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Efficient resource reservation scheme with optimal channel requests classification in cellular systems

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Abstract **This paper proposes the Time-based Bandwidth Reservation (TBR) based on real-time measures of mobiles (position, velocity and acceleration). The scheme consists in sending reservation requests to the neighboring cells based on an extrapolation of the mobile users motion. The goal of our scheme is to adjust the amount of time for which bandwidth has to be allocated and reserved in a cell. We have also proposed an optimal channel requests arrangement (CRA) algorithm in order to improve the performance of TBR. Performance of the proposed scheme (with and without CRA) and comparison with guard channel scheme are presented. The simulation results show that the proposed TBR scheme can ef ciently improve the connection dropping probability.**

KEY WORDS

Cellular systems, mobility, reservation, real time, classification.

I. Introduction

The new wireless mobile systems such as 3G and 4G are aimed to support voice and broadband data services. These services are expected to include multimedia applications with real-time constraints. To fulfill the quality-of-service (QoS) requirements of mobile users, these systems have to implement efficient bandwidth allocation strategies.

In a cellular network, a mobile station (MS) may visit different cells during its lifetime. Whenever MS moves from one cell to another, network resources need to be available for him else forced termination will occur. Since the blocking of a handoff request is less desirable than the blocking of a new call, the adjacent cells must provide sufficient resources for handoff connections. Therefore, network resources need to be reserved in anticipation of handoff so as to decrease handoff blocking probability and to provide quality of service (QoS) guarantees.

Resource reservation optimization approaches can be divided into two hierarchies : spatial allocations and temporal allocations. Some solutions use both reservation hierarchies. Minimizing the reserved spatial resources returns to reduce as possible the number of cells where bandwidth reservation need to be made. This can be achieved by considering a priori knowledge or prediction about mobiles future movement pattern. Whereas, minimizing temporal resources requires reducing the amount of time for which the resources are reserved in these selected cells.

In this paper, we explore the problem of resources reservation, we propose a Time-based Bandwidth Reservation (TBR). Our scheme is based on real-time measures (position, velocity and acceleration) which help to adjust the time interval during which the resources have to be reserved. The deviation of mobile users is taken into account and the next cell to which the mobile will do its handoff is estimated by extrapolating the motion of mobile stations. The performance of the proposed scheme is investigated through simulations. A comparison between TBR scheme and Guard Channel (GC) scheme is presented.

The remainder of this paper is organized as follows: In Section II, we give an overview of different related works. Section III describes the Time-based Bandwidth Reservation scheme. Section IV details the Channel Request Arrangement (CRA) algorithm which aims to improve TBR. We present in Section V the simulation model and simulation results. Finally, Section VI concludes this paper and defines some topics for further research.

II. Related works

In wireless network that support user mobility, a mobile user may handoff to neighboring cells during the lifetime of its call, network resources must be reserved in the cells a user might visit. If sufficient resources are not available at a new cell when the mobile user must handoff, the call must either suffer prolonged periods of significantly reduced QoS or be dropped. Different schemes have been proposed to deal with this bandwidth reservation for new calls and/or handoff calls.

The guard channel (GC) scheme [1] is the most basic approach which belongs to the fixed reservations family. The GC scheme aims to provide a kind of prioritization for handing off calls on new arriving call connexions. In this scheme, a fixed number of channels are kept aside (guard channel pool) and are permanently reserved exclusively for handoff connections. The main limitation of this scheme can be resumed in its static behavior which does not vary according to the changing traffic conditions.

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Many approaches [3], [4], [6] have been proposed to dynamically reserve bandwidth for handoff connections to reduce handoff connection dropping probability and increase bandwidth utilization. These schemes form the dynamic reservation approaches.

Unlike fixed reservation solutions, dynamic reservation approaches give some kind of solid guarantees on the QoS metrics of the system. They perform an adaptive reservation where bandwidth is dynamically reserved in response to anticipated mobility users predictions. All the proposed approaches differ in how and when the reservations are performed and the accuracy of the required bandwidth estimation. In a previous work [7], we have proposed a dynamic reservation approach we called time-based bandwidth reservation (TBR) scheme and which uses real-time mobility predictions. In this paper, we extend this work by taking into account the *deviation* of users in the mobility model. The main contribution of our work is that TBR is based on time resource reservation rather than completed and hard resource locking. Furthermore, TBR aims to reduce and optimize the length of the reservation in order to increase efficiently the bandwidth utilisation.

III. THE TIME-BASED BANDWIDTH RESERVATION (TBR) SCHEME

In the TBR scheme, resource reservation is based on the prediction of the users motion. Each mobile station (MS) periodically measures its position and orientation. These informations are sent to the base station (BS) which makes extrapolation for the projected further path of the MS. Based on the projected path, the next cell the mobile is heading toward is determined. Handoff and residence times in the next expected cell are estimated periodically to adjust the amount of time the resources are reserved. Accordingly, a reservation request can be sent by the mobile user to reserve its required bandwidth during this estimated time interval. When a mobile station suddenly deviates, its reservation may be invalid. In this case, a cancellation of reservation should be sent to deallocate the reserved resources.

We consider a cellular network with 2-dimensional cell layout. Cells are located in a rectangular grid and each one has four neighbors. Handoffs take place only between cells sharing an edge and not just a vertex. Let C_i be the capacity of a cell i in terms of bandwidth. The term resource refers to bandwidth which can be divided into units called channels. Hence, C_i denotes the number of channels of cell i.

A. Admission control

Let us consider an incoming mobile station (MS_n) in a source cell i. MS_n passes to the base station (BS_i) of cell i its required bandwidth B_n. The BS_i can estimate the MS_n residence time $t^r_{n,i}$ in the current cell i. We will detail in section III-D how this time is estimated. BS_i finds out if there is available bandwidth to satisfy the user request by checking the following condition given by

$$B_n + V_i[t] + R_i[t] \leq C_i, \forall t \in [t_0, t_0 + t^r_{n,i}] \qquad (1)$$

where V_i is the time slot vector of the currently used bandwidth and R_i is the time slot vector of the reserved bandwidth in cell i. For each slot, V_i contains the total used bandwidth in that slot and R_i contains the total reserved bandwidth in that slot. If the above condition is not satisfied, the call is rejected. Otherwise, the call is accepted and BS_i updates the vector V_i as follows

$$V_i[t] = V_i[t] + B_n, \forall t \in [t_0, t_0 + t^r_{n,i}] \qquad (2)$$

B. Reservation Process

1) Reservation Setup: Let us assume that a mobile station MS_n is currently located at cell i. It initiates the reservation procedure by sending its position, velocity and orientation to BS_i. BS_i uses these informations to make extrapolation for the projected further path of MS_n and predict the next neighboring cell j where MS_n is expected to do its handoff. BS_i sends a reservation request to cell j. The reservation request denoted by RESV is a triplet $< B_n, t^h_{n,i,j}, t^r_{n,j} >$ where B_n is the required bandwidth, $t^h_{n,i,j}$ is the estimated handoff time of MS_n from its current cell i to the neighboring cell j and $t^r_{n,j}$ is its estimated residence time in cell j. $t^h_{n,i,j}$ and $t^r_{n,j}$ are computed from (5) and (6) (see section III-D).

Upon receiving RESV message from MS_n, BS_j (at cell j) checks if there is available bandwidth to satisfy this reservation request. This is performed by checking the following condition

$$B_n + V_i[t] + R_i[t] \leq C_i, \forall t \in [t^h_{n,i,j}, t^h_{n,i,j} + t^r_{n,j}] \qquad (3)$$

If this condition is not satisfied, the request is ignored. Otherwise, B_n is reserved between $[t^h_{n,i,j}, t^h_{n,i,j} + t^r_{n,j}]$ and BS_i updates the vector R_i as follows

$$R_i[t] = R_i[t] + B_n, \forall t \in [t^h_{n,i,j}, t^h_{n,i,j} + t^r_{n,j}] \qquad (4)$$

2) Reservation cancellation: When a mobile station MS_n deviates from its predicted path and starts heading to a neighboring cell different from the one that was computed in the latest prediction, the current base station sends two messages. The first one is a reservation cancellation CACL addressed to the base station of the old predicted transit cell for MS_n. The second message is a reservation request to the base station of the new predicted transit cell. If a base station receives a CACL message for MS_n, its reservation gets rejected.

C. Handoff procedure

When the mobile station MS_n hands off to cell j at time t_{ho}, the base station of this cell (BS_j) verifies if it has a prior reservation. In this case, BS_j checks if MS_n's handoff time is within the reserved time interval and allocates the reserved channels to him (let C_k denotes these channels). Otherwise, if the handoff time is outside the reserved time interval, BS_j

computes a new time interval for MS_n: $[t_{ho}, t_{ho} + t^r_{n,j}]$. We remind that $t^r_{n,j}$ is the estimated residence time of MS_n in cell j. At this step, BS_j makes sure that the C_k channels are not used or reserved during the new time interval and allocates them during $[t_{ho}, t_{ho}+t^r_{n,j}]$. Otherwise, BS_j makes bandwidth available from the unreserved pool of bandwidth. However, if there is not enough bandwidth in the pool, BS_j allocates the initial C_k reserved channels during $[t_{ho}, t_{ho} + t^r_{n,j}]$ if they are not currently used by an other mobile user and eliminates the reservation of these channels during this time interval. In the case where MS_n arrives in cell j and has not already performed a reservation, BS_j tries to find free channels during $[t_{ho}, t_{ho} + t^r_{n,j}]$ and allocates them to MS_n during this time interval. Otherwise, the handoff is blocked.

D. Users mobility model

In this section, we describe how the mobile movement was integrated to two-dimensional plane of the cellular network. We aim to estimate the handoff and residence times of a given user MS_n. A probing time Δt is used to check the instantaneous acceleration, speed and position of each mobile user. To derive the handoff and residence times, we use the distance D. D is the remaining distance for MS_n in its cell i (we assume that the mobile station will not change its direction). From the distance D, the current speed v and the mean acceleration $\overline{a}$, we can compute $t^h_{n,i,j}$ based on the distance equation of uniformly accelerated motion. We obtain the following formula:

$$t^h_{n,i,j} = \frac{D}{v + \sqrt{v^2 + 2\overline{a}D}} \tag{5}$$

Using the same formula, we can derive the value of $t^r_{n,j}$. However, in this case the remaining distance D is equal to the $diameter_j$ of $cell_j$ which is the maximum distance MS_n can travel.

$$t^r_{n,j} = \frac{diameter_j}{v + \sqrt{v^2 + 2\overline{a}diameter_j}} \tag{6}$$

IV. The Channel Requests Arrangement (CRA) Algorithm

A. Problem statement

At every satisfied reservation request, a new time interval is placed in a given channel. Many arrangement algorithms can be used. The simplest one is to satisfy the request using the first free place. This method has the advantage to be very simple and light. However, it can lead to an ineffective use of channels since the intervals are placed in a random manner and a better sorting of the intervals can most probably be performed. Thus, our goal here is to increase the bandwidth utilisation thanks to a new arrangement algorithm called CRA (Channel Requests Arrangement) algorithm.

The main idea of CRA is to place the time intervals already placed on the channels in such a manner that the new classification minimizes the number of accupied channels (an occupied channel is a channel which at least contains one time interval). In other words, CRA aims to free a maximum number of channels in order to increase the probability to accept future hand off demands what ever is the required time intervals. CRA proceeds as follows : the intervals are sorted using their begining time. Then, they are placed in the first free channel where there is no overlapping with already placed intervals.

Our algorithm CRA is executed when an arriving hand-off request cannot be satisfied. Then CRA arranges all the requests as described below.

Let $S_0 = [t^b_0, t^e_0]$, .. , $S_{N-1} = [t^b_{N-1}, t^e_{N-1}]$ denote N requests to be placed in r channels in a given cell. We denote these channels C_0, C_1,..,C_{r-1}.

An arrangement e of these N requests over the r channels.

$$e = ((S_{K^0_1}, S_{K^0_2}, .., S_{K^0_{n_0}}), .., (S_{K^{r-1}_1}, S_{K^{r-1}_2}, .., S_{K^{r-1}_{n_{r-1}}})) \tag{7}$$

where $K^i_j \in [0..N-1]$, $i \in [0..r-1]$, $j \in [1..n_i]$. $S_{K^i_j}$ are the intervals located in the channel C_i which contains n_i intervals. Let us define the allocation begining time of channels:

$$\forall i \in [0..r-1], t^*_i = t^b_{K^i_1}$$

We denote by E the set of the e arrangements. $e \in E$ is said to be acceptable if the S_K time intervals placed in evry channel C_i are mutually disjointed. The set of acceptable arrangements will be denoted as.

$$A = \{e \in E, e \text{ is acceptable }\}$$

Definition Let us consider a given interval $S_{K^i_j}$ placed on channel C_i. We say that $S_{K^i_j}$ verifies the hypothesis H if

$$t^b_{K^i_j} = min\{t^b_{K^l_m} | t^b_{K^l_m} \geq t^e_{K^i_{j-1}},\ l \geq i, 1 \leq m \leq n_l\} \tag{8}$$

where we define $t^e_{K^i_0} = t^*_i$.

An arrangement e verifies the hypothesis H when every request $S_{k^i_j}$ verifies H. We denote $A_H = \{e \in A$ s.t. e verifies $H\}$.

B. proposition

Let e be an arrangement of N requests S_0, S_1, .., S_{N-1} using R channels ($0 \leq R \leq r$). If e is acceptable then it exists an arrangement e' which belongs to A_H using R' channels with $0 \leq R' \leq R$.

Proposition 4.1:

$$\forall e \in A, \exists e' \in A_H | 0 \leq R' \leq R$$

The idea of the proposition is to show that while leaving from any arrangement of N requests, we can rearrange them in a smaller (or equal) number of resources according to the hypothesis H.

Proof: Iteration steps to prove the proposition:

- Iteration 1: We place S_1 in the first channel C_0.
- Iteration N: The hypothesis (P_N) : any acceptable arrangement e of N requests using R channels can be

rearranged accordingly to H in R' channels with $0 \leq R' \leq R$.
Iteration N + 1: We consider an arrangement e_{N+1} of $N+1$ requests $S_0, S_1, .., S_N$, placed acceptably in R channels $C_0, C_1, .., C_{R-1}$.
We aim to demonstrate (P_{N+1}): it exists an arrangement e'_{N+1} of these $N+1$ requests so that e_{N+1} verifies H and uses R' channels, $0 \leq R' \leq R$.
With the notation of 7, let us consider $p \in \{0, .., R-1\}$ and $q \in \{1, .., n_p\}$ such that

$$t^b_{K^p_q} = min\{t^b_{K^i_j} \mid t^b_{K^i_j} \geq t^*_0, 0 \leq i \leq R-1, 1 \leq j \leq n_i\}$$

Let e' be the arrangement deduced from e when switching $(S_{K^p_q}, .., S_{K^p_{n_p}})$ in C_0 and $(S_{K^0_1}, .., S_{K^0_{n_0}})$ in C_p.

Lemma 4.2: The switching leads to an acceptable e' in which the time interval $S_{K^p_q}$ verifies the hypothesis H.

Proof: By definition, we have $t^b_{K^p_q} \geq t^*_0$, therefore, we can place acceptably $(S_{K^p_q}, .., S_{K^p_{n_p}})$ in C_0. On the other hand, also by the definition of $t^b_{K^p_q}$: $t^b_{K^0_1} \geq t^b_{K^p_q}$, so $t^b_{K^0_1} \geq t^e_{K^p_{q-1}}$, since the arrangement e was acceptable. Therefore it is possible to place $(S_{K^0_1}, .., S_{K^0_{n_0}})$ after $t^e_{K^p_{q-1}}$ in the channel C_p.
In the deduced arrangement e', we have

$$t^b_{K^p_q} = min\{t^b_{K^l_m},\ t^b_{K^l_m} \geq t^e_{K^p_{q-1}};\ l \geq p, 1 \leq m \leq n_l\}$$

Thus, $S_{K^p_q}$ verifies H. ■

On the other hand, it can be seen easily that one has the following result:

Lemma 4.3: If e' is an arrangement so that $S_{K^0_1}$ verifies H and if we apply any swiching of $S_{K^i_j}$ (other than $S_{K^0_1}$), then, in the arrangement e'' deduced, $S_{K^0_1}$ still verify H.

We can now demonstrate the proposition. From e, we perform the switching described above to obtain e'. We consider the N requests (other than $S_{K^p_q}$ which becomes $S_{K^0_1}$ in e') and the resources R' associated to the R channels with allocation begining times $t^{*'}_0 = t^e_{K^p_q}$ and $t^{*'}_i = t^*_i, 1 \leq i \leq r-1$.
From P_N, it exists an arrangement e'_N of the N requests $S_{K^i_j} \neq S_{K^p_q}$ so that e'_N verifies H. Let e'_{N+1} the arrangement derived from the concatenation of e'_N and $S_{K^p_q}$ that we note as

$$e'_{N+1} = \{(S'_{K^0_1}, .., S'_{K^0_{n_0}}), ..(S'_{K^{r-1}_1}, .., S'_{K^{r-1}_{n_{r-1}}})\}$$

In fact from Lemma 4.2 and 4.3, $S'_{K^0_1}$ (in e'_{N+1}) verifies H. Note that $S'_{K^0_1} = S_{K^p_q}$.
We consider now a request $S'_{K^i_j}$, for $i \geq 1$ or ($i = 0$ and $j \geq 2$). Then we have :
If $l \geq i$, and $m \in [1..n_l]$ such that $t^b_{K^l_m} \geq t^e_{K^i_{j-1}}$, then $t^b_{K^i_j} \geq t^b_{K^l_m}$

In fact If $i = 1$ and $j \geq 2$, $t^e_{K^0_{j-1}} \geq t^e_{K^0_1} > t^b_{K^0_1}$, so $S'_{K^l_m} \neq S'_{K^0_1}$. Thus $S'_{K^l_m} \in e'_N$ since $S'_{K^i_j}$ belongs also to e'_N (because $j \geq 2$) and e'_N satisfies H, then $t^b_{K^i_0} \geq t^b_{K^l_m}$.
Otherwise, $i \geq 1$ and so $l \geq i$ wich means that $S'_{K^l_m} \in e_N$ seemingly, since $S'_{K^i_j} \in e'_N$ and e'_N satisfies H. Then in e'_{N+1}, all the $S'_{K^i_j}$, $i \geq 0$, $1 \geq j \geq n_i$, satisfy H.
Therefore e'_{N+1} verifies H and P_{N+1} is demonstrated. ■

This proves and demonstrates that CRA can achieve a new arrangement of the time intervals using a smaller or equal number of channels that the one used by any original arrangement. The special case (ie. the number of channels are equal) occurs when the original arrangement is already optimal.

V. SIMULATIONS

In this section, we use an extensive set of simulation to investigate the performance of the proposed solution using OPNET simulator [5].

A. Simulation model

Our simulation network consists of 64 cells located in a rectangular grid. Each cell has exactly four neighbors, so that handoff take place only between cells sharing an edge, and not just a vertex. We generate a set of base stations each of them covers a cell randomly selected. The cell is represented by a subqueue with a profile containing the co-ordinates x and y, the bandwidth capacity and the set of free channels. To obtain the balance between the arrivals and departures in the cellular networks, all MSs leaving the last cell are re injected in the first zone, thus eliminating the board's effects. For example, a handoff to the east of cell 7 wraps to cell 0. Each cell has a diameter of 1000 m and a capacity of 20 channels.

The random mobile station mobility model proposed in this section is a continuous time stochastic process. Each MS movement consists of a sequence of random length intervals during which MS moves in a constant direction at a constant acceleration.

B. Simulation Results

In this section, we show the obtained simulation results we realized to highlight the performance of our TBR scheme and its behavior compared to the GC scheme. Two performance parameters were considered the Call Blocking Probability (CBP) and the Call Dropping Probability (CDP).

Fig. 1 depicts the handoff blocking rates for the TBR scheme and the guard channel scheme (with 2 and 3 guard channels noted in the figure GC2 and GC3 respectively) at various arrival rates. We notice that TBR gives a good improvement in terms of handoff blocking probability. This improvement is more significant when the arrival rate increases. Indeed, the proposed TBR scheme properly reserves bandwidth in the neighboring cell for handoff connections. However, GC schemes give better new call blocking rate than

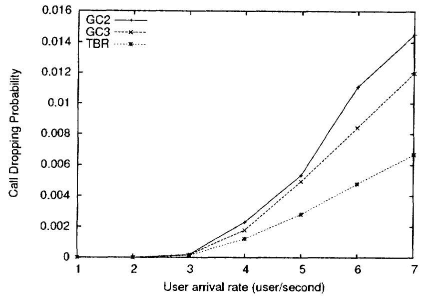

Fig. 1. CDP vs. connection arrival rate for TBR and GC schemes for $\Delta t = 3$ sec

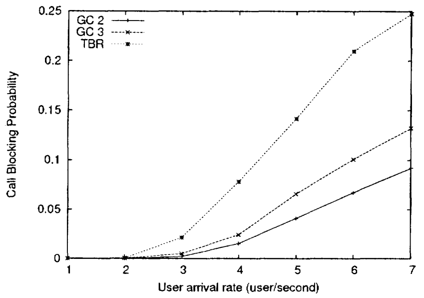

Fig. 2. CBP vs. connection arrival rate for TBR and GC schemes for $\Delta t = 3$ sec

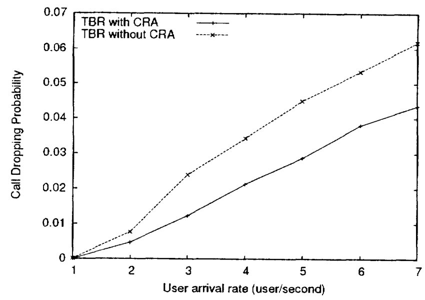

Fig. 3. CDP vs. connection arrival rate for TBR with and without CRA for $\Delta t = 3$ sec

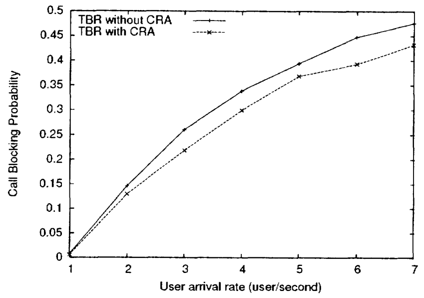

Fig. 4. CBP vs. connection arrival rate for TBR with and without CRA for $\Delta t = 3$ sec

the TBR scheme since less bandwidth is available for new arrivals in TBR scheme as shown in fig. 2.

Fig. 3 draws, for the TBR scheme, the handoff blocking probability according to the arrival rates with and without CRA algorithm for $\Delta t = 3$ sec. We notice that the algorithm CRA gives a good improvement in terms of call dropping probability. This can be explained as follows : CRA is executed at every handoff request failure. CRA arrages all the existing time intervals and tries to find a arrangement to the arriving handoff demand. It is worth to notice that this treatment is only exclusive to handoff calls. This is done in order to be consistent with the initial objective of prioritizing handoff call demands over new call ones. Consequently, a new call has less chances to be accepted when the algorithm is executed. This behavior can be noticed in Fig. 4.

VI. Conclusion

In this paper, we proposed a new scheme called time-based bandwidth reservation (TBR) to decrease the dropping probability in cellular networks. The purpose of our scheme is to adjust the amount of time for which the resources are reserved. We have described a method for estimating the handoff and residence time based on real-time measures (position, velocity and acceleration) of mobile users. An admission control and a reservation procedures have been presented. We have also presented the Channel Request Arrangement (CRA) algorithm which aims to perform TBR. Detailed simulation results have been derived to show the performance of TBR scheme (with and without CRA) compared to the guard channel scheme. The results show that our proposal leads to a clear improvement in terms of call dropping probability.

Topics for further research include the investigation of a more complex cellular topology for resource reservation. We will, also, propose a method to integrate the spacial and temporal resource reservation.

References

[1] Oliver T. W. Yu and Victor C. M. Leung, *Adaptive Resource Allocation for Prioritized Call Admission over an ATM-Based Wireless PCN*, IEEE JSAC, Vol. 15, No. 7, pp. 1208-1225, Sept. 1997.

[2] Geng-Sheng Kuo, Po-Chang Ko and Min-Lian Kuo, *A Probabilistic Resource Estimation and Semi-Reservation Scheme for Flow-Oriented Multimedia Wireless Networks*, IEEE Communications Magazine, February 2001.

[3] Sammart Ganguly, Badri Nath and Navin Goyal, *Optimal Bandwidth Reservation Schedule in Cellular Networks*, IEEE Infocom 2003.

[4] Ming-Hsing Chiu and Mostafa A. Bassiouni, *Predictive Schemes for Handoff Prioritization in Cellular Networks Based on Mobile Positioning*, IEEE JSAC, Vol. 18, No. 3, March 2000.

[5] http://www.opnet.com

[6] Jean-Lien C. Wu, Li-Liann Lu and Chien-Chih Hu, *The Study of Mobility-Dependent Resource Reservation Scheme in Wireless Multimedia Networks*, Proc of ISCC, pp 1072-1077 , July 2003.

[7] Ines Ben Hamida and Lila Boukhatem, *A Time-based Bandwidth Reservation Scheme in Cellular Networks*, WOCN, March 2005.