A 2D MOVEMENT DIRECTION-BASED RESERVATION SCHEME FOR WLAN CLUSTERS WITH PASSIVE ADVANCED RESERVATIONS

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ABSTRACT

QoS guarantee is a very important issue in wireless communications, when mobile nodes move among different coverage areas. This paper presents a novel 2D reservation scheme for WLAN environments. A general 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. A threshold-based algorithm is presented, trying to take into account the mobility behavior of mobile users, through the analysis of a directional probabilities matrix. Many simulations have been carried out and a performance analysis has been performed, finding a good trade-off between bandwidth utilization and prediction error.

Index Terms— MRSVP, WLAN, MIP, Smooth Random Mobility Model, Predictive Reservation

1. INTRODUCTION

This work is based on a wirelessLAN 802.11 scenario, where MIP users [1], [5], [8] make service requests to the access points, requiring some 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) [1], [5], having some information about users mobility behaviour [2], [3], [8]. The mobility model has a heavy impact on the obtained results and they can be unrealistic if the model is not appropriate. We employed the Smooth Random Mobility Model (SRMM) proposed in [4] for a two-dimensional set of cell clusters. The proposed technique is of general application and does not depend on the specific mobility model; it is based on the knowledge of two important statistics: the CST distribution and the Hand-off Directions Probabilities values (HDP); so, based on the work [8], in addition to the CST statistic, HDP values are necessary in order to consider future positions of mobile hosts: combining CST and HDP information, a prediction technique is proposed for a two-dimensional environment. It is shown that the obtained results with the proposed algorithm are better than those of the previously proposed reservation schemes, based on a static reservation policy such as presented in [13]. This paper is organized as follows: the threshold-based algorithm is presented in section II; simulation results and conclusions are respectively summarized in sections III and IV.

2. CELL STAY TIME AND DIRECTION AWARE THRESHOLD-BASED ALGORTHM

The mobility analysis of mobile hosts is the main aim of our work. First of all, many simulations have to be carried out in order to obtain some information about users' behavior; under a chosen mobility model (the SRMM in our case) and a certain cell coverage topology, the average Cell Stay Time (CST) can be observed, as in previous works [12], [13] under the hypothesis of a Call Holding Time (CHT) exponentially distributed. 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, as verified by the Kolmogorov-Smirnov (KS) normality test [9]. As mentioned above, we used the SRMM and mobile hosts follow the stop-turn-and-go behavior with thoroidal topology, with the same parameters of urban-environment as in [4]. 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 [12]. As exposed in [13], without information about directional movements of mobile hosts, only a circular reservation over C_r is possible, with a lot of passive bandwidth over predicted cells. This work introduces a novel algorithm, based on some additional information about users' directional behavior and the value of C_r can be decreased, making it nearer to C_e.

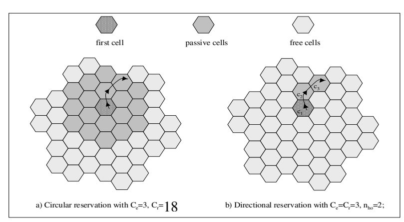

Figure 1. An example of circular directional reservation.

Figure 1 depicts the difference between a circular reservation policy and a directional one (with a number of predicted hand-off n_{ho}=2). A generic 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). A set S_{ho} of *n* possible movement directions can be then obtained: let us indicate them with $d_1 \ldots d_n$, where $d_j=\underline{\theta}\cdot(2\cdot j-1)/2$ *rad.*, $\underline{\theta}=2\pi/n$ *rad.* and $j=1..n$, so $S_{ho}=\{d_1, ..., d_n\}$ and $|S_{ho}|=n$. Once *n* has been chosen, a square *nxn* mobility probabilities matrix *M* can be defined with the following elements:

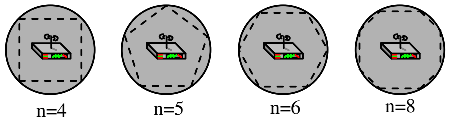

Figure 2. Possible area approximation with regular polygons.

$$M(x,y)=p(out\ to\ y\in S_{ho}\ t=t_0+CST/in\ from\ x\in S_{ho}\ t=t_0), \quad (1)$$

that is to say $M(x,y)$ indicates the probability of generic user i, for a fixed mobility model, of handing out to direction $y\in S_{ho}$ after *CST* amount of time after having handed-in the current cell from direction $x\in S_{ho}$. The matrix M can be filled out through a first addicted campaign of simulations. 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 $h_i=C_{ei}-1$ can be obtained such as shown in [12]. Let vh_i be an information support-array, where $vh_i[k]$ with $k=1..h_i$ indicates the information 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.

2.1 Evaluation of *first hand-off* direction and cell id.

Since no hand-in direction is available when a flow is admitted in a cell, matrix M cannot be used for predicting the next cell for 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 [10], [11] and, hypothesizing 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. 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 handing-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.

2.2 Evaluation of next directions and cells ids.

Let us hypothesize 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 $k=1..h_i-1$; the following pseudo-code resumes the adopted policy when predicting cells for user ***i***, hypothesizing that the first hand-off cell is already known:

```
//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 us 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 after the
  //(k-1)-th hand-off
  p_curr=current_tuple.p_cell_id;
  //find the "more suitable" hand-out candidate cells over
  //the possible n hand-out directions
  for (int p=1; p ≤ n; p++) {
   //the probability of hand-out on direction p after having
   //handed in on direction curr_hand_in_dir 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, so the k index scans vh_i until the h_i-*th* position; a prediction must be made for each cell of the $vh_i[k]$ list; 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 $vh_i\,[k]$, $l=1…vh_i[k].size()$ 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 $\delta^{f(k)}$, 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 $vh_i\,[k+1]$. The exponent $f(k)$ is a function of k; in this work it is assumed that $f(k)=k$ but other kind of functions can be considered in the future; the power operation is necessary in order to take into account the increase of prediction error for higher values of k: since $0<\delta<1$, the comparison threshold $\Delta=\delta^k$ goes decreasing for higher values of k and a higher number of cells can be selected. 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. The prediction result is the set of cell identifiers of the tuples for each vh_i list. A different approach has been followed in [13]: the static scheme does not account for *M* structure and a prediction sequence *i*-*j*-*k* for the first three hand-off events must be specified as an input parameter, specifying the prediction of *i* cells for the first hand-off, *j* and *k* for the second and third ones. For details see [13]. The hypothesis of *M* composed by constant values is not suitable: after many simulations and tests (following the theory in [9]), we can conclude that the elements *M(x,y)* can be well approached with a Gaussian approximation, so in the proposed pseudo-code $M(x,y)=N(\mu_{x,y},\sigma_{x,y})$ as depicted in figure 3. From these values of directional distributions, it can be seen that the average number of next predicted cells decreases for higher δ as illustrated in table I.

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 [4], with *n*=6.

TABLE I
AVERAGE NUMBER OF PREDICTED CELLS FOR DIFFERENT THRESHOLD VALUES

δ values	0.6	0.5	0.2	0.1	0.05
pred. cells	1	1.76	1.76	5.18	5.18

3. PERFORMANCE EVALUATION

Our network consists of 7 clusters of cells and users moves thoroidally, according to the SRMM, with the same mobility parameters of [4]. An exponentially distributed CHT with mean λ=180s has been considered. Simulation results are compared with those of the static-scheme of [13] and some enhancements are shown. Figure 4 illustrates the average system utilization if MIP and MDP [12] flows can be admitted; the threshold δ is fixed to 0.01: if only MDP traffic is allowed (so MIP-MDP percentages are set to 0 and 100 respectively) there is an increasing trend for higher Erlang (requests/s) values from 75.6% to 95.4%, because of the higher active assigned bandwidth; the utilization goes diminishing for increasing percentages of MIP flows, because of the higher presence of passive and unused bandwidth, but the trend is always increasing for the same previous reason; perhaps, as it can be seen, if only MIP traffic is admitted into the system, the utilization drastically goes down and it is slightly decreasing for higher Erlang values, because of the higher presence of unused passive bandwidth (from a minimum level of 10.34% of 25 Erlang to a maximum level of 13.11% of 5 Erlang). For the other values of δ (we simulated from 0.01 to 0.6) the "only-MDP" scenario is not affected, because there are no passive reservations to do, while for intermediate percentages (040-060 and 060-040) the utilization does not decrease in a sensible way; if "only-MIP" traffic is allowed in the system, the utilization falls down to 5-6% for δ=0.6. An increase of the threshold value means, as we see later, a higher number of predicted cells, so a higher presence of passive pre-reservations. The comparison with the static policy of [13] with "only-MIP" traffic is also shown; dashed lines represent the maximum and minimum values under the static policy, obtained for 25 Erlang and *i*=1 or *i*=3 respectively: the static policy performs better in terms of utilization for *i*=1, but this value is not suitable because, as shown in figure 5, it leads to a heavy amount of prediction error (over 50%) beginning from the second hand-off. For other *i* values (e.g. *i*=3) the utilization falls down, under the minimum obtained with the proposed scheme.

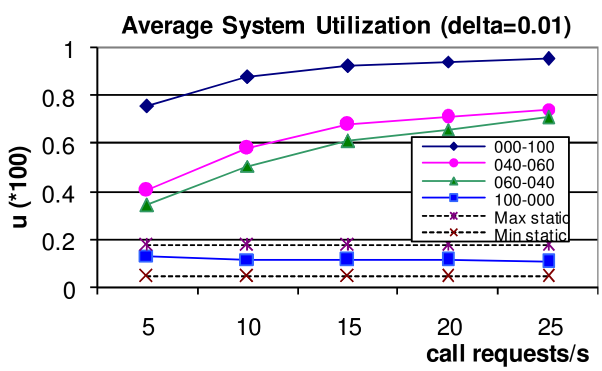

Figure 4. Average system utilization for different erlang values.

In figure 5 another comparison between the static scheme of [13] and the threshold-based one is made, in terms of the average number of predicted cells for different hand-off events. Dashed lines refer to the static scheme for different i-j-k values as in [13], while continuous ones refer to the threshold-based scheme for different δ values; the arrow indicates decreasing values of δ. The average number of per-flow predicted cells does not depend on the Erlang value and the different continuous curves refer to δ=0.60 δ=0.20 and

δ=0.05; for the static scheme the curves for 1-1-1, 1-2-3 and 3-3-3 sequences are illustrated. It is shown that introducing the threshold, a gain in terms of predicted cells is obtained, with some improvements in system utilization, as early described if "only-MIP" traffic is employed: the difference between the two policies is more evident for lower δ values and higher hand-off number.

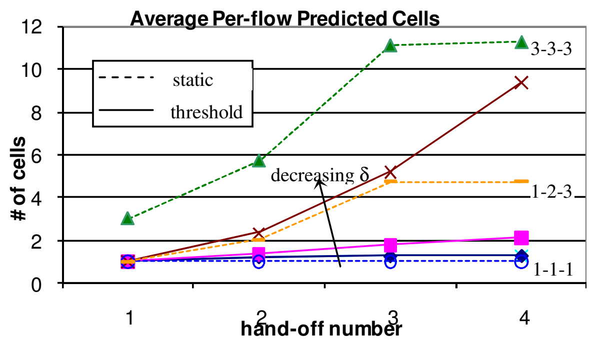

Figure 5. Average number of per-flow predicted cells for different i-j--k and δ values.

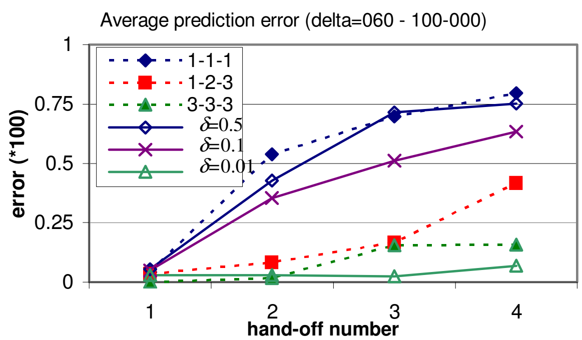

Figure 6. Average prediction error for different hand-off events with static and threshold-based schemes.

Figure 6 depicts the committed error on predicting future cells only for MIP users: for the *n*-th hand-off event, it is calculated as the ratio between the number of MIP users that handed-in a cell during the *n*-th hand-off event without finding an available bandwidth pre-reservation and the number of total MIP users that made the *n*-th hand-off. The best results are evident for δ =0.01, because the error is maintained below 8% for all hand-off events. For other combinations of *i-j-k* values there is always a δ value that offers better performances. This suggests that the choice of low δ values (like 0.01 or 0.05) offers a good trade-off between error and system utilization.

I. CONCLUSIONS

A novel threshold-based prediction algorithm has been proposed, in order to manage the QoS in a 2D wireless environment. It faces the problem of pre-reserving 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 information 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. Many simulations have been carried out in order to make a comparison with previous schemes. Simulations results have revealed that the threshold-based scheme performs better than the previous ones, because it reduces the average number of predicted cells, while leading the error to slightly lower levels; in addition it dynamically decides how many cells must be involved in the pre-reservation phase.

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