Adaptive Reservation in WLAN Networks under Smooth Random Mobility Model

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Abstract—**This papers presents a novel technique to predict the number of WLAN cells visited by a mobile host during its call holding time. A two-dimensional wireless mobility model called Smooth Random Mobility Model (SRMM) has been considered, because it makes the movement of users smoother and more realistic than *well-known* in literature random mobility models. A prediction technique based both on the analysis of Cell Stay Time and on the direction probabilities of hand-in and hand-out events of mobile nodes from wireless cells is outlined, as a method for QoS guarantees, lower bandwidth wastage and higher system utilisation. An integrated architecture able to make active and passive reservations has been applied as possible application of the proposed approach. Simulation results have been carried out and an interesting bandwidth management usage has been observed.**

Keywords: WLAN, Smooth Random Mobility model, MRSVP, adaptive reservation, predictive policy, Cell Stay Time (CST).

I. INTRODUCTION

One of the main problems in wireless scenarios with mobile hosts is the capacity of continuous QoS guarantees during connections between users and access points (or base stations), without neither dropping of calls during hand-off events nor high bitrate fluctuations, out of permitted bounds; the MRSVP protocol [1], as extension of RSVP [10], makes it possible by introducing a passive reservations policy, but it requires some additional informations about the mobility behaviour of users, in order to know what coverage areas they will be located below during their active connections. For this reason, users' mobility models are very important in wireless environments, because of their capability to carefully describe how a mobile node moves during an active call. With an accurate analysis of a generic model, interesting statistics (like the Cell Stay Time, the Average Number of Hand-off events or the direction preferences of users) can be obtained and employed for prediction purposes: in a wireless scenario with QoS constraints, for example, the *Cell Stay Time* (*CST*) statistic is often used in order to evaluate the average number of cells that a user will visit while maintaining an active call [2,3]. The *CST* is often a random variable with a particular probability distribution and it gives an idea of the average time spent in a coverage area by a user. In this work the *Smooth Random Mobility Model* (*SRMM)* mobility model is used in order to outline a prediction technique, as a method for QoS guarantees and high system utilisation [4].

In this work, the *Smooth Random Mobility Model* (*SRMM*) proposed in [4] is used for a two-dimensional wireless environment, because it makes the movement of users smoother and more realistic than previous random models. In addition, a prediction technique is outlined, as a method for QoS guarantees and higher system utilisation.

When a mobile host is moving among different coverage cells while requiring a MIP (Mobile Independent Predictive) service [5], passive reservations are necessary in order to hold calls' quality during hand-off events; so, when a MIP service request is admitted to the network, resources are reserved not only on the current cell (that belongs to the actual coverage area of the user), but there is also the need of making passive reservations over future cells that the MIP user will probably visit, until the service termination. It's clear that if no prediction assumptions are made, there is no knowledge about the cells that must provide service guarantees for a MIP request: in the simplest manner, passive reservations may be done over all the system cells, but it leads to an enormous resource wastage, as referred in [5]; in order to increase systems' utilisations, there must be a way to in-advance know the cells that each MIP user will probably visit: with this knowledge, the MRSVP protocol makes reservations of passive bandwidth only on interested cells.

This paper is organised as follows: section II gives an overview on the adaptivity in wireless networks; section III describes the employed SRMM mobility model; in section IV the proposed algorithm is explained and section V shows simulation results; section VI concludes the paper.

II. ADAPTIVE WLAN

The adaptive multimedia networking paradigm can play an important role to mitigate the highly-varying resource availability in wireless/mobile networks. Compared to wired networks, the fluctuation in resource availability in wireless networks is much more severe and results from two inherent features of such networks: fading and mobility [6,7]. In order to offer an adaptive QoS to mobile hosts or a service "better than best-effort", due to the inherent time varying environmental conditions evident in radio communications (e.g. fading), an architecture capable to reserve bandwidth levels and to offer guaranteed services is used. This last one is the Integrated Services Networks with mobile host and Mobile Resource Reservation Protocol (MRSVP) is used for exchanging state information of wireless networks [1,8]. This protocol can offer soft QoS (adaptive QoS) for a class of services called *Mobility Independent Predictive* (MIP) and for services depending from mobility called *Mobility Dependent Predictive* (MDP). MIP and MDP services have two different management in terms of admission control and bandwidth assignments. In this paper MIP services, that use a pre-reservation phase to reserve bandwidth for mobile host in the current cell and in the cells that mobile host probably will visit (passive and active reservations), have been considered. When a MIP user is admitted to the network by a certain admission control algorithm (like the one proposed in [5]), some pre-reservation scheme must be adopted, in order to guarantee the continuity of service to the active connection so, when the MIP user changes its coverage area, it does not observe any fluctuation of the received QoS. Figure 1 shows the passive pre-reservation policy for the uni-dimensional case.

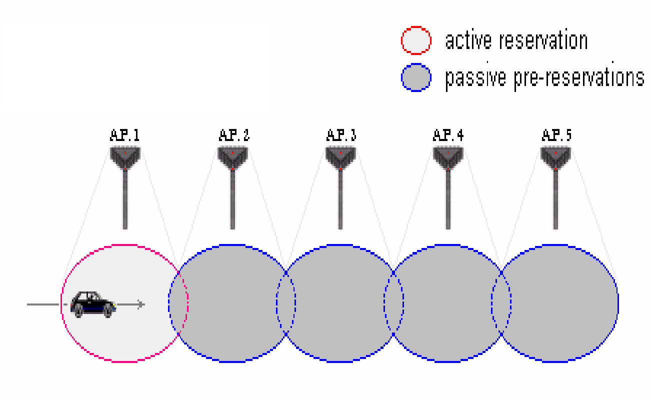

Figure.1 Uni-dimensional pre-reservation example for MIP users

In our work, the mobility has been considered through the behaviour of mobile hosts and the *hand-in* (when a new flow enters in a cell for hand-off or for a new call request) and *hand-out* (when a flow leaves a cell) of calls among the visited cells.

The pre-reservation policy has been applied in a bi-dimensional grid where the mobile node can move. In this case, it is hard to predict the movement and it can be useful to select one or more cells neighbour to the first cell (the cell where the call starts) in advance to make the MIP reservations. In next sections the adopted mobility model and the in advance reservation scheme will be presented.

III. Mobility Model

Mobility models are often needed for radio resources management (like bandwidth assignments) or network dimensioning; there are many works in literature about these models [2,3], but they are based on some simple assumptions about users' behaviour and do not lead to any analytical expression. The choice of the mobility model has a significant effect on the obtained results. If the model is unrealistic, invalid conclusions may be drawn.

In our work, the *Smooth Random Mobility Model* (*SRMM*) proposed in [4] is used for a two-dimensional wireless environment with hexagonal cell coverage, because it makes the movement of users smoother and more realistic than previous random models. It is based on two stochastic processes for direction φ and speed v and their values are correlated to the previous ones, in order to avoid unrealistic patterns (like $dv/dt \to \infty$ or high $d\varphi/dt$ for high speeds). Speed/direction changes occur according to a Poisson process and different typical patterns or environments can be modelled by defining a set of preferred speeds. In particular, a mobile node moves with constant speed, until a new target speed v^* is chosen by the stochastic process, so it accelerates/decelerates in order to reach v^*. A set of preferred speeds $\{v_{pref0}, v_{pref1}, \ldots, v_{prefn}\}$ is defined to obtain a non-uniform speed distribution, between v_{min} and v_{max}.

Then, the p.d.f. of speed values is:

$$p(v)=\begin{cases} p(v=v_{pref\,1})\delta(v-v_{pref\,1}) & v=v_{pref\,1}\\ p(v=v_{pref\,2})\delta(v-v_{pref\,2}) & v=v_{pref\,2}\\ \ldots & \\ p(v=v_{prefn})\delta(v-v_{prefn}) & v=v_{prefn}\\ \dfrac{1-p(v_{pref})}{v_{\max}} & 0<v<v_{\max}\\ 0 & otherwise \end{cases} \qquad (1)$$

with $p(v_{pref})= p(v_{pref0}) + p(v_{pref1}) + \ldots + p(v_{prefn}) < 1$, $v_{pref0}<v_{pref1}<\ldots<v_{prefn}$ and v_{max} is a fixed threshold.

Let t^* denote the time at which a speed change event occurs and a new target speed $v^*=v^*(t^*)$ is chosen. Now, an acceleration $a(t^*)\neq 0$ must be set. It is taken from

$$p(a)=\begin{cases} \dfrac{1}{a_{\max}} & \text{for } 0<a\le a_{\max}\\ 0 & \text{else} \end{cases} \qquad (2)$$

if $v^*(t^*)>v(t^*)$, or from

$$p(a)=\begin{cases} \dfrac{1}{a_{\max}} & \text{for } a_{\min}\le a<0\\ 0 & \text{else} \end{cases} \qquad (3)$$

if $v^*(t^*)<v(t^*)$. A is set to 0 if $v^*(t^*)=v(t^*)$. Then other two variable 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 time the new speed v(t) is changed according to the uniformly accelerated motion as follows:

$$v(t)=v(t-\Delta t)+a(t)\Delta t \qquad (4)$$

until $v(t)$ achieves $v^*(t)$. a_{max} and a_{min} values are fixed to the values specified in table III in the section V.

IV. Reservation Algorithm in WLAN Clusters

When a mobile host is moving among different coverage cells while requiring a MIP (Mobile Independent Predictive) service, passive reservations are necessary in order to hold calls' quality during hand-off events; so, when a MIP service request is admitted to the network, resources are reserved not only on the current cell (that belongs to the actual coverage area of the user), but there is also need of making passive reservations over future cells that the MIP user will probably visit, until its service termination. It's clear that if no prediction assumptions are made, there is no knowledge about the cells that must provide service guarantees for a MIP request: in the simplest manner, passive reservations my be done over all the system cells, but it leads either to an enormous resource wastage or to very low systems utilisation as referred in [5]. This problem can be faced as in [9] but some additions are necessary for a two-dimensional environment: the evaluation of *CST* gives the knowledge of the number of cells that a user will visit, but it does not offer any information about the directional decisions of mobile hosts. That is to say, with the *CST* distribution knowledge, only the number of probably visited cells can be predicted but no studies can be made about what cells in the two-dimensional topology the user will be located below. It is clear that the model proposed in [9] must be extended, by a probability treatment, regarding directional decisions that users make during an active session. The *CST* distribution and the direction probability treatment lead to a higher system utilisation in a two-dimensional environment, by diminishing the amount of passive reservations over future cells.

The considered system consists of a certain number of two-dimensional wireless clusters, with a cell radius r=250m, as illustrated in figure 2. As mentioned above, we used the *SRMM* and mobile hosts follow the *stop-turn-and-go* with *bounce* behaviour as in [4], with two preferred speeds v_{pref0}=0 Km/h, $v_{pref1}=v_{max}$ Km/h; a *Poisson call arrival time distribution* with an *exponentially distributed call holding time* (*CHT*) has been considered and, in order to obtain the predictive evaluation of the number of effective visited cells C_e, that the mobile host will cross during its call, the Cell Stay Time of mobile hosts has been evaluated; simulations results have shown that the *CST* distribution can be well approached by a gaussian distribution, for different values of v_{max} (figure 2). Unfortunately, without directional information about user's mobility pattern, the predicted value of C_e can be only used to make passive reservations in a circular way, around the current cell (where the call has been admitted): following the same approach in [9], only the value of C_e can be *a-priori* obtained, so the number of required passive reservations C_r for MIP services increases with polynomial trend, such as follows

$$C_r=3C_e\cdot(C_e-1)+1 \qquad (4)$$

as shown in figure 3a. So, if the system has no knowledge about the possible directional movements of the generic mobile host, then there will be a lot of resources wastage, due to the enormous amount of passive pre-reserved bandwidth over C_r cells, which increases for longer calls or for higher values of v_{max}, as shown in tables 1 and 2, for fixed values of *CHT* and v_{max} respectively.

TABLE I. Number of effective and necessary cells for CHT=180sec

v_{max} (Km/h)	μ_{CST}	σ_{CST}	C_e	C_r
10	85.6273	16.0935	2-5	7-61
20	72.8041	5.2554	3-4	19-37
30	59.0236	3.23	3-4	19-37
40	49.8957	2.3647	4-5	37-61
50	43.1735	1.7092	4-5	37-61
60	38.2564	1.3625	5-6	61-91

TABLE II. Number of effective and necessary cells for V_{MAX}=50Km/h

CHT (sec.)	C_e	C_r
60	2	7
120	3	19
180	5	61
240	6	91
300	7	127
360	9	217

If additional information about the directional behaviour of users is employed, the above problems can be avoided and the value of C_e can be decreased, making it equal to C_e. Directional information can be obtained as follows: referring to a generic hexagonal cell, as shown in figure 4, a finite set S_{ho} of possible hand-off directions can be defined as $S_{ho}=\{1, 2, 3, 4, 5, 6\}$ (each direction univocally identifies the next adjacent coverage cell). With the CST evaluation model in [9], the value of C_e can be obtained for a generic MIP call c_{MIP}, so the predicted number of hand-off events for c_{MIP} is $n_{ho}=C_e-1$. The probability of hand-out on direction *j* an incoming c_{MIP} from direction *i* for a wireless cell *c* can be defined as $p_{i,j}$, where *i* is the hand-in direction, *j* is the hand-out direction and $i,j \in S_{ho}$. In other words

$$p_{i,j} = p_{CMIP}(i,j)=p(j\in S_{out},\ t=t_0+\mu_{CST} / i \in S_{in},\ t=t_0) \qquad (5)$$

where $S_{out} \subset S_{ho}$ is the set of hand-out events, $S_{in} \subset S_{ho}$ is the set of hand-in events, t_0 is the time instant in which the mobile host enter in a considered cell and μ_{CST} is the average value of the p.d.f. of the *CST*.

For the first hand-off event, the hand-in direction *i* can be considered as the *born-region* of the c_{MIP} call, where *born-regions* are delimited by six equilateral triangles composing the hexagonal cell, as illustrated in figure 4. So, for the first hand-off, the S_{in} set is substituted by the S_{born} one, where $S_{born}=\{r_1, r_2, r_3, r_4, r_5, r_6\}$. In this way, for the first hand-off event, expression (1) is rewritten as follows:

$$p_{ri,j} = p_{CMIP}(r_i,j)=p(j\in S_{out},\ t=t_0+\mu_{CST} / r_i \in S_{born},\ t=t_0) \qquad (6)$$

The obtained *CST* p.d.f. for the SRMM model with two preferred speeds is expressed through a gaussian distribution as referred in eq.3 and shown in Figure 2:

$$f_{X_{CST}}(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (7)$$

where $\mu = \mu_{CST}(v)$ and $\sigma = \sigma_{CST}(v)$ are respectively average and variance of the Gaussian distribution.

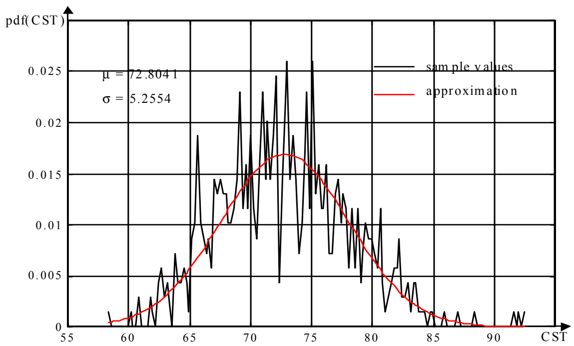

Figure.2 Example of Cell Stay Time probability density function for v_{max}=20Km/h

If m is the number of elements of set S_{ho}, a square (m x m) probability matrix M can be defined, with

$$M(i,j) = p_{C_{MIP}}(i,j) \quad (8)$$

Thus, if a mobile host, belonging to c_{MIP}, is covered by cell c_k after k hand-off events with hand-in direction i, it will hand-out on direction j to a cell c_{k+1} with probability $M(i,j)$, where $k=2..n_{ho}-1$. For k=1 (first-hand-off) direction i is considered as *born-region* r_i. Figure 3b illustrates an example of visited cells sequence. The m^2 elements of the probability matrix M can be obtained by a campaign of simulations, observing the behaviour of mobile hosts, depending on the adopted mobility model (in our case the SRMM).

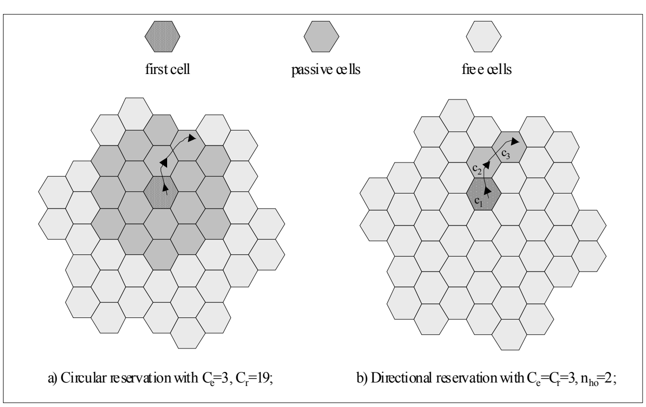

Figure.3 Simulated net topology with two types of pre-reservation policy: a) circular; b) directional.

If the input mobility parameters for φ and v, like the set of preferred speeds, probability of a direction change or acceleration/deceleration values, lead to similar values of $p(i,j)$ for a fixed hand-in direction i, there are no preferred hand-out directions when a mobile host comes from the hand-in direction i, so pre-reserving over only one future cell can lead to high error in predicting next visited cells, as illustrated in next section. This problem can be solved by making next reservations not only over one next cell, but pre-reserving over multiple hand-out directions.

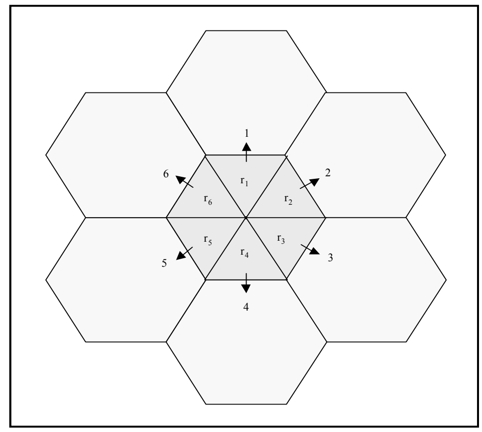

Figure.4 Hand-off directions and born-regions for a hexagonal wireless cell.

V. SIMULATIONS RESULTS

Each cluster of WLAN cells has been associated to seven WLAN coverage areas with a transmission range of 250 meters. In order to evaluate CST distribution and the directional probabilities of the matrix M proposed in the previous section, many simulation campaigns have been carried out, with the following mobility model parameters (for details about the SRMM to see [4]):

TABLE III. MOBILITY PARAMETERS

v_{pref0} (m/s)	$v_{pref1}=v_{prefmax}$ (m/s)	a_{min} (m/s^2)	a_{max} (m/s^2)	μ_v	$p\phi$*	p_{v1}	p_{v2}
0	13.9	-4	2.5	5	0.2	0.4	0.4

The obtained M matrix is:

$$M = \begin{pmatrix} 1,22 & 44.3 & 42.36 & 1.07 & 4.75 & 4.28 \\ 0.75 & 46.73 & 42.65 & 0.76 & 4.79 & 4.30 \\ 0.72 & 42.75 & 46.44 & 0.78 & 4.37 & 4.93 \\ 0.99 & 41.50 & 46.89 & 1.18 & 4.53 & 4.90 \\ 1.21 & 42.38 & 43.39 & 3.52 & 4.62 & 4.87 \\ 3.57 & 43.30 & 42.46 & 1.22 & 4.73 & 4.71 \end{pmatrix}$$

where each term of matrix is multiplied for 10^{-2}. The obtained CST probability density function can be well described by a gaussian distribution (like the one depicted in figure 2).

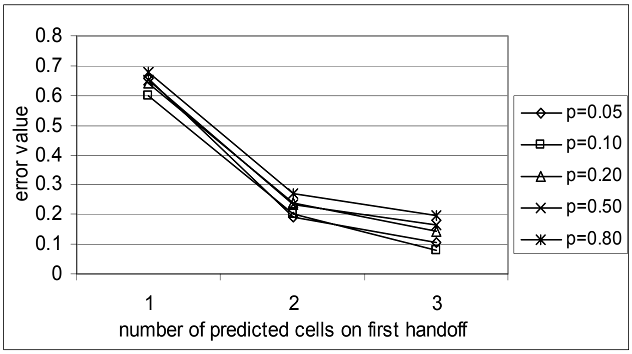

Figure.5 Prediction error on first hand-off event.

Figure 5 illustrates the percentage of MIP flows that do not receive QoS guarantees on the first hand-off event: due to the similar values of *p(i,j)* obtained for matrix *M*, multiple pre-reservations are necessary, in order to reduce the number of MIP flows that do not find any pre-reserved bandwidth after the first hand-off. If the number of interested cells is higher than one (like 2 or 3), the error on predicting future cells reduces drastically, from 60% to a value lower than 10%. Infact, when the mobile MIP host leaves its first cell, it moves along one of the preferred hand-off direction. Thus, there is a high probability to obtain service guarantees if there are pre-reservations on an higher number of coverage cells. So increasing the number of neighbor predicted cells reduces the error prediction but it increases the bandwidth wastage. Our future works will be addressed to define a trade-off between higher bandwidth utilization and lower prediction error.

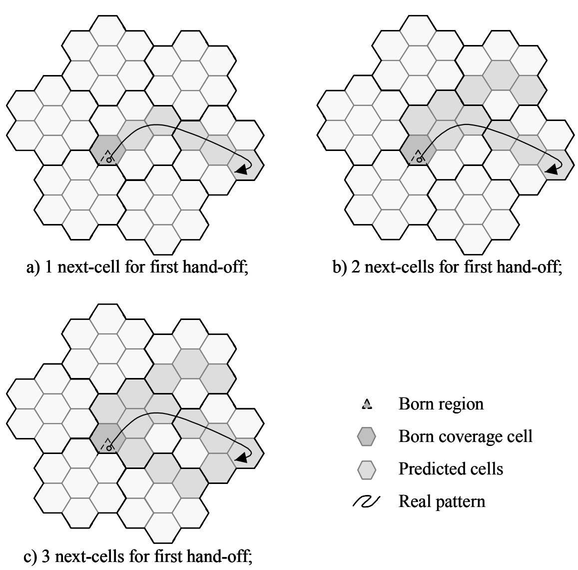

Figure.6 Different mobility pattern and resource reservation for different number of first predicted cells.

VI. CONCLUSIONS

In this work a novel approach for making passive reservations in a wireless LAN environment has been proposed. The argumentation of [2] introducing either a two-dimensional topology and a directional predictive method is proposed in order to reduce the amount of unused bandwidth, necessary to offer certain guarantees to MIP services. It has been shown that the number of cells affected by pre-reservations can be drastically reduced with the introduction of a probability matrix.

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