Pattern Prediction in Infrastructured Wireless Networks: Directional vs Temporal Statistical Approach

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***Abstract*—The main desire of end-users of a telecommunication system is to take advantage of satisfactory services, in terms of Quality of Service (QoS), especially when they pay for a required needing. Unfortunately, when hosts are moving into an infrastructured network, it is very important to mitigate hand-over effects, which may cause heavy flow degradations or disruptions. In this paper, we are interested in investigating how the continuity of services can be guaranteed in QoS networks, by the analysis of users mobility from two different points of view: the first based on a directional modeling of users mobility, the second based on a time-based modeling of Cell Permanence Time (CPT). After a hand-over event, bandwidth availability should always be granted for those users who need to take benefits from QoS networks: the only way to face this issue is represented by the employment of a mobility prediction scheme, in order to know "how and when" users move among infrastructured coverage areas. Based on a large number of experiments, the proposed schemes are then compared, in order to observe what are the benefits of the considered policies and when it is preferred to use each of them.**

Keywords- Mobility, Prediction, Passive, Reservations, Directional, Cell Permanence Time, QoS, CBP, CDP, Wireless, Networks, Vehicular, Cellular.

I. INTRODUCTION

In the last decade, mobile computing has been extensively studied in both the computer and communication communities. However, most of the recent studies focus on the network layer communication protocols (as Socievole et Al. show in [1], [2]) and few of them on the mobility aspects caused by mobile hosts behavior. The concept of mobility management has been used in cellular mobile networks for many years, but it was primarily designed to support mobile voice communication. We argue that to maintain uninterrupted high-quality service for distributed applications in a mobile environment, data routing should not only passively reflect the change of terminal location, but also aggressively anticipate the behavior of mobile users. In addition, mobility prediction is also important when passive reservations need to be made. In [3], an aggressive mobility management scheme is proposed by Liu and Maguire: a set of Mobile Motion Prediction (MMP) algorithms is used to predict the "future" location of a mobile user according to user's movement history patterns. The data or services are pre-connected and pre-assigned at the new location before a user moves into the new location. Authors analyze the goodness of the proposed scheme in terms of prediction accuracy rate versus mobility randomness factor: obviously the prediction is more accurate when the mobility randomness is lower. In [4] a Mobility-Dependent Predictive Resource Reservation (MDPRR) scheme is proposed by Lu et Al. to provide flexible usage of limited resource in mobile multimedia wireless networks. The coverage area of a cell is divided into non-hand-off, pre-hand-off and hand-off zones, so that bandwidth is reserved in the target/sub-target cell as mobile stations move into the pre-handoff zone and leave the serving base station. An admission control scheme is also considered to further guarantee the QoS of real-time traffic as, for example, Voice over IP, as proposed by Tomala [5] and Rozhon [6]. The guard channel scheme is generally referred as the Fixed Bandwidth Reservation (FBR) scheme (Epstein and Schwartz [7]), which can improve the dropping probability of handoff connections by reserving a fixed number of channels exclusively for handoff connections. The drawback of this scheme is that the reserved bandwidth is often wasted in the hot spot area. Through estimation of mobile users' trajectory and arrival/departure times in Aljadhai [8], a group of future cells is determined: it constitutes the most likely cluster into which a terminal will move. In this paper, based on our previous works [9], [10], [11] (by Fazio et Al.), in which interesting results about Cell Permanence Time (CPT) distribution were obtained, we are now interested in investigating how the continuity of services can be guaranteed in QoS networks, in particular by the analysis of users mobility from two different points of view: directional (considering the way users change their coverage areas, basing our considerations on a directional modeling of users mobility) and time-based (considering the amount of time users stay into coverage cells). We considered vehicle mobility, but the proposed idea is suitable for every possible mobility scenario (pedestrian, trains, etc.). For the directional approach, the prediction of the more suitable set of "future possibly visited" cells is proposed: the most of the previous illustrated schemes (as well as other works in literature) makes only a dynamic one step prediction, so passive reservations can be made step by step, during host movements; these schemes reduce the overhead of the system, but do not ensure a "dropping-free" system, because when the next cell is determined, there are no guarantees about the bandwidth availability in that cell. For the time-based approach, users mobility is analyzed in terms of speed and CPT, proposing a passive reservation scheme based on a circular approach, minimizing the Call Dropping Probability, despite of system utilization and over-head. Based on a large number of experiments, the proposed schemes are then compared (in terms of system utilization, prediction errors, Call Dropping and Call Blocking probabilities), in order to observe what are the benefits of the considered policies and when it is convenient to use each of them. It must be underlined that the proposed ideas are independent on the considered technology, mobility model or vehicular environment.

II. Considered Protocol, Issues and Contributions

As portable computers become more powerful and the accessibility of a fixed network from a mobile host becomes easier, the number of mobile users increases and, additionally, mobile users will demand the same real-time services available to fixed hosts. Applications such as Internet cellular phone, access to real-time data through the Web (e.g., call center application), require that the network offers a certain level of QoS to moving users. Host mobility has a significant impact on QoS parameters, which must be negotiated at the beginning of sessions, between flows and net, by the RSVP protocol [12] (Baker et Al.) or by the MRSVP or DRSVP protocols in mobile scenarios [13], [14] (Talukdar et Al.). In addition, another signaling protocol, i.e., Next Step In Signaling (NSIS), was proposed in the literature. In 2001, the Internet Engineering Task Force created the NSIS Working Group to solve new signaling needs [15] (Fu et Al.). When a mobile host moves from a location to another one with an active flow, the data flow path changes. If the new location into which the mobile host moves is overcrowded, the available bandwidth in the new location may not be sufficient to provide the throughput it was receiving at the previous location. In addition, the mobile user may suffer temporary disruption of service during hand-off while the connection is teared down along the old path, and it is established along the new path. In some extreme cases, some connections to mobile users may have to be dropped if the minimum QoS requirements of all users cannot be satisfied. To obtain a quality of service which is not affected by mobility, it is necessary to make in-advance resource reservation on future locations where a mobile host may arrive during an active session. In this paper, we consider a network architecture like the one depicted in Fig. 1, in which a mobile host can make in-advance resource reservations along the data flow paths to and from the locations that it may visit during connection lifetime. In the network of Fig. 1, link (N_1, N_2) has a capacity 2B and all other links have a capacity B each. Locations C_1, C_2 and C_3 are in the mobility specification of Mobile Host MH_1 and locations C_4 and C_5 are in the mobility specification of mobile host MH_3. In a flow, MH_1 is the receiver and MH_3 is the sender. MH_1 requires a bandwidth B; for MH_1 an active reservation is setup to C_3 and passive reservations are setup to C_1 and C_2.

The considered model supports two types of reservations: active (in the coverage areas where hosts make service requests) and passive (in the coverage areas which will be visited in the future). In the considered reservation model, a mobile host can make in-advance reservations on a set of coverage locations, called Mobility Specification (MSPEC). Ideally, the MSPEC should be the set of locations the mobile host will visit with an active flow. The in-advance determination of the set of locations to be visited by a mobile host is an important research problem (in next sections the prediction scheme is illustrated).

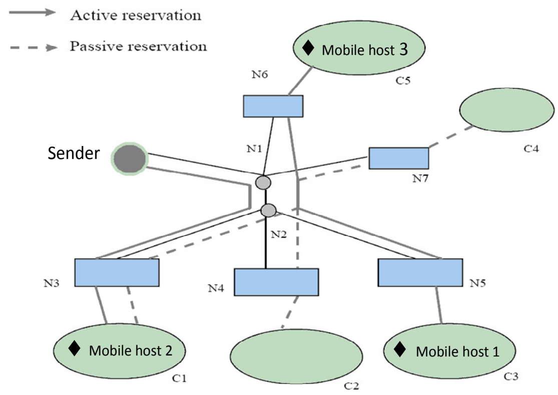

Fig. 1: An example of mobile scenario.

For MH_3, an active reservation is setup from C_5 and a passive reservation is setup from C_4. In another flow, Mobile host MH_2 requires a weaker QoS guarantee and successfully makes an active reservation from the fixed sender S_1 to C_1 for a bandwidth B. Among the different available protocols, we considered the MRSVP [13], so the handoff events can be managed in an adequate manner, and the mobile users can make reservation requests over more than one cell by their proxy agents, e.g., local proxy agents (which handle active reservations) and remote proxy agents (which deal with passive reservations). An MRSVP connection starts with a proxy discovery protocol phase in which the user can know the addresses of its remote agents. Then, a resource request can be made, which will reach the net sender, to begin data packet transmission. After the proxy addresses are discovered, users send active_RESV messages to their local access points and passive_RESV messages to their remote access points, so the system must effect an admission control (as explained in next sections) to accept or refuse the users' requests. When a user moves from a coverage area to another one, the handoff event is managed by a reservation switch and the reserved resources in the old access point are released. The main contributions of this paper are:

- Proposal of a new passive reservation algorithm based on directional mobility analysis, in order to know the MSPEC for each user aimed at increasing system utilization;
- Proposal of a circular passive reservation policy based on time statistical analysis, in order to evaluate the possibility of minimizing the Call Blocking Probability (CBP);
- Performance comparison for both schemes in order to evaluate when is suitable to use them.

III. Proposed Algorithms

In this section the details about the proposed schemes are given. First the directional approach is proposed, then the time-based one is introduced.

A. Directional Mobility Prediction (DMP)

As shown in [9] and [10] a generic coverage area can be described by a regular polygon, for which a finite set *HO* of hand-over directions can be defined; if the polygon has *n* edges, then $||HO||=n$. Choosing $n=6$ (hexagonal approximation), the finite set *HO* will be $\{d_1, d_2, d_3, d_4, d_5, d_6\}$ (in this case, each direction univocally identifies the next adjacent coverage cell). As in [9], [10] CPT can be evaluated, so the conditional probability that a mobile host will be handed-out to direction d_j after CPT amount of time, if it was handed into current wireless cell from direction d_i can be defined as $p_{i,j}$:

$$p_{i,j}=p(\text{out to } d_j \text{ at } t=t_0+CPT\,/\,\text{in from } d_i \text{ at } t=t_0) \qquad (1)$$

where t_0 is the time instant at which the mobile host enters in the considered cell. Once *n* has been chosen, a square *n x n* Mobility Matrix (MM) can be defined with the elements $M(i,j)=p_{i,j}$. It is composed by the hand-in directions on the rows and the hand-out ones on the columns. Once the coverage map has been chosen (i.e. the coordinates of each cell), the values of MM can be obtained by observing how Mobile Hosts (MHs) move into the considered coverage region. In particular, given a certain cell c_k, $MM_k(i,j)$ can be evaluated as follows:

$$MM_k(i,j)=\frac{TR_k(i,j)}{TR_k(i)} \qquad (2)$$

where $TR_k(i,j)$ represents, for cell c_k, the number of total hand-over events from direction d_i to direction d_j and $TR_k(i)$ is the number of total handover events from direction d_i to any other one. In our work we considered a mobility generation carried out by C4R simulator [16] implemented by Fogue et Al., able to consider real roads deployment on a geographical area. Generally, the $MM_k(i,j)$ elements are statistically distributed, so they have to be represented in the right way (in (2) we consider the average values). A MM_k is associated to each cell and it depends only on the adopted mobility model, network cells subdivision and it is the same for all users in the system. Detailed information and specific values about MM_k will be given in the performance evaluation section. Once MM_k has been obtained, it can be used to make predictions on user movements; if, for cell ck, the hand-in direction d_i of a user is known, then the hand-out direction d_j can be chosen by:

$$d_j = index\{\max_j[MM_k(d_i,d_j)]\} \qquad (3)$$

In this way, the most probable hand-out direction is chosen, given that the MH handed-in c_k on direction d_i (in (3) it is assumed that d_i and d_j can be used as indexes to choose a matrix element).

B. Time-based Mobility Prediction (TMP)

CPT is an important parameter in wireless networks because it permits the evaluation of how long a user will stay in a cell during its Call Holding Time (CHT) and how many cells he will visit. This can be useful in resource reservations, for an environment where node mobility is supported. In this work a further contribution is given to CPT evaluation, through a statistical treatment in order to know how CPT is distributed. With the availability of thousands of CPT samples, the distribution can be well observed and, after a results analysis, a CPT distribution has been obtained, like the one depicted in Fig. 2, with a Gaussian approximation for a coverage radius r=250 meters.

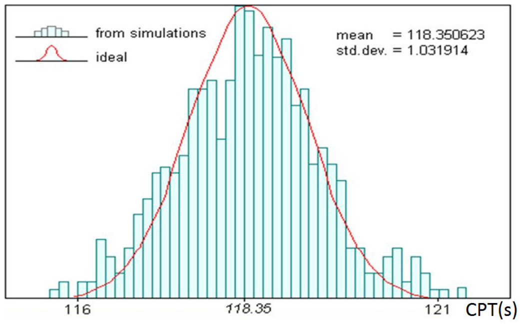

Fig. 2: Cell Permanence Time pdf approximation (r=250m).

So the general expression of the CPT probability density function can be written as:

$$f_{X_{CPT}}(x)=\frac{1}{\sqrt{2\pi}\sigma_{CPT}}e^{-\frac{(x-\mu_{CPT})^2}{2\sigma_{CPT}^2}}, \qquad (4)$$

where μ_{CPT} and σ_{CPT} are the average and standard deviation of the Gaussian distribution respectively. If the average CHT avg_{CHT} is known, it is possible to consider the term N_c (number of cells) as:

$$N_C=\left\lceil \frac{avg_{CHT}}{\mu_{CPT}} \right\rceil \qquad (5)$$

representing the number of cells that a generic MH will visit during its lifetime. In this way, given the starting cell (where MH is trying to make an active reservation), it is possible to make a Passive Reservation over $P_R=N_C-1$ cells, following a circular policy like the one in Fig. 3.

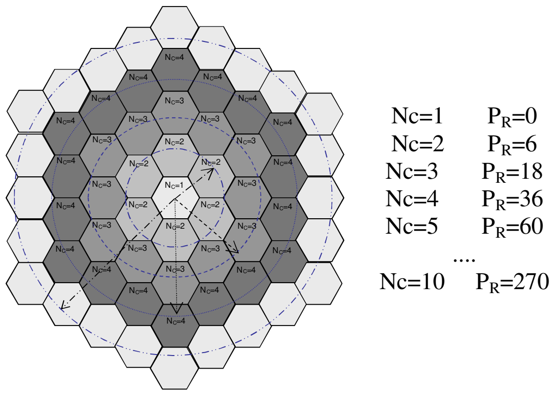

Fig. 3: Circular reservation policy for different numbers of predicted cells.

Since no information about directional behavior is available, when N_c=2, for example, there will be only one hand-over event, so the user will move from the active cell into one of the adjacent cells (six in this case); the MRSVP will send a passive_RESV to all six adjacent cells (P_R=6). The relation between N_c and P_R is:

$$P_R = 3 \cdot N_c \cdot (N_c - 1) \qquad (6)$$

The assumption of the normally distributed CPT, with different means and standard deviations depending on the fixed mobility and system parameters, has been verified through the Kolmogorov-Smirnov (KS) normality test, as shown in Montgomery [17]; different p-values (a p-value for a comparison test represents the likelihood, under the assumption that the null hypothesis is true, that the data would yield the obtained results) have been obtained, showing that there is a negligible error if a Gaussian approximation is employed for the CPT distribution. As introduced in section 3.1, the $MM_k(i,j)$ elements are statistically distributed and the KS normality test [17] has been also made for them, with different combinations of mobility parameters: the Gaussian distribution hypothesis can be made. In the next section, simulation results are illustrated, considering a mobile urban scenario. We applied DMP and TMP schemes separately, then we compared them in terms of different performance parameters.

IV. Performance Evaluation

As simulation scenario, we considered a geographical region of 1000 x 1000 m^2 of different cities and we illustrate the obtained results for the city of Rome, with a coverage radius of 250m for each cell (as depicted in Fig. 4). The geographical area is fully covered by 35 cells.

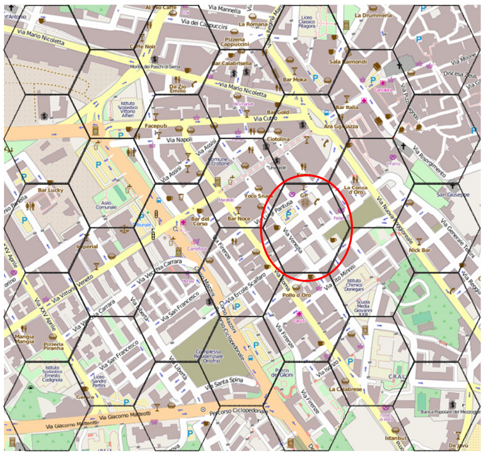

Fig. 4: The considered urban scenario (city of Rome - Italy).

Mobility has been generated with C4R [16], according to Wagner rules [18]. An example of the obtained mobility matrix for cell 18 (indicated with a circle in Fig. 4) MM_{18} is illustrated in Fig. 5. Each row contains the mean value and the standard deviation. For the CPT, Fig. 6 shows the obtained values for cell 18: it is clear how a Gaussian approximation is suitable, according to section 3.2. In Fig. 7 it is possible to observe the trend of the average network utilization, in the range [0, 1], for different percentages of Non-Tolerant Traffic (NTT): NTT represents the % of traffic which is asking the system for QoS; 0 means that no QoS connections are requested to the system, while 1 means that all the MHs make QoS requests. Utilization for each cell is evaluated as the ratio between the active portion of bandwidth and the total capacity. It is shown that the trend is decreasing for high NTT percentages, because the system, in both TMP and DMP cases, receives more QoS requests (more passive reservations are made). The effects on system utilization for the considered approaches are evident also in Fig. 8, in which the average number of P_R per MH is depicted (according to (6)). TMP requires an enormous amount of passive reservation in order to ensure the proper level of QoS. Fig. 9 shows the average prediction error for both TMP and DMP schemes. It is evaluated as the percentage of NTT hosts which do not find a passive reservation after a hand-over event.

$$MM_{18} = \begin{vmatrix} 0.271072 & 0.149047 & 0.155588 & 0.119348 & 0.154518 & 0.150427 \\ 0.029653 & 0.02497 & 0.025759 & 0.022814 & 0.025041 & 0.024207 \\ \\ 0.19932 & 0.237766 & 0.208252 & 0.124466 & 0.122317 & 0.10788 \\ 0.024955 & 0.024024 & 0.023964 & 0.020378 & 0.019933 & 0.018556 \\ \\ 0.124915 & 0.206507 & 0.238845 & 0.198155 & 0.109082 & 0.122496 \\ 0.019344 & 0.024139 & 0.02836 & 0.02494 & 0.019902 & 0.022357 \\ \\ 0.121575 & 0.153779 & 0.151786 & 0.26855 & 0.150536 & 0.153774 \\ 0.022873 & 0.025686 & 0.023252 & 0.030941 & 0.025564 & 0.025546 \\ \\ 0.124522 & 0.1254 & 0.108004 & 0.195957 & 0.240405 & 0.205712 \\ 0.020919 & 0.02049 & 0.020234 & 0.024791 & 0.025924 & 0.025183 \\ \\ 0.198397 & 0.108277 & 0.123875 & 0.123982 & 0.205851 & 0.239619 \\ 0.024348 & 0.020101 & 0.021004 & 0.020568 & 0.025094 & 0.027464 \end{vmatrix}$$

Fig. 5: An example of the obtained directional matrix.

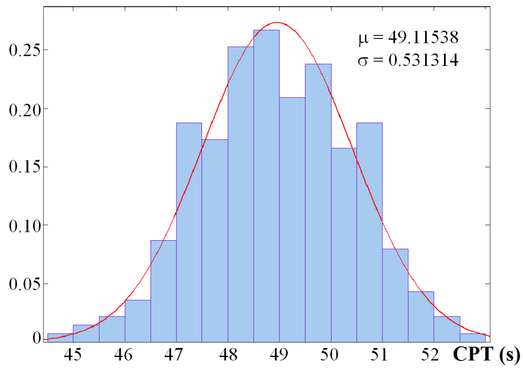

Fig. 6: CPT pdf for cell 18.

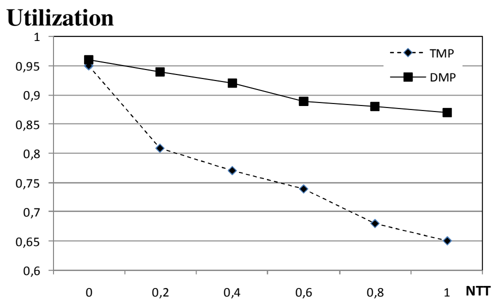

Fig. 7: Average network utilization.

The error for the TMP is negligible, because the reservations are made on all the possible cells into the system, based on the value of N_c; the value is not zero (but negligible, because under 4%) because, sometimes, the number of N_c (evaluated as in (5)) is lower than the real number of visited cells, so a MH may enter a new cell, without having a passive reservation. Fig. 10 and Fig. 11 shows the average trend of CBP and CDP respectively; in terms of CBP, TMP presents a worse behavior, because more passive requests are made into the system and there is a higher probability that a cell rejects a passive service request, due to the lack of available resources. In terms of CDP, negligible droppings are obtained with TMP, while a higher probability (near to 13,5%) is obtained for the DMP case, due to the absence of a high number of passive reservations.

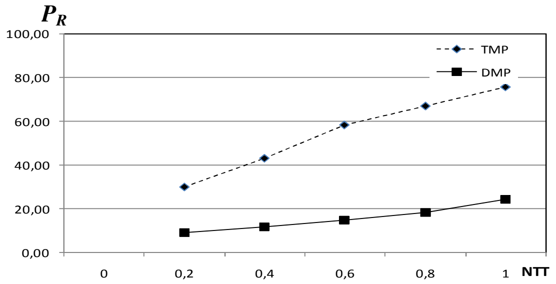

Fig. 8: Average number of predicted cells for each MH.

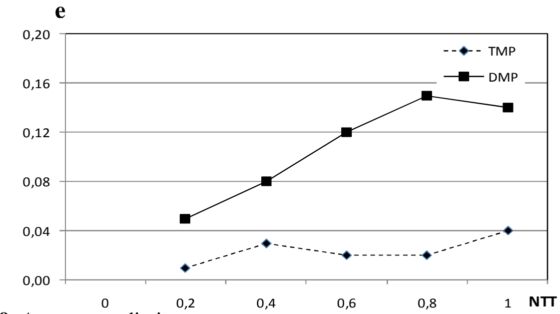

Fig. 9: Average prediction error.

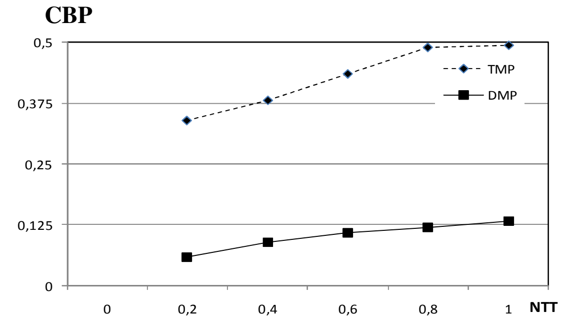

Fig. 10: Average Call Blocking Probability.

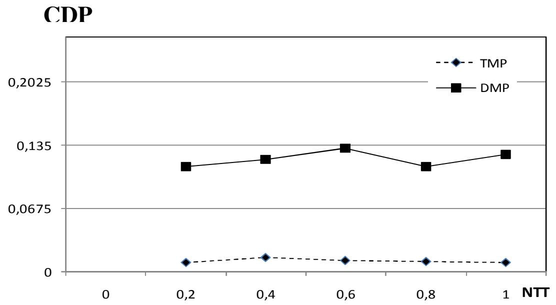

Fig. 11: Average Call Dropping Probability.

V. CONCLUSION

In this paper, two reservation schemes are proposed for the passive resource management in a cellular environment. The proposed idea is independent on the considered technology or mobility scenario. Two algorithms are proposed, one based on directional behavior of mobile users, and another based on cell permanence time analysis. The obtained results have shown that a direction-based approach leads the system to a higher utilization, with a higher prediction error and dropping probability; a time-based approach leads the system to a lower utilization, with a high number of involved cells and a lower level of prediction error.

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