Call Admission based on Interference in DS-CDMA Cellular Systems

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Abstract

The increase in the size of the wireless community together with new applications obliges better utilization of the scarce wireless resources. The requirement for communications on-the-move compels the call admissions mechanism to combat forced call termination. Channels need to be reserved in the surrounding cells, and call admissions must employ mechanisms considering these reservations. Keeping in mind that CDMA has been chosen as the air interface for the 3rd generation, we propose a call admission scheme based on interference. As opposed to the previous work in the literature, we have also developed a realistic mobility model to evaluate our proposal. We model the moving-in-groups behaviour of the subscribers on real maps while respecting the non-pass-through feature of parts of the terrain like households.

1 Introduction

Wireless communications has experienced major progress in the last two decades. Especially, the last decade has been the golden era for wireless communications to prove essential and practical. While *AMPS (Advanced Mobile Phone System), NA-TDMA (North American Time Division Multiple Access System)* and *IS-95 (Interim Standards-95)* served North America, *GSM (Global System for Mobile Communications)* dominated all European countries. The roaming feature of GSM has attracted major appreciation over the other named systems.

Two major metrics to be considered while evaluating cellular systems are call blocking and call dropping rates. Both failures result from the lack of wireless resources. The rejection of a new call request is called *call blocking* while the premature termination of the call without the will of the subscriber is called *forced call termination*. It is widely accepted in the literature that forced call termination is more annoying than call blocking.

Although the *communications on-the-move* requirement of the subscriber can be fulfilled by the *handover* (or *handoff*) mechanism, it does not guarantee uninterruption of the ongoing call. The call may be terminated by the system prematurely due to the lack of resources in the new cell. In order to provide uninterrupted service to the subscriber, the system must reserve enough resources in the new cell. Since the mobile stations are carried by autonomous subscribers, the system cannot dictate the next cell for the mobile. However, a good guess of the next cell will improve user satisfaction. The trivial solution to this problem would be to reserve a channel, called a *guard channel*, in *all* neighbouring stations. However, it is obvious that such a solution would waste the scarce wireless resources, and result in high call blocking rates. Thus, a more intelligent mechanism must be employed in determining the set of cells in which guard channels will be reserved though it is apparent that there is always a trade off between forced call termination and call blocking rates. In this paper, we propose a scheme that will improve forced call termination rate while keeping the call blocking rate at a reasonable level. We have also developed an advanced mobility simulator that can model the "movement-in-groups towards a destination" feature of thousands of *autonomous* mobiles over a given real map.

In the next section, we discuss previous work in literature. Section 3 describes how the reservation area is determined based on subscriber's movement pattern. In Section 4, channel reservation based on interference is discussed. The mobility model is introduced in Section 5. We provide numerical results in Section 6, and conclude in Section 7.

2 Previous Work

In [1], Gavish has introduced *Threshold Priority Policy (TPP)* against *Cutoff Priority Policy (CPP)*. In TPP, new call is accepted only if the number of new calls is below a certain threshold. On the other hand, in CPP, a limit is imposed on the total number of calls. In [1], reservations are implemented in terms of fixed number of guard channels, and the evaluation of the

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proposed scheme is based on a very simple model. In [2], a scheme with soft guard channels is introduced for CDMA systems by considering only the number of channels. However, Ma does not consider the soft capacity and interference sensitivity of CDMA systems, and does not explain how the reservation area is determined. In [3], Levine introduces the shadow cluster concept for TDMA/FDMA hybrid systems. Levine benefits from analytical methods to justify his work without considering the real life behaviours of the subscribers.

In [4], an interference-based reservation scheme is proposed for CDMA systems. However, the number of guard channels is again fixed. In [5], Liu introduces a scheme similar to the one in [4], considering *signal-to-interference ratio (SIR)* instead of interference. In [6], a dynamic channel reservation scheme is proposed in which only the new call and handoff arrival rates at a cell are considered. In our proposal, we overcome their deficiency of useless reservations not on the moving direction of the mobile. Furthermore, unlike [6] in which fixed number of guard channels is used, we optimize the number of guard channels and consider hot spots.

In [7], the subscribers are classified into high-speed and low-speed groups, and an influence curve is drawn based on dwell time and subscriber speed.

3 Reservation Area Based on Movement Pattern

The reservation area is the ellipse-shaped region that represents the area in which the mobile is likely to reside in the near future. This area is drawn by utilizing the location, speed and direction information of the mobile. All this information can be gathered by *GPS (Global Positioning System)*.

In case the future mobility pattern of the mobile cannot be estimated the reservation area is circle-shaped. However, considering the following hints, the reservation area can be better shaped like an ellipse:

- A mobile is likely to keep its direction as an inertial behaviour. This hint can be concluded from the fact that subscribers tend to move towards a destination as opposed to making random moves over the terrain, though there may be minor deviations in direction due to physical obstacles.
- A mobile that has been changing its direction frequently in the near past is likely to keep doing so in the near future. A mobile moving on streets will exhibit such a behaviour.
- The likeliness that a mobile will be at a specific point in the near future is directly proportional to the distance.
- The speed of the mobile, the duration for which the subscriber has requested uninterrupted service and the maximum allowed dropping probability determine the size and shape of the elliptical region.

An ellipse has two axes, called major and minor axes. The length on the major axis, the width on the minor axis, the locus of the center together with the orientation, i.e. the angle between the major axis and the x-axis, define the ellipse. In order to specify the reservation area, we need to formulate these four parameters of the ellipse. The direction of the mobile dictates the orientation of the ellipse. The length in the major axis is determined by the speed of the mobile and the duration for which reservations are to be made. The width in the minor axis is determined by the variance in the direction of the mobile in the near past together with the length in the major axis. The weighted average of the past directions is used to estimate the next change in direction. If the estimated value is greater than or equal to 90°, the shape of the ellipse is distorted to a circle. A factor of 30° is added to avoid diminishing the minor axis in case of an estimated value of 0°. Finally, the locus of the center of the ellipse is determined from the one of the foci and the length and width of the ellipse. The ellipse is drawn such that the first focus is located at the current position of the mobile.

Although there is some previous work in the literature proposing channel reservation to decrease forced call termination rate, one guard channel is reserved in each candidate cell for each reservation request. However, since the mobile will move into only one of the candidate cells, the rest of the reservations will remain as redundant capacity, resulting in higher blocking rates. To help keep blocking rate at a low value, we associate a *likeliness value* with each reservation request. The likeliness value specifies how likely it is that the mobile will move into the candidate cell. The number of guard channels reserved by each base station is determined by the sum of likeliness values of all incoming reservation requests. Thus, the number of guard channels is less than or equal to the number of reservation requests. The likeliness value is determined by the distance between the candidate cell center and the mobile together with the angle between the direction of the mobile and the line connecting the candidate cell center. The likeliness can be formulated as:

$$L = \omega_1 \cdot \left(1 - \frac{"mobile - cellcenter" dis\tan ce}{2 \cdot a + R}\right) + \omega_2 \cdot \frac{|\beta_1 - \beta_2|}{\pi}$$

where

L is the likeliness that mobile will visit the cell during the reservation period,

ω_1 is the weight of the mobile-cell center distance
ω_2 is the weight of the location of the cell center with respect to the direction of the mobile,
a is the semi-major axis (half of the length) of the ellipse representing the reservation area,
R is the cell radius,
β_1 is the angle between the line that connects the mobile to the cell center and x-axis,
β_2 is the direction of the mobile.

4 Interference-based Reservation of Channels

CDMA cellular systems are classified as interference sensitive systems, i.e. the performance of the system is heavily dependent on the interference encountered, since the signal of the intended subscriber is distinguishable from other signals and noise if and only if the required E_b / N_o ratio is maintained. Therefore, in CDMA systems, channel reservation must be implemented based on interference as opposed to the number of channels as in TDMA/FDMA systems. This is accomplished by granting a channel to a new call request only if the total interference received by the base station will remain below the total interference margin even when the guard channels are also occupied. The reader is referred to [4] for further details of interference based channel reservation. The work in [4] considers fixed number of guard channels in each cell. We extend this idea to adaptive number of guard channels by making use of the reservation area concept.

5 The Mobility Model

The mobility model used in the evaluation of a cellular system is one of the key measures of the validity of the evaluation. Unrealistic mobility models will prove a proposed scheme to be true only under unrealistic conditions and make the reader feel suspicious about the proposal. A realistic mobility model should employ the following features:

- Since the mobiles are carried by the subscribers, they should exhibit *autonomous* and *random* mobility patterns while capturing the *moving-in-groups* behaviour of the society. In other words, the mobility patterns of the mobiles should be independent although an overall view gives the impression that people are moving back and forth between their offices and homes.
- The terrain should include hot spots. Therefore, the mobiles must be distributed over the terrain in a *non-uniform* manner.
- The terrain should also include different structures like the houses, streets, highways, malls, lakes and etc. Mobiles should respect to the *non-pass-through* feature of some structures. For example, the mobiles should not drive over the houses.
- The transitions between these different structures should be well defined and the call patterns should also change accordingly. For example, the probability that a mobile gets on the street should be defined, and the call pattern of the mobile on the street should be different from the one at home.
- The mobility pattern should also include the calculation of the actual interference values.

Fig. 1 A part of Istanbul map (Asian side)

The last item is especially important in the case of CDMA systems. Almost all of the work in literature utilizes the approximation provided in [8] that was published in 1991. This approximation makes the unrealistic assumption that the mobiles are uniformly distributed inside the cell. Since this violates the second item above, employing the approximation in [8] implies the violation of both of the second and the last items. In our mobility model, we aggragate the actual interferences created by each mobile based on the locus of the subscriber by assuming a free space propagation model. The interference from each mobile is propagated to the neighboring 18 cells.

In this paper, we also introduce a realistic mobility model and justify our proposal for channel reservation with this model. The mobility and call patterns of the subscribers are determined according to a real map (See Fig. 1). Thousands of mobiles make autonomous moves while obeying to the features listed above. The simulator we have implemented moves the mobiles over a given map while generating calls with the given distributions.

Given a topography and a parameter set specifying the properties of the different types of structures in the terrain, the mobiles exhibit realistic movement patterns. The details of the mobility model are given in [9].

6 Results

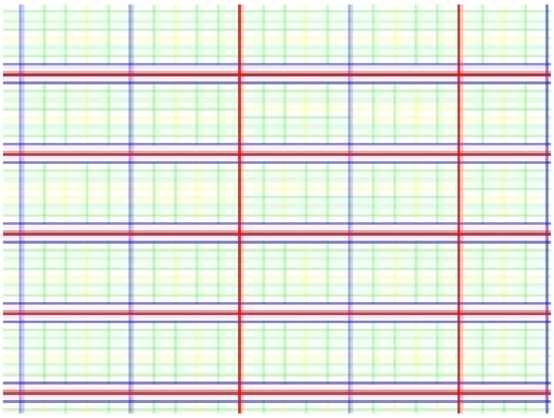

Fig. 2 A Manhattan style topography

At the moment we are providing some early results. The tests have been performed on a simple map (see Fig. 2) of 48 km^2, which is a perfect example of a Manhattan style topography, therefore not much realistic. Currently, we are digitizing and colouring a real map of Istanbul, a metropolitan city of more than 10 millions of population. Just a part of the map before colouring is given in Fig. 1.

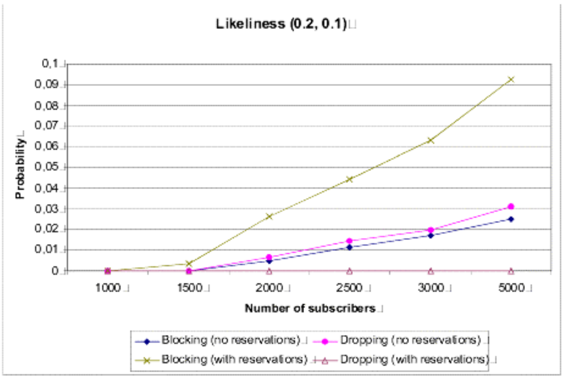

Fig. 3 Reservations made with high likeliness values

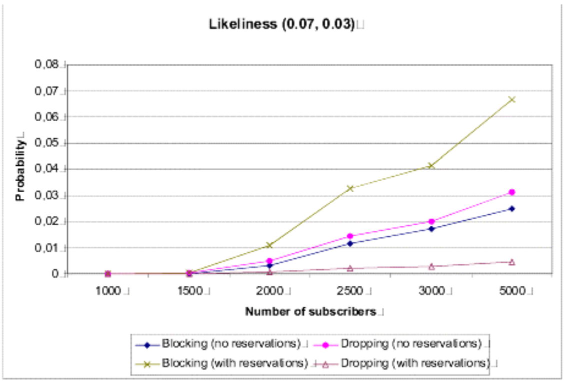

Fig. 4 Reservations made with medium likeliness values

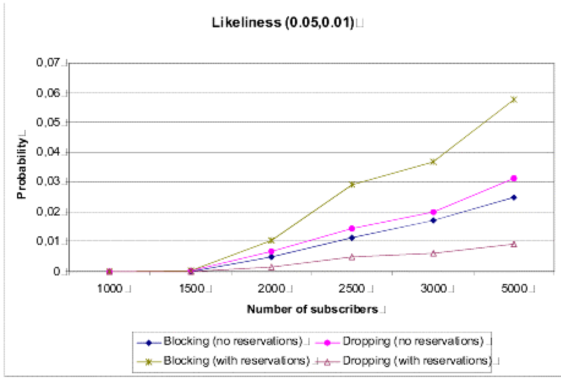

Fig. 5 Reservations made with low likeliness values

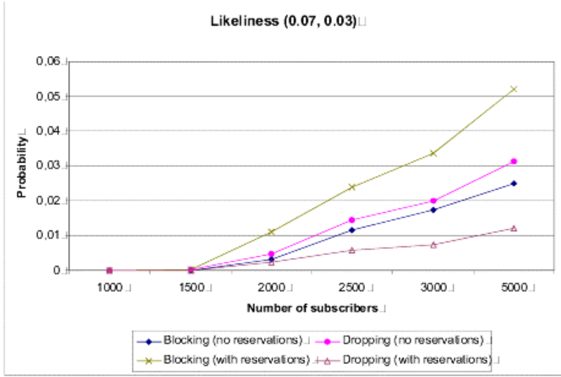

Fig. 6 Reservations made with medium likeliness values for shorter reservation duration

In the tests that were run with the topography of Fig. 2, 1000 to 5000 mobiles with very active call patterns were used. The cell radius was set to 1 km, and the speeds of the mobiles ranged from 5 km/hr to 150 km/hr. The outer cell interference was propagated to 18 neighbouring cells and a single frequency band was used in all cells. The results are presented in Fig. 3-6.

Fig. 3-5 show the effect of the ω_1 and ω_2 parameters. All these graphs represent the performance of a very heavily loaded network. From Fig. 3, it is apparent that application of the reservation scheme reduces call dropping probability from 0.03 to 0 at cost of increasing blocking probability from 0.025 to 0.09. Same behaviour can be observed in Fig. 4 and 5. As the weight parameters are decreased, the increase in blocking probability is reduced to a reasonable level.
The increase in blocking probability is due to the reservations made in the candidate cells intersected by the reservation area. Therefore, the size of the reservation area is one of the major factors that effect the increase in blocking probability. Since the length of the reservation area in the major axis is determined by the reservation duration, the effect of reservation

duration on the blocking adn dropping probabilities also needs to be examined. The reservation duration for Fig. 3-5 is 120 seconds. In other words, the reservations are made 2 minutes ahead. The experiments that consititute Fig. 4 have been repeated for a reservation duration of 30 seconds. The results of these new tests are provided in Fig. 6. It is apparent that shorter reservation duration improves system capacity. This is due to the decrease in redundant capacity. The parameters like likeliness weights and reservation duration need can be better tuned with more tests.

7 Conclusions and Future Work

In this paper, we have proposed a new call admission scheme that employs channel reservations to lower the forced call termination rate. Since the air interface in the 3rd generation cellular systems will be CDMA, the reservations are made based on interference. We have associated a likeliness value for each reservation request to minimize redundant capacity. Finally, we have evaluated our proposed model with a realistic mobility model.

More tests will be done as a future work. Currently, we are digitizing and colouring the map of Istanbul for the tests. The new test results will be analyzed in more detail to figure out the optimum values of the parameters.

8 Literature

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