A channel reservation scheme using real-time users mobility informations in cellular systems

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Abstract–This paper proposes a channel reservation scheme based on real-time users mobility informations (position, velocity and acceleration). The scheme called TBR (Time-based Bandwidth Reservation) consists in sending reservation requests to the neighboring cells based on the extrapolation of the users motion. The TBR scheme aims to adjust the amount of time for which bandwidth has to be allocated and reserved in a cell. Performance of the proposed scheme and comparison with guard channel scheme are presented. The simulation results show that the proposed TBR scheme can efficiently improve the connection dropping probability.
Key words: Cellular networks, probing time, mobility, reservation, real-time.

1 INTRODUCTION

Currently, multimedia applications that need real time guarantees are urgently expected in wireless networks. To fulfill the quality-of-service (QoS) requirements of mobile users, the new wireless mobile systems such as 3G and 4G 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 2, we give an overview of different related works. Section 3 describes the Time-based Bandwidth Reservation scheme. In Section 4, we detail users mobility model. We present in Section 5 the simulation model and simulation results. Finally, Section 6 concludes this paper and defines some topics for further research.

2 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. In a cell with a limited bandwidth capacity, a handoff call is allocated any free channel, while a new call can not be assigned channels from the guard channel pool. The main limitation of this scheme can be resumed in its static behavior which does not vary according to the changing traffic conditions.

Many approaches [2], [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 which can be divided in two families : space-based and time-based reservation schemes.

A space-based reservation scheme aims to select the neighboring cells which are concerned by the bandwidth reservation while a time-based reservation scheme tries to minimize the amount of time the resources are reserved in these selected cells. Both of these schemes are based on either history or real-time measures.

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.

3 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 de-allocate the reserved resources.

The idea behind the use of a time-based reservation is to dynamically adjust the time of using or reserving the required bandwidth. This scheme allows the reservation of the same resource by different mobile users provided that there is no overlapping between their time intervals. The resources are not blocked even when users are currently using them. Indeed, reservation demands can concern these resources since no conflict is noted between reserved and used time intervals.

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.

3.1 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 4 how this time is estimated. From $t^r_{n,i}$, the current time t_0 and the required bandwidth B_n, BS_i finds out if there is available bandwidth to satisfy the user request. This is achieved by checking the following condition given by

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

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

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

3.2 Reservation Process

3.2.1 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 4).
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

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

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

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

3.2.2 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. The cancellation mechanism is illustrated in Figure 1 which shows five cells : cell A and its four neighboring cells. At time t1, BS A sends to cell B a reservation request for mobile MS_n. At time t2, due to a sudden deviation of MS_n, BS A sends to cell B a cancellation message for MS_n and addresses a reservation request to cell C.

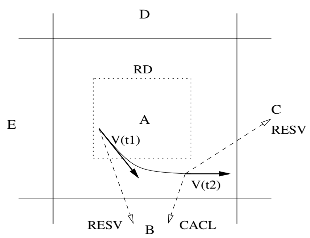

Figure 1: A reservation cancellation scenario in TBR scheme

We notice a Reservation Distance (RD) can be specified to eliminate the false reservation which duration is equal to $t_2 - t_1$. RD is a distance smaller than the diameter of the cell. If the mobile is located at a distance from BS smaller than RD, no reservation requests are sent by the BS. The value of RD needs to be carefully selected : larger values of RD may cause undesirable delay in the submission of true reservations; smaller values of RD may cause frequent false reservations.

3.3 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 mob ile 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.

When a mobile user remains in a cell more than the reserved time interval (this can happen when the residence time estimation was not enough accurate), the base station estimates for him its remaining time in the cell. Then, BS extends the mobile's time interval and deletes, if necessary, the conflicting reservations.

4 USERS mobility model

In this section, we describe how the mobile movement was integrated to two-dimensional plane of the cellular network.

Let us consider a mobile station MS_n located in a position $M(x_0, y_0)$ in its home cell i (Figure 2). MS_n has a velocity vector $\overrightarrow{v}$.

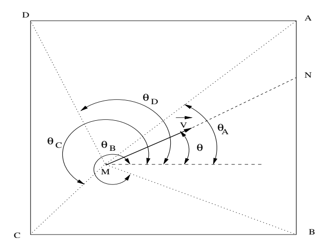

Figure 2: Mobile station mobility model

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). So, the distance D is equal to the distance between the two points M and N (Figure 2).

We note θ the angle between $\overrightarrow{V}$ and the horizontal.

$$D = \begin{cases} \frac{diameter - x_0}{\cos\theta} & \text{if } \theta \in [0, \theta_A[\cup [\theta_B, 2\pi]; \\ \frac{diameter - y_0}{\cos(\frac{\pi}{2} - \theta)} & \text{if } \theta \in [\theta_A, \theta_D[; \\ \frac{x_0}{\cos(\pi - \theta)} & \text{if } \theta \in [\theta_D, \theta_C[; \\ \frac{y_0}{\cos(\frac{3\pi}{2} - \theta)} & \text{if } \theta \in [\theta_C, \theta_B[. \end{cases}$$

Where θ_A (resp. θ_B, θ_C and θ_D) is the angle between MA (resp. MB, MC, and MD) and the horizontal. 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.

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

5 SIMULATIONS

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

5.1 Simulation model

5.1.1 Network topology and traffic 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 coordinates 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.

5.1.2 Mobile station mobility model

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. To calculate the coordinates of a mobile n at time t during an interval i of duration T^i_n, angle θ^i_n and acceleration a^i_n, we first calculate the distance D traversed by MS_n, $D = a^i_n * (T^i_n)^2 + V^{i-1}_n * T^i_n$. Then, we compute x^i_n, y^i_n local co-ordinates, $x^i_n = D\cos\theta^i_n$, $y^i_n = D\sin\theta^i_n$. At the end, we calculate the global co-ordinates by changing scale. To compute the velocity V^i_n, we use the following equations $V^i_n = a^i_n * T^i_n + V^{i-1}_n$. x^0_n (resp v^0_n) is randomly selected between $[0, diameter]$ (resp $[V_{min}, V_{max}]$). V_{min} and V_{max} are fixed at 10 and 20 m/s.

5.2 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).

Figure 3 plots the connection dropping probability against the increasing users arrival rate. Different values of Δt are considered. Remind that Δt is the time separating two successive reservation requests. We notice that the CDP increases with Δt. Indeed, more Δt observes high values, more the adjustment of the reservation intervals are spaced. Therefore, a mobile user may very likely leave its current cell before its corresponding reservation adjustment occurs. Consequently, a new call has more chances to be accepted when Δt is high. This can be noticed in fig. 4 where the call blocking probability is inversely correlated with Δt. It is better to choose a small value of Δt because the time interval adjustment is more accurate. Obviously, choosing a smaller value of Δt causes an overhead on processing time and signaling traffic. Consequently, a compromise have to be done between a reasonable processing time and a smaller call dropping probability. A simple solution can be the use of a CDP threshold and derive from fig. 3 the suitable value of Δt.

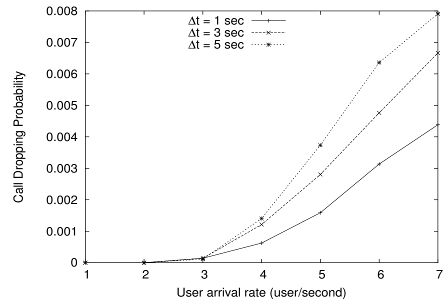

Figure 3: CDP vs. connection arrival rate

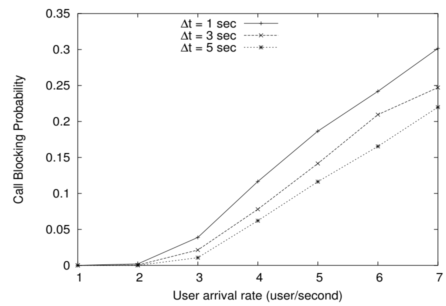

Figure 4: CBP vs. connection arrival rate

Figure 5 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 the TBR scheme since less bandwidth is available for new arrivals in TBR scheme as shown in fig. 6.

Figure 7 draws up, for the TBR scheme, the hand-

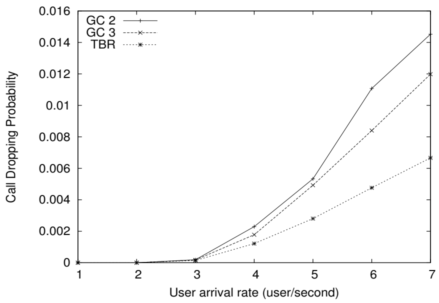

Figure 5: CDP vs. connection arrival rate for TBR and GC schemes for $\Delta t = 3$ *sec*

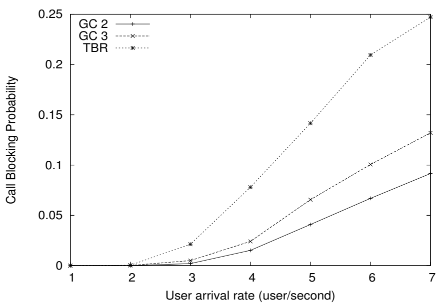

Figure 6: CBP vs. connection arrival rate for TBR and GC schemes for $\Delta t = 3$ *sec*

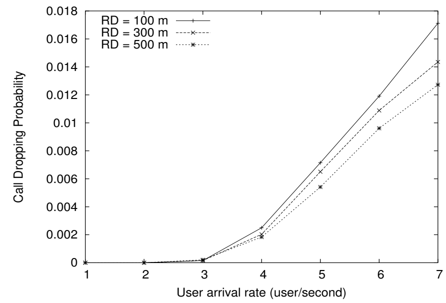

Figure 7: CDP vs. connection arrival rate for $\Delta t = 3$ *sec*

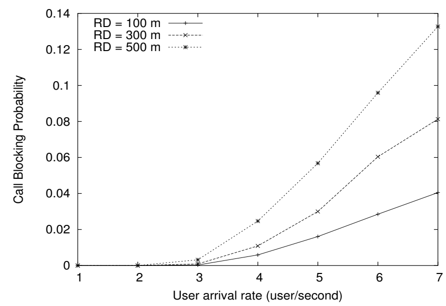

Figure 8: CBP vs. connection arrival rate for $\Delta t = 3$ *sec*

off blocking probability according to the arrival rates for $\Delta t = 3$ *sec*. Different values of *RD* are considered. We notice that the call dropping probability is inversely correlated with *RD*. Indeed, when the reservation distance increases, the adjustment of the reservation intervals is more accurate. However, when *RD* observes small values, a mobile user may very likely leave its current cell before its corresponding reservation adjustment occurs. Consequently, a new call has more chances to be accepted when *RD* is low. This behavior can be illustrated in fig 8.

6 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. Detailed simulation results have been derived to show the performance of TBR scheme 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.

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