A New Bandwidth Statistical Multiplexing scheme for 2D WLAN Environments with passive reservations

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ABSTRACT

The last studies about telecommunications and computer-science have increased the need and the availability of communication devices, such as laptops and palmtops; at the same time, the research in digital wireless communications has made possible the connection of notebooks to Internet wherever they are. Providing adequate Quality of Service is a very important issue in wireless communications, because of the heavy impact of users' mobility, especially when mobile nodes move among different coverage areas. In this paper a novel 2D passive reservation scheme for WLAN environment is presented: the Cell Stay Time distribution is analyzed under the Smooth Random Mobility Model in terms of mean and standard deviation; then, a new prediction technique is proposed as an enhancement of previous Mobility Independent Predictive (MIP) pre-reservation schemes, that led to an acceptable service degradation with very low system utilization. With the help of the CST statistical multiplexing introduced in this paper, better results are obtained in terms of higher system utilization, maintaining the Quality of Service and prediction error at acceptable levels. The proposed idea has been validated through many simulation campaigns, with a good performance analysis in terms of bandwidth utilization, prediction errors and other interesting parameters.

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

INTRODUCTION

Quality of Service (QoS) ([1], [2]) has been one of the main topics of research and development in packet networks for many years. QoS generally describes the assurance of sufficiently low delay and packet loss for certain types of applications or traffic. The requirements can be given by human factors, e.g., bounds on delay for interactive voice communications, or by business needs, e.g., the need to complete a transaction within a given time horizon. QoS can be described qualitatively (relative) or quantitatively (absolute). Applications differ in their QoS requirements. Most applications are loss-sensitive; while data applications can recover from packet loss via retransmission (losses above 5% generally lead to very poor effective throughput). Data applications such as file transfer are not generally delay-sensitive, although human patience imposes lower throughput bounds on applications such as web browsing. Continuous media applications such as streaming audio and video generally require a fixed bandwidth, although some applications can adapt to changing network conditions (as we will see in next sections). In short, it is likely that at least portions of the Internet will see service differentiation in the near future ([3], [4]). Since best-effort service will continue to be dominant, all Internet QoS mechanisms are layered on top of the existing Internet, rather than replacing it with a new infrastructure. In addition, many proposals have been made for real-time applications on Integrated Services Packet Networks (ISPNs), like audio-library, image-browsing, video-conferencing and video-on-demand (these kinds of applications need of some constraints on the packet delivery ratio, packet loss rate and so on). In [5] an architecture for ISPNs is described, with the support of real-time traffic; two main components of the proposed architecture are: the Call Admission Control (CAC) scheme and the reservation protocol. A new architecture, able to operate with users' mobility, is needed. In this paper, a wirelessLAN scenario with MIP users [6], [7], [8] is considered. In the proposed work, the advantages of the passive reservations policy are investigated, through the introduction of a new prediction scheme, that is able to make advanced passive reservations when the flow is initiated. This paper is organized as follows: next section presents a short summary of related work about the prediction and reservation techniques; then a brief overview of the Mobile RSVP protocol (applied in our work in order to make passive reservations) and the considered mobility model is given; the prediction algorithm and the reservation scheme are then presented and their simulation results with the conclusions are respectively summarized in the last two sections.

RELATED WORK

Different telecommunication concepts are considered in this work, from users' mobility to bandwidth reallocation; a complete communication network has been considered, based on some studies that have been proposed in the literature. In our work we considered the IEEE 802.11 family mobile environment, where the QoS can be provided with the help of the MRSVP. In particular, taking into account the considerations of [7], [8], only MIP requests have been analyzed here: Mobility Independent Predictive (MIP) service class belongs to tolerant real-time applications, subject to certain bounds on packet delays, with a guaranteed service continuity during hand-off events. MIP users make service requests to the access points, requiring the needed QoS guarantees, like low delay-jitter or low call dropping probability during hand-off events; the only way to avoid service degradations or disruptions during a mobile session is to make in-advance reservations (i.e. passive reservations) [6], [7], accounting for users mobility behaviour [8], [9], [10]. In [7], [16] the authors propose some rate adaptation schemes based on some specific QoS indexes such as Fairness, Degradation Degree and so on, in order to dynamically adjust the bandwidth of the on-going calls, especially in overloaded situations. So in the wireless adaptive networks, adaptations of the applications at multiple bandwidth levels become a key issue. Two prediction-based resource reservation techniques are proposed in [12]. These techniques consider the Wiener prediction theory and the time series analysis in order to make a predictive resource reservation under non-Poisson and/or non stationary arrival processes, arbitrary distributed call and channel holding time and arbitrary per-call resource demands. We employed the Smooth Random Mobility Model (SRMM) proposed in [13] for a two-dimensional set of cell clusters. The MRSVP protocol is used for exchanging state information of wireless network; the key issue of this work regards the enhancement of the MIP pre-reservation phase, when mobile hosts reserve a certain amount of passive bandwidth in the cells that they will probably visit [14]. In [15], a hierarchical user mobility model based on an appropriate pattern matching and Kalman filtering is presented. This approach permits to get the necessary information for advance resource reservation and optimal route establishment in wireless ATM networks. In this work a two-level user mobility model is used to represent the movement behavior at global and local levels.

In this paper it is shown that, with a certain knowledge of the Cell Stay Time (CST) distribution and a good prediction alogrithm of the possible future visited cells [11], the unused passive bandwidth can be multiplexed for other MIP users. In this way, high system utilizations can be achieved. The proposed technique is of general application and does not depend on the specific mobility model. In [8] it is shown that the CST random variable, under the SRMM, follows a Gaussian trend, depending on the preferred speeds of users, strictly related to their behavior; in addition to the CST statistic, HDP values are necessary in order to consider future positions of mobile hosts; so, combining CST and HDP informations, a new passive reservation scheme is proposed for a two-dimensional environment. The threshold-based algorithm [11], that uses CST and HDP values to dynamically select the cells, where to in advance reserve the bandwidth, is used. The above considerations are taken into account in next sections, when the new bandwidth multiplexing scheme is proposed.

IMPORTANCE OF RESERVATION PROTOCOL AND MOBILITY MODEL

In IS networks with mobile hosts, each flow can receive different QoS levels that must be negotiated at the beginning of sessions, between flows and net, by the MRSVP protocol [6]. The Mobility Independent Predictive (MIP) class is provided in IS Packet Networks (ISPNs) and it deals with tolerant real-time applications (subject to certain bounds on packet delays). Other classes (like Mobility Dependent Predictive MDP and Mobility Independent Guarantee MIG) are provided in ISPNs, but, in this paper, the attention is focused only on MIP services that use a pre-reservation phase for QoS guarantees. In order to handle users' mobility and to offer guaranteed services (independent from mobility) the ReSerVation Protocol (RSVP) has been extended with the MRSVP. For more details about MRSVP see [6]. There are many works in literature about these models [13], but they are based on some simple assumptions about users' behavior and do not lead to any analytical expression. This work employs the Smooth Random Mobility Model (SRMM) proposed in [13] for a two-dimensional set of cell clusters; this model makes users' movements smoother and more realistic than previous random models, because it relates speed and direction changes; in addition it leads to a general set of analytical expressions, that can be used for different wireless scenarios. In [13], Bettstetter introduces a new mobility model that can be used in simulations of mobile and wireless networks, in which the individual movement behaviour of users is reflected: two stochastic processes are used: one process determines at what time a mobile station changes its speed and the other one determines when the direction is changed. Many mobility models in the literature consider that the new choice for speed v and direction φ is not correlated to previous values (such as in the RWPMM). This may cause unrealistic movement behaviour with sudden speed changes ($\frac{\partial v(t)}{\partial t} \to \infty$) or sharp turnings (high $\frac{\partial \varphi(t)}{\partial t}$ when v is high). The SRMM includes both autocorrelation features. The modelling of speed behaviour of nodes is based on the use of target speeds (the speed a node intends to achieve) and linear acceleration. A node goes with constant speed v until a new target speed is decided by a random process. The node then accelerates (or decelerates) until this desired speed is achieved (or again a new target speed is chosen in the meantime). The speed behaviour of a node at time t can therefore be described by three parameters: its current speed $v(t)$, its current acceleration $a(t)$ and its current target speed $v^*(t)$. In addition, three static speed parameters that characterize a certain node class are defined: a maximum speed v_{max}, a set of preferred speeds $\{v_{pref0}, v_{pref1}, ..., v_{prefn}\}$ and the maximum values for acceleration/deceleration. The relationship $0 \leq v(t) \leq v_{max}$ must be verified at any time t. When a simulation starts, at the beginning, all nodes are created with an initial speed $v(t=0)$, which is chosen from a certain speed distribution $p(v)$. For example, if there are three preferred velocities $v_{pref0}=0$, $v_{pref1}=4/7 v_{max}$ and $v_{pref2}=v_{max}$, then the distribution will be the one expressed in eq. (1). Remember that $p(v_{pref})=p(v_{pref0})+p(v_{pref1})+ \ldots +p(v_{prefn})<1$, $v_{pref0}<v_{pref1}<\ldots<v_{prefn}$ and v_{max} is a fixed threshold.

$$p(v)=\begin{cases} p(v=0)\delta(v) & v=0 \\ p(v=\frac{4}{7}v_{\max})\delta(v-\frac{4}{7}v_{\max}) & v=\frac{4}{7}v_{\max} \\ p(v=v_{\max})\delta(v-v_{\max}) & v=v_{\max} \\ \frac{1-p(v_{pref})}{v_{\max}} & 0<v<v_{\max} \\ 0 & else \end{cases} \quad (1)$$

As mentioned above, a node goes with constant speed v until a speed change event occurs. Upon this event, a new target speed v* is chosen. The author of [13] modelled the frequency of speed change events according to a Poisson process: in a discrete-time simulation with normalized time $t/\Delta t$, a speed change event occurs with a certain probability p_{v*} each time step, where $p_{v*}<<1$. Using continuous time t, the time between two speed change events can be chosen from an exponential distribution with $\lambda=p_{v*}/\Delta t$. Let t^* denote the time at which a speed change event occurs and a new target speed $v^*=v^*(t^*)$ is chosen; an acceleration $a(t^*)\neq 0$ is set (it is set to 0 only if $v^*(t^*)=v(t^*)$). Then, other two variables are used: a_{max} and a_{min}. The first one represents the maximum possible acceleration and the second one the maximum possible deceleration. In discrete instant times, the new speed $v(t)$ is changed, according to the uniformly accelerated motion as follows:

$$v(t)=v(t-\Delta t)+a(t)\Delta t \quad (2)$$

until $v(t)$ achieves $v^*(t)$.

CELL STAY TIME ANALYSIS AND PREDICTION-MULTIPLEXING SCHEMES

Evaluation of the number of possibly visited cells

Under a chosen mobility model (the SRMM in our case) and a certain cell coverage topology, the average Cell Stay Time (CST, the time between a completed hand-off procedure and the beginning of a new one) can be observed, as in previous works [16], under the hypothesis of a Call Holding Time (CHT) exponentially distributed. As in other studies, it can be seen that the CST distribution can be well approached by a Gaussian distribution, with different means and standard deviations, depending on some fixed mobility parameters. The Kolmogorov-Smirnov (KS) normality test [17] has been led out to evaluate the correctness of a Gaussian approximation of CST distributions under the SRMM; different *p-values* have been obtained [17], showing that there is a negligible error if a Gaussian approximation is employed for the CST distribution. So a probability distribution function can be derived for the CST, expressed such as in eq.3

$$f_{X_{CST}}(x)=\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (3)$$

where $\mu=\mu_{CST}(v)$ and $\sigma=\sigma_{CST}(v)$ are respectively the mean value and the standard deviation of the Normal distribution. It is possible to derive the *cumulative distribution function* c.d.f. of the CST by eq.4 as follows:

$$F(x)=P(X_{CST}\le x)=\int_{-\infty}^{x}\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2}dt \quad (4)$$

through eq.4, the probability that CST is lower than a value x with a fixed error threshold ε is given from eq.5

$$P(X_{CST}\le x)=P\left(Z\le\frac{x-\mu_{CST}}{\sigma_{CST}}\right)=\Phi\left(\frac{x-\mu_{CST}}{\sigma_{CST}}\right)=1-\varepsilon \quad (5)$$

where $Z=\frac{X_{CST}-\mu_{CST}}{\sigma_{CST}}$, X_{CST} are random variables and $\Phi(\cdot)$ is the standard Normal distribution. Through the tabular values of the standard Normal distribution it is possible to get the CST estimation for a given threshold ε such as referred to in [18]. As mentioned above, we used the SRMM and mobile hosts follow the stop-turn-and-go behavior with toroidal topology as in [13], with two preferred speeds v_{pref0}=0 Km/h, $v_{pref1}=v_{\max}$ Km/h; a Poisson call arrival time distribution has been considered. With the knowledge of the CHT and CST distributions, the number of visited cells (including the active one) C_e can be evaluated. It is possible to select a cell stay time T_{cst} for a mobile host so that $Prob(X<T_{cst}) <1-\varepsilon$, where X is normally distributed. T_{cst} is called a $(1-\varepsilon)*100\%$ upper confidence bound for X. If the average call holding time T_{cht} is known, it is possible to consider the term C_e as:

$$C_e=\frac{T_{cht}}{T_{cst}} \quad (6)$$

Thus the knowledge of μ_{CST} and σ_{CST} is necessary to obtain a good estimation of the CST distribution and the number C_e of probably visited cells. It must be outlined that the described analysis does not depend on the specific mobility model and it can be always applied. Unfortunately, without directional information about users' mobility patterns, the predicted value of C_e may be only used to make passive reservations in a circular way, as in figure 1; the number of required passive reservations C_r for MIP services in a two-dimensional environment with hexagonal coverage areas increases with polynomial trend, such as follows:

$$C_r=3\cdot C_e\cdot(C_e-1) \quad (7)$$

Possibly visited cells identification with directional probabilities analysis

The above wastage problem can be avoided and the value of C_r can be decreased, making it nearer to C_e, depending on the adopted reservation threshold. Figure 1 depicts the policy adopted in the circular reservation technique. A WLAN coverage area, generally with a circular shape, can be approximated with a n-edge regular polygon as depicted in figure 2 (n can be considered as an input control parameter).

As it can be seen from figure 2, for higher values of n better approximations can be reached.

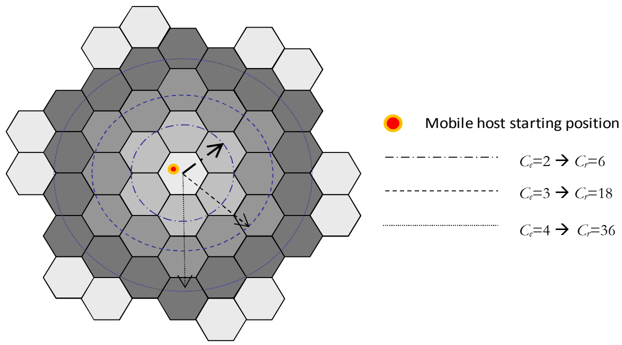

Figure 1. Circular reservation in a 2D cluster of cells

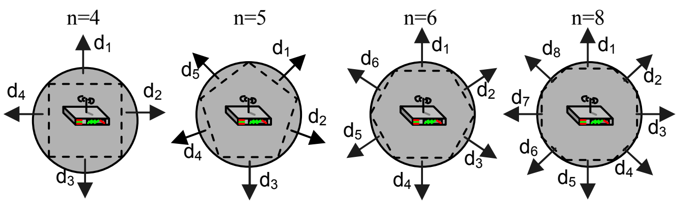

Figure 2. Possible Access Point (AP) coverage area approximations

A set S_{ho} of n possible movement directions can be then obtained: let movement directions indicate with $d_1...d_n$, where $d_j=\underline{\theta}\cdot(2\cdot j\text{-}1)/2$ *rad.*, $\underline{\theta}=2\pi/n$ *rad.* and $j=1..n$, so $S_{ho}=\{d_1, .., d_n\}$ and $|S_{ho}|=n$. After n has been chosen, a square nxn mobility probabilities matrix M can be defined as:

$$M(x,y) = p(out\ to\ y\in S_{ho}\ t=t_0+CST\ /\ in\ from\ x\in S_{ho}\ t=t_0). \qquad (8)$$

That is to say $M(x,y)$ indicates, for a fixed mobility model, the probability that a generic user i will be handed-out to direction $y\in S_{ho}$ after CST (a normally distributed value) amount of time, if it was handed into current wireless cell from direction $x\in S_{ho}$. Note that matrix M depends only on the adopted mobility model and network cells subdivision and it is the same for all users in the system. The matrix M has the hand-in directions on the rows and the hand-out ones on the columns; it can be filled out through a first addicted campaign of simulations, by observing hosts movements. Generally the $M(x,y)$ elements are statistically distributed and not symmetric, so they have to be represented in the right way. If λ indicates the mean of CHT of MIP users, the predicted number of hand-off events for user i $h_i = C_{ei}\text{-}1$ can be obtained such as in eq.6. Let vh_i be an information support-array, where $vh_i[k]$ with $k=1..h_i$ indicates the informations about *k-th* future hand-off of user i; i.e. each entry in the array vh_i, $vh_i[k]$, can be a pointer to a list of tuples $\{cell\_id, from, to, p_{cell\_id}\}$ for *k-th* hand-off event; *cell_id* is a cell identifier and $from \in S_{ho}$, $to \in S_{ho}$ are respectively the hand-in and hand-out directions for the *cell_id* cell; p_{cell_id} is the probability that user will be under the coverage of the *cell_id* cell after the *k-th* hand-off; the algorithm predicts *to* directions, given *cell_ids*, *from* directions and p_{cell_id} values; let δ be an input threshold for the cell estimation phase (as for n, δ is an input control parameter); the following steps are performed in order to obtain the complete set of predicted cells that MIP user ***i*** will probably visit during an active connection:

Evaluation of first hand-off possible direction

After the initialisation of vh_i with h_i "*to-null*" pointers, the algorithm must start with predicting cells for the first hand-off. Since no hand-in direction is available when a flow is admitted in a cell, matrix M cannot be used for a prediction on the first hand-off, so the algorithm evaluates the current mobility direction $\boldsymbol{d_j} \in S_{ho}$ of user ***i*** in the *current_id* cell with one of the approaches of [19], [20] and, supposing that user i will probably follow direction d_j until the first hand-out event, the term *first_id=first_Cell_id(current_id,* d_j*)* can be obtained, by an appropriate function *first_Cell_id()* that evaluates the identifier of the cell that user ***i*** will visit following direction $\boldsymbol{d_j}$ from the current position; in the simulation tool, the implementation of the above function depends on the data structures used for representing the network topology, while in a real network it can be obtained through an appropriate signalling protocol. At this point, a tuple $\{first\_id, \_ , d_j, 1\}$ can be created and appended in $vh_i[1]$; the *from* direction cannot be discovered because user ***i*** has started his flow in the current *first_id* cell, without handin-in it from any direction while $p_{first\_id}=1$ because the probability of hand-out from *first_id* cell during the first hand-off is 1; now the algorithm can continue with predicting next cells, as exposed in the next step.

Evaluations from 2-nd to h_i-th hand-off events

Let us suppose for now that the elements of M are constant values; the main aim is now the prediction making for all the cells contained in the list of $vh_i[k]$, with $k=1..h_i\text{-}1$; the pseudo-code below resumes the adopted policy when predicting cells for user ***i*** and it is fully described in the following:

THRESHOLD-BASED ALGORITHM

```
//for every predicted hand-off event of user i
for (int k=2; k ≤ h_i; k++) {
  //index on the cells of the k-th hand-off event
  int l=1;
  //for each cell of the current k-th hand-off event
  while (l ≤ vh_i[k].size()) {
    //let analyze the current l-th tuple in the k-th element
    current_tuple= vh_i[k].elementAt[l];
    //the hand-in direction is known
    curr_hand_in_dir= From(current_tuple.to);
    //probability of user i of being in current cell
    p_curr=current_tuple.p_cell_id;
    //find the "more suitable" hand-out candidate cells
```

```
    for (int p=1; p ≤ n; p++) {
     //the probability of hand-out is evaluated
     curr_prob=M(curr_hand_in_dir, p)*p_curr;
     //threshold based comparison
     if  (curr_prob ≥ δ^f(k)){
       //the current cell can be considered a valid candidate
       id=Cell_id( current_tuple.cell_id,  p);
       //the v_hi vector must be updated
       create_a_tuple{curr_hand_in_dir, p, id, curr_prob};
       append the tuple in vh_i[k+1];
     }
    }//for p
    l++;
   }//while l
   clean vh_i[k+1] from duplicates;
  }//for k
create an empty cell identifiers list p_cells;
//extract cell ids from tuples and append them to p_cells
for (int k=1; k<=t_i; k++) {
  for (int l=0; l<vh_i[k].size(); l++)  {
    current_tuple=vh_i[k].elementAt(l);
    append current_tuple.cell_id to p_cells;
  }
}
return p_cells.
```

The whole procedure must be repeated h_i*-1* times (*k* goes from 2 to h_i because for the first hand-off event the prediction has already been made); so the *k* index scans vh_i until the h_i*-th* position ($C_{ei}-1$ times); a prediction must be made for each cell of the $vh_i[k]$ list ($|v_{hi}[k]|$ is *n* in the worst case); each tuple in $vh_i[k]$ contains the hand-in direction, the cell identifier and the probability of user ***i*** of being in the cell after the (k-1)-th hand-off; through a threshold-based comparison the algorithm must decide what are the cells that user *i* will visit with higher probability when handing-out the cell of the *l-th* tuple of vh_i *[k]*, $l=1 \ldots vh_i[k].size()$ with a well known hand-in direction; the hand-in direction *curr_hand_in_dir* (obtained by a *From()* function that translates hand-out directions into hand-in ones) belongs to S_{ho}, so it specifies a unique row of *M*; the algorithm calculates the probability of hand-out from the current cell on direction *p* after having handed-in from direction *curr_hand_in_dir* when the probability of being in the previous cell before the current hand-off is p_{curr}: if the obtained value is higher than $\Delta=\delta^{f(k)}$, then the cell that is adjacent to the current one on direction *p* must be considered as a possible future cell and a tuple {*from*, *p*, *adjacent_p_cell, curr_prob*} is appended in vh_i *[k+1]* (*p=1..n*, so the probability evaluation is made *n* times, as the number of elements on a row of *M*). The exponent *f(k)* is a function of *k* and the power operation is necessary in order to take into account the increasing of prediction error for higher values of *k*. After the considerations above we can conclude that the computational complexity of the proposed scheme, in the worst case, is polynomial: $O(C_e \cdot n^2)$.

In the pseudo-code above some functions are introduced: let "***cell_id Cell_id(cell_id current_id, direction to)***" be a function that, given a cell identifier ***current_id*** and a hand-out direction ***to***, returns the identifier of the cell adjacent to ***current_id*** cell on ***to*** direction; let "***direction From(direction to)***" be a function that translates the hand-out direction ***to*** of the previous cell in the hand-in direction of the next cell. When repeating all the steps h_i*-1* times, a cleaning routine must be executed after finishing appending elements in $vh_i[k]$ position, because of possible duplications of cell identifiers; the same results can be obtained if the append function avoids duplicates. It must be outlined that the prediction scheme is totally independent from the chosen mobility model (the SRMM in our case) and only *M* gives to it the right knowledge about users' mobility behavior. *M* can be derived for the desired mobility model.

The hypotesis of *M* composed by constant values is not suitable: after many simulations and tests (following the approaches of [17]), it can be concluded that the elements *M(x,y)* can be well approached with a Gaussian distribution, so *M(x,y)* is a couple of values, the mean and the standard deviation of the obtained distribution, as depicted in figure 3. So in the proposed pseudo-code $M(x,y)=N(\mu_{x,y}, \sigma_{x,y})$.

0.0137, 0.0061	0.0244, 0.0128	0.2779, 0.0429	0.3663, 0.0497	0.3034, 0.0476	0.0256, 0.0132
0.0325, 0.0166	0.0132, 0.0044	0.0399, 0.0198	0.3700, 0.0525	0.5056, 0.0554	0.0549, 0.0251
0.3708, 0.0545	0.0430, 0.0203	0.0125, 0.0030	0.0316, 0.0174	0.0521, 0.0227	0.5054, 0.0552
0.3692, 0.0462	0.2798, 0.0464	0.0249, 0.0133	0.0129, 0.0060	0.0248, 0.0138	0.2994, 0.0461
0.3743, 0.0554	0.5094, 0.0581	0.0440, 0.0210	0.0328, 0.0173	0.0127, 0.0031	0.0437, 0.0213
0.0318, 0.0170	0.0426, 0.0223	0.5094, 0.0579	0.3769, 0.0556	0.0427, 0.0212	0.0145, 0.0071

Figure 3. Directional probabilities matrix M in terms of μ,σ for the mobility parameters of [13], with n=6

Statistical bandwidth multiplexing

Another important issue of the proposed work is the statistical passive bandwidth multiplexing: when a MIP users pre-reserves a certain amount of passive bandwith in the remote Access Points (APs - statistically identified by the proposed algorithm in the previous section III-B) it may be considered as available resource when other incoming calls request to enter into the system. So, the Call Admission Control (CAC) module of the whole Access Points constellation have to implement a time-based bandwidth multiplexing. Let us suppose that MIP user *j* (MIP_j) has been admitted into the net, after making of its active reservation and its passive reservations and another MIP user k (MIP_k) is making a new service request ($j \neq k$). Let us suppose that MIP_j has also made a passive reservation in the remote AP h (AP_h); predicting that MIP_j will probably reach AP_h at the enter time instant $t\text{-}in_{jh}$, then its passive bandwidth PBW_{jh} (Passive BandWidth of MIP_j reserved in AP_h) can be re-used by MIP_k until the time $t\text{-}in_{jh}$; so if MIP_k will probably leave AP_h at the exit time $t\text{-}out_{kh}$, then it can re-use PBW_{jh} for the period $T_{kh}=[t\text{-}in_{kh} \div t\text{-}out_{kh}]$ only if $t\text{-}out_{kh} < t\text{-}in_{jh}$. That is to say MIP_k will leave AP_h before MIP_j enters it with the request of the availability of PBW_{jh}, that will be switched into active bandwidth. In this way, the wastage of PBW_{jh} is avoided at least for the T_{kh} duration.

The overall AP bandwidth capacity C, without multiplexing, can be so considered as composed by three main contributions:

a) The bandwidth used by MIP active reservations (A_{MIP});

b) The free bandwidth, available for new active-passive requests (S);

c) The passive and unused bandwidth (P_{MIP}) that can be multiplexed.

It is always verified that $C\text{-}S=A_{MIP}+P_{MIP}$. The AP utilization U is defined as $U=A_{MIP}/C$. When the time-based multiplexing is utilized, the P_{MIP} contribution is further subdivided in: $ActiveP_{MIP}$, the active MIP bandwidth multiplexed on P_{MIP}, $PassiveP_{MIP}$, the passive MIP bandwidth multiplexed on P_{MIP} and $FreeP_{MIP}$, the amount of P_{MIP} not yet multiplexed. In this case, the AP utilization increases to $U=(A_{MIP}+ActiveP_{MIP})/C$. The CAC module must ensure that $A_{MIP}+ActiveP_{MIP}+FreeP_{MIP}+S \leq C$ is always verified. The CAC algorithm can be resumed as the following pseudo-code when a new active or passive service request arrives to the AP_h; the request is accepted if a *true* value is returned:

CAC ALGORITHM WITH STATISTICAL MULTIPLEXING

//let BW_{req} be the bandwidth level requested by MIP_k
//the request can be accepted with no multiplexing
if ($BW_{req} \leq S$) {
  //the available free bandwidth must be decreased
  $S\text{-}=BW_{req}$;
  //AP_h is an active Access Point
  if (MIP_k request == active) $A_{MIP}+=BW_{req}$;
  //AP_h is a remote Access Point
  else $P_{MIP}+=BW_{req}$;
  return true;
//the CAC tries to accept the request on the passive bandwidth
else {
  //determine the amount of bandwidth that can be multiplexed
  availableBW=$determineP_{MUX}(MIP_k)$;
  if ($BW_{req} \leq$ availableBW) {
    if (MIP_k request == active) $ActiveP_{MIP}+=BW_{req}$;
    //AP_h is a remote Access Point
    else $PassiveP_{MIP}+=BW_{req}$;
    return true;
  }
}
//the request must be refused
return false;

The key function of the multiplexing CAC in the AP_h is "***BWlevel determineP$_{MUX}$(BW request)";*** when it receives the argument MIP_k, it evaluates the time period T_{kh} for the bandwidth request k; then it compares the obtained time period with all the occupance periods of the n non-multiplexed accepted passive reservations MIP_j as previously exposed, so $j=1..n$. The returned value *BWlevel* takes into account all the j non-multiplexed reservations for which $t\text{-}out_{kh} < t\text{-}in_{jh}$ is verified.

PERFORMANCE EVALUATION

Our network consists of 7 clusters of wireless cells (only one cluster is illustrated in figure 4); users move thoroidally, according to the SRMM, with the same mobility parameters of [13].

An exponentially distributed CHT with mean λ=180*s* has been considered. For sake of simplicity we considered an exponent function $f(k)=1$; δ has been fixed to 0.6. Other results have been observed to follow a similar trend for other exponent function $f(k)$ ($f(k)=\frac{\alpha}{k}$, $f(k)=\frac{1}{\alpha \cdot k}$ and so on) and for this reason they are not shown in this paper.

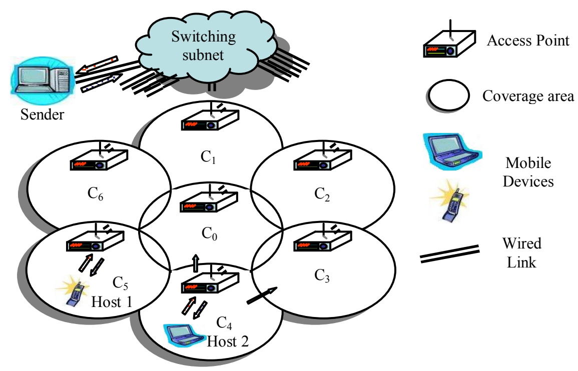

Figure 4. One of the 7 simulated clusters

Different campaigns of simulations have been carried out, in order to appreciate the correctness of the proposed algorithm in terms of prediction error and system utilization. Figure 5 shows the average system utilization for increasing values of MIP requests, as a comparison of the proposed threshold-based scheme with the static scheme proposed in [21], where the number of passive cells must be specified as input parameters. In both cases, the trend is decreasing because of the higher number of passive reservations, with a consequent reduction of MDP admitted flows. When no MIP users make service requests the utilization reach its maximum value, around 92%-93%, because no passive reservations are present in the system; on the contrary, the system is very under-utilized if only MIP users make service requests.

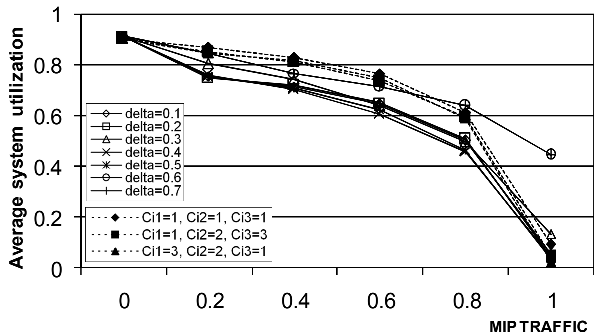

Figure 5. Average system utilization vs MIP traffic percentage

The maximum gap between static and dynamic schemes is observed for a MIP percentage of 60% and it is around 10%-12% (the case of 100% MIP is excluded because no MDP are present into the system). As it can be seen the static scheme performs slightly better than the dynamic one in terms of system utilization, except for high percentages of MIP flows, because high values of δ lead to a system utilization of about 46%. For all the following figures, the two curves are obtained with the same prediction threshold-based scheme, but the *NO-MUX* one does not account the CAC multiplexing effect, following the classical admission control (that is to say the call is admitted only on the free available bandwidth *S*).

Figure 6 shows the average received bandwidth from MIP users, in function of the number of MIP service requests per second made to the system. The course is slightly decreasing in both cases because of the higher presence of admitted flows and the maximum gap between two curves is about 4-5Kbps; it can be concluded that the introduction of the multiplexing scheme does not introduce appreciable enhancements on the received bandwidth.

Figure 7 depicts the average system utilization: with the *NO-MUX* approach the obtained values in function of MIP requests per second do not exceed the bound of 10%. A so lower utilization value is unacceptable and it is due to the heavy presence of passive and unused bandwidth. In addition, the trend is constant because the system is always saturated, independently from the number of service requests. Introducing the multiplexing policy, an appreciable enhancement is visible, expecially for higher values of MIP requests per second. The utilization grows up from about 30% to about 70%, and these values are not comparable with those of the classical scheme. So, figure 5 shows the obtained enhancements in terms of system utilization. Figure 8 depicts the course of the average number of admitted flows; as for the system utilization, the obtained enhancements are evident, especially for high values of MIP requests per second.

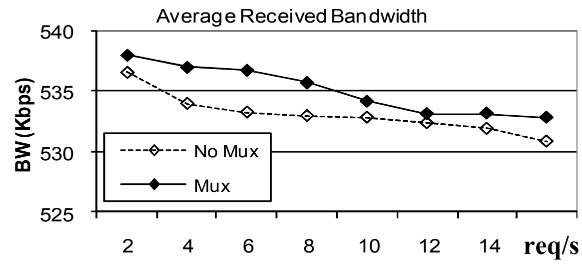

Figure 6. Average received bandwidth from MIP users

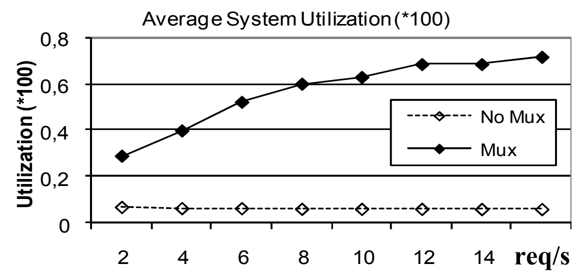

Figure 7. Average system utilization

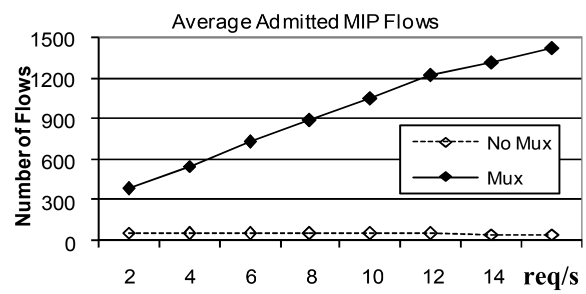

Figure 8. Average number of admitted flows

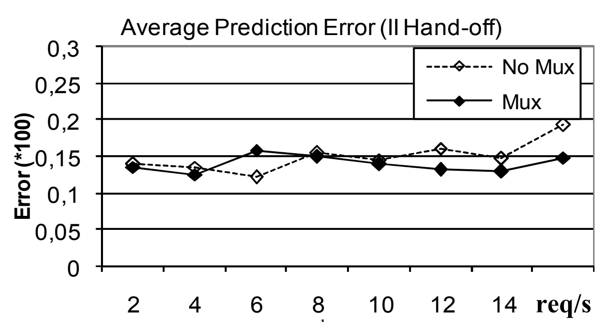

Figure 9. Prediction error on 2^{nd} hand-off event

The number of admitted flows into the system goes up near to 1450, versus about 100 admitted flows of the *NO-MUX* classical scheme (also in this case the system is always saturated because of the heavy presence of passive and unused bandwidth).

Figure 9 illustrates the average error on predicting future visited cells for second hand-off event; since the multiplexing CAC algorithm does not affect the prediction module, no big differences can be outlined between *MUX* and *NO-MUX* curves. However, the proposed algorithm gives an average error of about 15%, obviuosly independent from the number of service requests.

CONCLUSIONS

A novel CAC 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. The proposed scheme implements a dynamic matrix analysis through an input threshold value, solving the problem of previous static schemes that have to specify the number of cells on which passive reservations must be made for different consecutive hand-off events. In this way, it dynamically decides how many cells must be involved in the pre-reservation phase. In addition a multiplexing scheme is also proposed; if it is combined with the threshold-based predictor, then a good CAC can be obtained. Many simulations have been carried out in order to observe the obtained performances. Simulations results have revealed that the threshold-based scheme, integrated with the multiplexing one, performs well in terms of admitted MIP flows and system utilization; received bandwidth and prediction error are also acceptable (QoS bounds are always satisfied).

REFERENCES

[1] P. Ferguson and G. Huston, "Quality of Service: Delivering QoS in the Internet and the Corporate Network", Wiley Computer Books, New York, NY, 1998.

[2] I. Foster and C. Kesselman, "The Grid: Blueprint for a New Computing Infrastructure", Morgan Kaufmann Publishers, San Francisco, California, 1998.

[3] L. Breslau and S. Shenker, "Best-effort versus reservations: A simple comparative analysis", *ACM Computer Communication Review*, vol. 28, pp. 3–16, 1998.

[4] B. Teitelbaum, S. Hares, L. Dunn, R. Neilson, R. Vishy Narayan and F. Reichmeyer, "Internet2 qbone: Building a testbed for differentiated services", *IEEE Network*, vol. 13, pp. 8–16, 1999.

[5] Clark, D.D. Shenker, S. and Zhang, "Supporting Real-Time Applications in an Integrated Services Packet Network: architecture and mechanism", Proc. SIGCOMM, 1992.

[6] A.K.Talukdar, B.R.Badrinath, A.Acharya, "MRSVP: A Resource Reservation Protocol for an Integrated Services Network with Mobile Hosts," *Wireless Networks Kluwer Journal*, pp.5-19, 2001.

[7] V.Bharghavan, K-W.Lee, S.Lu, S.Ha, J-R.Li, D.Dwyer, "The TIMELY Adaptive Resource Management Architecture," *IEEE Personal Communications Mag.*, pp.20-31, Aug.1998.

[8] F. De Rango, P.Fazio, S.Marano, "Cell Stay Time Prediction for Mobility Independent Predictive Services in Wireless Networks," *IEEE Wireless Communications and Networking Conference (WCNC2005)*, New Orleans, Los Angeles, USA, 13-17 March 2005.

[9] M.M.Zoonozi, P.Dassanayake, "User Mobility Modeling and Characterization of Mobility Patterns," *IEEE Journal on Select.Area on Comm.*, vol.15, no.7, 1997.

[10] T.liu, P.Bahl, I.Chlamtac, "Mobility Modeling, Location Tracking,and Trajectoty Prediction in Wireless ATM Networks", *Journal on Select.Area on Comm.*, vol.16, no.6, Aug.1998.

[11] F.De Rango, P.Fazio, S.Marano, "A New Threshold-Based Predictive Reservation Scheme," *65th Vehicular Technology Conference (VTC Spring 2007)*, Dublin, Ireland, 22-25 Apr 2007.

[12] T.Zhang et al., "Local Predictive Resource Reservation for Handoff in Multimedia Wireless IP Networks," *IEEE Journal on Selected Area in Communications*, vol.19, no.10, Oct.2001, pp.1931-1941.

[13] C.Betstetter, "Mobility Modeling in Wireless Networks: Categorization, Smooth Movement, and Border Effects," *ACM SIGMOBILE Mobile Computing and Communications Review*, Vol. 5, Issue 3, pp. 55–66, July 2001.

[14] Talukdar A. K., Badrinath B.R. and Acharya A., "On Accomodating Mobile Hosts in an Integrated Services Packet Network", *In the Proceedings of the IEEE INFOCOM '97*, April.

[15] F. De Rango, S. Marano, "An Average Degradation Degree and Ratio based Rate Adaptation Algorithm for Wireless Mobile Networks", in *15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC04)*, Barcelona, Spain, Sept. 2004.

[16] F. De Rango, P.Fazio, S.Marano, "Mobility Independent and Dependent Predictive Services Management in Wireless/Mobile Multimedia Network," *IEEE Vehicular Technology Conference 2004 Fall (VTC Fall 2004)*, Los Angeles, CA, USA, Sept.2004.

[17] M.A. Stevens, R.B. D'Agostino, "Goodness of Fit Techniques", Marcel Dekker, New York 1986.

[18] J.Banks, J.S.Carson et al., "Discrete-Event System Simulation," Third Edition, Prentice Hall, 2001.

[19] C.F. Lin, A.G. Ulsoy, "Vehicle Dynamics and External Disturbance Estimation for Future Vehicle Path Prediction", *Proceedings of the American Control Conference*, Seattle Washington 1995.

[20] Achir, M.; Ghamri-Doudane, M.; Pujolle, G, "Predictive resource allocation in cellular networks using Kalman filters" on *IEEE International Conference Communications (ICC '03)*, Vol.2, 11-15 May 2003, pp.974 – 981.

[21] F. De Rango, P.Fazio, S.Marano, "Mobility Independent Predictive Services in WLAN Networks with Predictive Reservation Policy under a 2D Mobility Model," in *Wireless Telecommunication Symposium (WTS 2006)*, Pomona, CA, USA, Apr. 27-29, 2006.