Mobility Prediction in Wireless Cellular Networks for the Optimization of Call Admission Control Schemes

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Abstract— **In last years there have been a growing interest for cellular networking, due to the availability of different mobile applications and the explosion of mobile devices utilization. If managed in an adequate way, cellular systems with mobile hosts can offer excellent performance and satisfactory QoS levels. In order to avoid service degradations, it is very important to decide whether a new connection can be accepted into the system, with the main aim of maximizing bandwidth utilization while avoiding quality degradations, with more emphasis for non-tolerant applications. Our proposed idea shows how a statistical approach can enhance system performance, without considering a particular prediction scheme (based on Markov theory, neural networks, data mining, Holt-Winters or similars): the proposal has been integrated with a threshold-based statistical bandwidth multiplexing scheme in order to propose the In-Advance Multiplexing Call Admission Control (IAM-CAC) scheme for cellular networks. Simulation campaigns have shown that the performance of the proposed idea in terms of admitted flows, and bandwidth utilization are really acceptable.**

Keywords-Hand-over, CDP, CBP, Mobility, Prediction, Pattern, Survey, Markov, Neural, Citymob, Passive, Resource, Reservation, Time, Multiplexing, Call Admission Control, CAC.

I. INTRODUCTION

Users mobility in cellular networks has a heavy impact on real-time service parameters and the existing architectures for fixed hosts are not able to support mobility effects of mobile hosts, needing of employing new protocols as the MRSVP. In addition, the propagation of portable devices has led to a constant increasing of Quality of Service (QoS) requests: when many users try to be covered by the same cell, a certain level of links congestion may be suffered and, as consequence, not all the QoS constraints can be respected, with a "surely degraded" received service.

The main aim of this work is to permit to each coverage cell to know "a-priori" which connection requests are incoming from different directions through the employment of a prediction scheme: in this way, fixed an admission threshold, each cell can evaluate whether the new request can be admitted or not, for providing the requested QoS constraints to multimedia (in general non-tolerant) applications.

In this way, a macro-mobility prediction scheme [1], [2], [3] can be integrated with a time multiplexing approach [4], in order to obtain a statistical Call Admission Control (CAC) policy for evaluating the possibility of accepting new incoming requests.

There are many protocols able to ensure in-advance signalling, like Next Step In Signaling (NSIS) [5], Dynamic ReSerVation Protocol (DSRVP) [6] and Mobile ReSerVation Protocol (MRSVP) [1] and, on the basis of our previous works [1], [2], [3], we considered the MRSVP, which gives the possibility to exchange the right communication messages among the predicted coverage cells, achieving the needed passive amount of bandwidth in the cells where a Mobile Host (MH) will probably hand-in.

The structure of this paper follows this scheme: section II gives an overview of the main existing works (state of the art) about mobility prediction, Cell Stay Time (CST) analysis, time multiplexing, and CAC schemes; section III proposes the In-Advance Multiplexing CAC (IAM-CAC) algorithm, while in section IV simulation results are shown; conclusions are summarized in section V.

II. STATE OF THE ART AND RELATED WORK

In cellular networks it is very important, as shown in next sections, to observe how the time spent in a cell is distributed. In [12] some studies on the CST (or Cell Residence Time - CRT) of the novel Personal Communication Services (PCS) networks were carried out, showing how the classical assumptions of exponentially distributed Call Holding Time (CHT) and CRT are not appropriate in real scenarios. In our previous works, like [13], a prediction technique based on the CST statistical analysis and evaluation of a mobile user has been proposed.

At the best of our knowledge, most of the existing prediction schemes are aimed at the prediction of a single next cell and do not introduce bandwidth multiplexing. Other works predict future locations by considering users practices during the day and do not take into account the geographical morphology of the considered region, in terms of roads.

The only way to ensure in-advance reservations is the employment of the passive reservation policy [1], [2], [3]. In

[7], authors propose a mobility prediction scheme for cellular networks based on the analysis of personal mobility in large spatial and temporal scale, employing Hidden Markov Model (HMM) for system modeling, demonstrating how HMM is efficient and accurate if adopted in factual communication system.

In [8] authors demonstrates how an accurate mobility prediction can mainly improve the handoff performance under fixed bandwidth allocation, but not under dynamic bandwidth allocation, which is more cost-effective to improve. Two passive reservation techniques are proposed in [9], exploiting Wiener prediction and time series theory, making in-advance reservations under non-Poisson and/or non stationary arrival processes, arbitrary distributed call and channel holding time and arbitrary per-call resource demands. In [10] a new framework to estimate service patterns and to track mobile users is proposed: it is based on historical records, allowing the estimation of next cells into which a mobile user will possibly make the next hand-in action. In [11] the authors give a contribution in WLAN infrastructure planning, basing their decisions on mobility prediction and proposing a new method based on a neural network classifier and a genetic algorithm, reaching an acceptable prediction accuracy. In [1] we have shown how system performance can be enhanced considering utility functions and bandwidth reallocation when making in-advance reservations. In [2] we introduced a statistical approach for analyzing and making predictions on users mobility in a 2D environment under the smooth random mobility model, reaching a good level of accuracy. In [3] we based our proposal on previous studies in which we observed that a distributed approach is better than a centralized one when making mobility prediction, because each coverage cell can train its predictor based on the specific roads topology. In [14] system parameters are optimized in terms of Call Dropping Probabilities (CDP) and Call Blocking Probabilities (CBP) introducing a prediction algorithm based on data mining approaches, in order to implement a distributed Call Admission Control (CAC) scheme, considering also the throttle flag as indication of the usage of each cell. The work proposed in [15] authors propose a model for data and voice services CAC in cellular networks while in [16] authors proposed a new CAC scheme for reducing CBP in heterogeneous wireless environments, based on a higher order Markov chain. Three classes of traffic have been considered, with different QoS requirements. The scheme proposed in [17] serves both voice and data services with QoS provisioning, for supporting heterogeneous network architectures, service types, QoS levels, and user mobility characteristics. Authors used a one-dimensional Markov model for voice service to analyze interworking system performance metrics. Their results show that average CBP and CDP values are reduced, outperforming both traditional disjoint static CAC schemes. In our work, we considered all the issues described before, in order to obtain a statistical predictor for each cell. We based our studies on the MRSVP protocol (for more details refer to [1]), able to diffuse RESV messages into the network (which are able to handle passive reservations), but the approach is of general application. We considered infrastructured networks, where ad-hoc communications (Vehicular, Delay Tolerant and Mobile networks) are not possible and energy consumption issues maybe not trivial [18], [19]. Mobility predictions (based on directional or temporal approaches [20]) and, hence, early bandwidth reservations are used to guarantee service continuity when mobile hosts are moving among different coverage cells. With our proposal, a cell is able to decide if a new request (active or passive) can be accepted or not, because it will know the predicted time instant of the arrival and the permanence time of the request. At this aim, the CAC scheme should employ a prediction scheme, based also on the knowledge of the CST distribution, and a multiplexing algorithm [21]. The main contributions of this paper are:

a) Employment of a general multi-step pattern predictor: it is not necessary to know exactly the employed algorithm for cells prediction (if based on conventional or unconventional approaches); the CAC scheme has to know only which are the probabilities of visiting an adjacent cell;

b) Employment of a passive reservations multiplexing scheme, by which the in-advance reserved amount of bandwidth in a cell can be reused by active MHs, leading to a reduction of the total resource wastage;

c) Distributed approach for admitting a request: each coverage cell (no matter what radio technology is employed) has its own CAC module, which interacts with the adjacent cells through the signaling of the reservation protocol (MRSVP in our case). In the next section the main idea is illustrated.

III. IN-ADVANCE MULTIPLEXING CALL ADMISSION CONTROL (IAM-CAC)

As illustrated in fig. 1, we considered a cellular system, composed by a set of coverage cells $C=\{c_1,...,c_c\}$ and a coverage radius R.

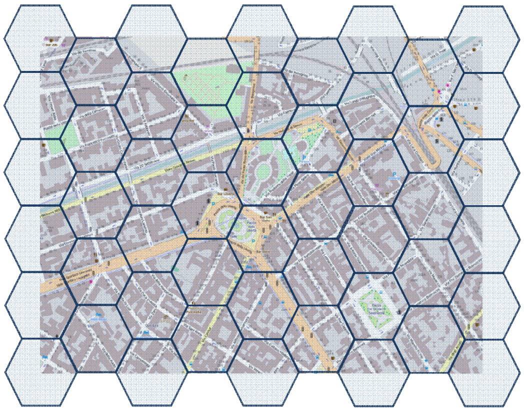

Fig. 1. An example of geographical region and related coverage cells.

The MRSVP session starts when a MH performs a service request in the current coverage area (active cell) $c_A \in C$ (cell c_{16} in fig. 1): if there are no free channels in the current cell the call is refused, else c_A applies the results of a CST evaluation algorithm, as in [1],[13], to evaluate the number of predicted hand-over events *NHO*. If CST > CHT no hand-over events are required (the user will spend the whole time in c_A), then the call is accepted, else c_A will apply the results of a mobility predictor in order to know the probabilities of moving to neighboring cells $c_{neigh} \in Adj(c_A)$, where $Adj(c_A)$ is the set of neighbors of cell $c_A \in C$ and $||Adj(c_A)||=n$, where n is the number of possible hand-over directions.

If the considered user will probably move to cell $c_{neigh} \in Adj(c_A)$, then a passive reservation message is sent to cell c_{neigh}, through the PASSIVE_RESV MRSVP packet. This procedure is repeated for each predicted cell. For more details about MRSVP signaling refer to [1]. In this work, we are not focusing on the particular approach used for making prediction about users future locations, but we consider that a predictor is associated to each cell. Then, we can define the set $PRED=\{p_1, ..., p_c\}$, with $||PRED||=c$, containing the set of predictors for the c cells of the considered system. As considered in [1], [3], [10], [22], [23], different conventional or unconventional approaches are very suitable for making predictions, especially if they are employed in a distributed architecture. As demonstrated in [23], in which Markov theory is used to build-up a prediction algorithm, a distributed approach is suitable in cellular networks because it is able to capture, during the training phase, local dynamics of users mobility. The general structure of the predictor is composed by an input layer (or input vector) in_{pi} and an output layer (or output vector) out_{pi}: the meaning of the considered variables for input and output layers depends on the particular employed approach. Typical considered variables are position (in terms of x, y and z coordinates), movement direction or acceleration, hand-in side, cell identifier, Direction of Arrival (DoA) for the input layer while, generally, the output layer consists of the probabilities of going into a particular direction [2], [3], [10], [22]. So the main behavior of the predictor $p_i \in P$ can be resumed as follows:

$$output_{p_i} = F_i\left(input_{p_i}\right) \qquad (1)$$

where F_i is an operator related to the particular approach and, in particular, it resumes the training procedure and the typical MH mobility behavior of the covered region. In this work each cell has been approximated with an hexagonal shape so, as shown in our previous works ([2]), a set S_{ho} of *6* possible movement directions can be obtained. In general, directions can be indicated with $d_1...d_n$, so $S_{ho}=\{d_1, ..., d_n\}$ and $||S_{ho}||=n$. In the classical approaches on cellular networks n is set to 6. Each predictor gives the opportunity of knowing which are the probably visited cell, but a new approach for time prediction is necessary, as shown in the next sub-section.

The second contribution of this paper regards the possibility of considering the pre-reserved amount of bandwidth as available in time for new incoming requests: as discussed in early works ([1], [13]), the CST for each cell $c_l \in C$ can be approximated by a Gaussian function with parameters μ_l, σ_l, which depend on the specific covered region. When a cell $c_l \in C$ receives a passive reservation request, it evaluates the CST through its parameters μ_l, σ_l: in this way it is able to know if the request should be forwarded one more time, taking into account the values of CST. So, given a MH u, if $handoff^u{}_{in}(h)$ and $handoff^u{}_{out}(h)$ are the predicted hand-in and hand-out times to/from a cell respectively for the *h-th* hand-off event of u, it can be written:

$$handoff^u{}_{in}(h+1) = handoff^u{}_{in}(0) + \sum_{m=1}^{h} \overline{handoff_{lm}}(m) \qquad (2)$$

where $handoff_{in}(0)$ is the time of the active reservation, $handoff_{lm}(m)$ is a pdf CST realization for the predicted cell c_{lm} for the *m-th* hand-off. As stated in [24], $\sum_{m=1}^{h} \overline{handoff_{lm}}(m)$ is still a random variable, because the terms in the summation are Gaussian random variables. In this way, for each MH u, it is possible to evaluate all the predicted hand-in and hand-out times $handoff^u{}_{in-m}(h)$ and $handoff^u{}_{out-m}(h)$ for each *h-th* hand-over and the cell identifier m can be obtained with the prediction approach introduced in previous sub-section. So, given MH u and the predicted cell m, from equation 2, it is possible to obtain the duration of each passive request for the *h-th* hand-off as:

$$delta^u{}_m(h) = handoff^u{}_{out-m}(h) - handoff^u{}_{in-m}(h) \qquad (3)$$

If users u and v are reserving passive bandwidth in cell m for *h-th* and *k-th* hand-over respectively, they can be multiplexed on the same slot if their reservation times have an empty intersection. So, the condition that has to be satisfied is:

$$delta^u{}_m(h) \cap delta^v{}_m(k) = \varnothing \qquad (4)$$

In this way, more passive reservations can be multiplexed in time on a single slot.

As known, each cell of a cellular system has a certain number of available transmission channels; so, we can say that each coverage cell $c_l \in C$ has a capacity set of channels $B_l = \{ch_1, ..., ch_{cl}\}$ (in our approach, without loss of generality, $B_l=B$, $\forall c_l \in C$). After the application of the distributed prediction scheme, for a MH u a predicted path of cells $PATH^u$ is obtained and it can be written that:

$$PATH^u = \{c^u_0, c^u_1, c^u_2, ..., c^u_{k-1}\} \qquad (5)$$

where $c^u{}_0$ is the cell where the call has originated (active cells) and the remaining *k-1* cells are the cells on which a passive bandwidth request will arrive, with $||PATH^u||=k$. The number of probably visited cells and, consequently, the number of hand-over events for the generic MH u can be evaluated through the approach proposed in [1], [2], [3]. The way of choosing a predicted cell is always the same, independently on

$$handoff^u{}_{in}(h+1) = handoff^u{}_{in}(0) + \sum_{m=1}^{h} \overline{handoff_{lm}}(m)$$

the particular employed predictor, so the probability of choosing cell c_j as next predicted cell if user belongs to cell c_i is:

$$p_{ij} = \max(output_{p_i}), \quad j = index[\max(output_{p_i})] \in Adj(c_i) \quad (6)$$

where $ouput_{pi}$ is the output vector of the predictor p_i associated to c_i containing the probabilities of hand-in the adjacent cells of c_i and j is the index of the most probable next cell. At this point, for each cell $c_l \in P^u$ it is possible to associate the Reaching Probability (RPROB). So, fixed an admissibility threshold p_{min}, when a cell c_l receives a reservation request for MH *u* for *h-th* hand-over, it applies the *IAM-CAC* scheme verifying two conditions:

$$p_{01} \cdot p_{12} \cdot \ldots \cdot p_{(l-1)l} = \prod_{ij,i\neq j}^{j=l} \mathrm{p}_{\mathrm{ij}} \geq \mathrm{p}_{\min} \quad (7)$$

$$\exists ch_i \in B_l \;/\; delta^u{}_l(h) \cap delta^v{}_l(k) = \varnothing \;\forall\; \mathrm{v} \neq \mathrm{u}, \quad (8)$$

that is to say that the probability of reaching cell c_l is higher than a minimum threshold and exists a channel ch_i in c_l on which the request of MH *u* can be multiplexed.

IV. PERFORMANCE EVALUATION

Some simulations experiments have been carried out in order to consider the performance of the proposed scheme. First of all, different mobility traces have been created by the C4R generator, based on the work in [25] and considering the map illustrated in fig. 1. The value of B_l has been fixed to 30 for each cell. In order to analyze CST distribution and train the predictors, a first addicted campaign of simulations has been led-out, considering 500 runs (with 500 moving vehicles for each run) with a single duration of 1000s. The call arrival process has been assumed to Poissonian with a rate λ of 2 calls/s, uniformly distributed into the map, shown in fig. 1 with an extension of 1 Km^2. Next, the considered mobility map has been covered by a set of coverage cells of radius *R*. Markovian predictors have been considered [23] for the set *PRED* and $\|C\|=\|PRED\|=c$ depends on the value of the considered coverage radius. Each predictor $p_i \in PRED$ has $\|input_{pi}\|=\|output_{pi}\|=1$ (only hand-in and hand-out directions are considered as input/output parameters and the probabilities of handing-out a cell on all directions are contained in the transition probability matrix of the predictor). Figure 2 shows the trend of the number of admitted MH requests in the whole system: in this case there is a decreasing course for larger coverage areas, because the number of available channels remains the same for each cell, while the number of cells decreases, so there are less chances to accept new requests (even if multiplexed). On the other hand, an increase in CAC threshold value gives more chances to the requests to be multiplexed into the available channels. Figure 3 and Fig. 4 show the trend of CBP and CDP for different values of *R* and p_{min}. It can be seen how increasing the threshold value, both curves have a diminishing course for the curves: in the case of CBP, this is due to the higher probability of be admitted into the system, since more obtained values of RP can be considered; for the CDP, there will be more passive reservations (on more cells) so, also in this case, values below 0.1 are obtained.

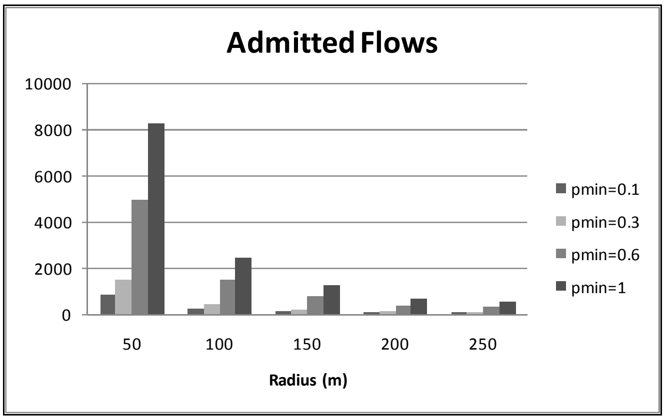

Fig. 2. Average number of admitted flows versus coverage radius R.

For higher values of *R*, there is a general increasing trend: for CBP, the number of available channels remains the same, so less MHs can enter the system; for the CDP, a lower number of passive reservations are made, with a higher probability of finding scarce resources.

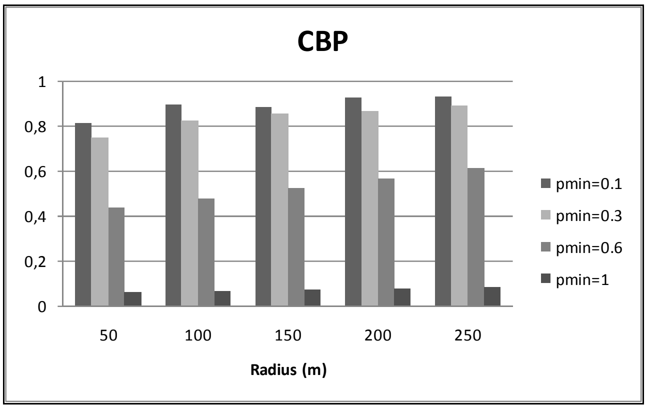

Fig. 3. Call Blocking Probability versus coverage radius R.

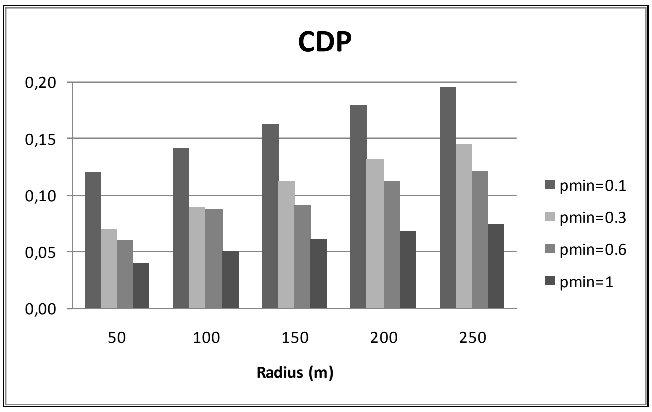

Fig. 4. Call Dropping Probability versus coverage radius R.

Figure 5 shows the obtained results in terms of system utilization U, evaluated as the average ratio of the used channels and the available ones (the average is evaluated on time and on the number of system cells). The trend is increasing for higher values of R and p_{min}: for higher coverage radius, the network reaches the saturation point, because the number of total available channels decreases, while the rate of call requests remains the same; in addition, higher values of p_{min} give the opportunity to accept more MH requests.

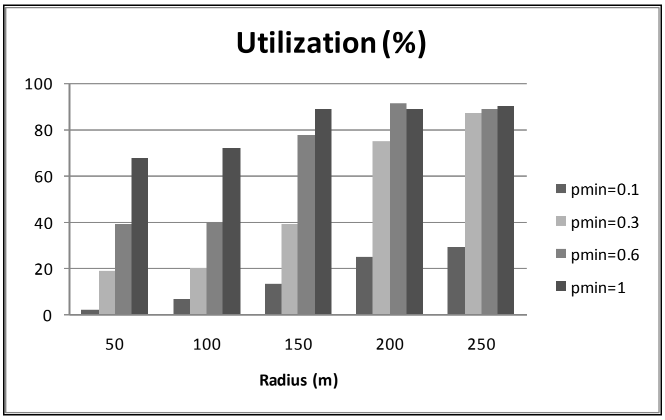

Fig. 5. Average system utilization versus coverage radius R.

V. CONCLUSIONS

In this paper a new CAC scheme for cellular networks has been shown. This proposal, in order to guarantee QoS on the wireless platform, is based on an in-advance reservation scheme that decides whether a new connection can be accepted into the system, with the main aim of maximizing bandwidth utilization while avoiding quality degradations. The main characteristics are the independence from the way the future visited cells are predicted and from the cellular technology. The proposal is called IAM-CAC and it is based on a threshold approach. The paper show how for values equal or higher than 0.6, it performs well in terms of CBP/CDP, number of admitted flows and system utilization.

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