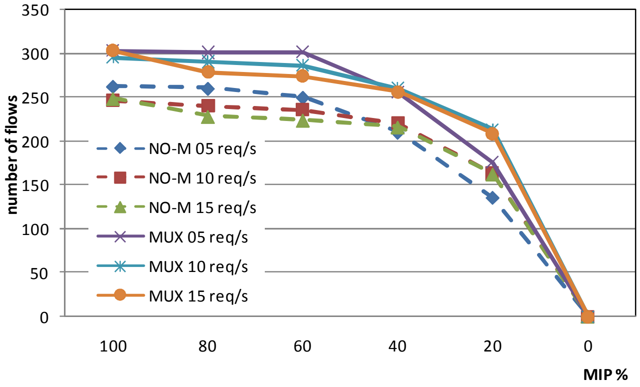


Figure 7. Average number of admitted MIP flows.

V. CONCLUSIONS

In this work a new CAC multiplexing algorithm has been proposed, in order to manage the QoS in a 2D wireless environment. It faces the problem of pre-reserving and multiplexing passive bandwidth for MIP flows over the cells that compose the system, trying to minimize the wastage of passive resources. It is based on the knowledge of the average CST and some statistical informations about users' mobility behavior, but the innovative multiplexing scheme is introduced, in order to solve the main problem of low system utilization when heavy MIP traffic percentage is present in the system. In this way, the problem of bandwidth wastage due to the presence of unused bandwidth is avoided, giving to the system a higher bandwidth availability for active and passive reservations, as explained in next section. Important statistical analysis is made in order to obtian the correct knowledge about users' resources dynamics. Many simulations have been carried out in order to observe the obtained performances. Simulations results have revealed that the multiplexing scheme performs well in terms of admitted MIP flows and system utilization; received bandwidth is worse but still acceptable.

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