Using Statistical Data for Reliable Mobile Communications

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Abstract

We examine the extent to which statistical mobility information can increase the reliability of the service experienced by users in mobile networks. Interrupted or dropped calls are an aspect of reliability that stems from the mobility of users. An existing user can move to a cell where there are no resources available to support his call. A natural solution is the reservation of resources in multiple cells that the user is likely to move to. This scheme is called *selective reservations* and it relies on predicting the next move of the user. Recently, there has been some work on estimating the movement probabilities (also known as the *mobility profile*) of the user. In this paper, we quantify the usefulness of the mobility profile to improve the reliability of the service perceived by the mobile users. We identify two parameters which characterize the profile: *Accuracy* and *Focus*. Accuracy expresses the probability that the host will move as we expect it to. Focus describes how well we can identify patterns in the movement of the users. In our simulations, we examine the effect of the quality of the predictions on the performance of the system. We show that Accuracy and Focus have great impact on the performance of selective reservations. We also show how flexibility in hand-offs can help in decreasing the dropping probability, and how this can be facilitated by letting the users make a second try at moving in case it fails the first time.

1 Introduction

In this paper, we examine the extent to which user-mobility information can increase the reliability of mobile networks. The mobility of users [1] poses many reliability issues in wireless networks. We focus on premature call termination or call dropping probability, which is an essential part of the reliability a user perceives from a service. *Selective reservations* is a scheme where we reserve resources in the neighboring cells anticipating that the user will move into one of them. Obviously, the effectiveness of this method relies on our ability to predict such cells accurately, which in turn, depends on the quality of the statistical data of the user movements. The goal of our work is to model and quantify the effect of the quality of this data on the reliability of the network.

[1] We use the following terms interchangeably: *user, host, mobile host.*

Advance reservations is an approach that promises to increase the reliability without lowering the utilization. The idea is to reserve, ahead of time, resources [2] for each user to guarantee their availability once he moves. Reserving in all the neighboring cells of the current [3] cell leads to low utilization; fewer users can be supported. This motivates the need to request reservations only in cells which the user is more likely to move into. This approach is called *selective reservations*, and it has been studied by several researchers [8, 1, 5, 6]. Most previous research has focused on the issue of how to predict the right cells given some statistical data. Obviously, the validity of the predictions is crucial for the effectiveness of the selective reservation scheme.

Here, we study the importance of the quality of the predictions on the performance of the network. First, we introduce two parameters, *Accuracy* and *Focus*, that try to capture the quality of the statistical data. Accuracy represents the likelihood that the host will move as predicted by the mobility profile [4]. Focus describes how well we can identify patterns in the movement of the users. Note that Accuracy and Focus capture significantly different aspects of the probability. For example, if we assume only three neighboring cells, the data may be of narrow Focus, e.g., [1,0,0], or broad Focus, e.g., $[\frac{1}{3}, \frac{1}{3}, \frac{1}{3}]$. If we assume this to be correct, in the narrow Focus case, the user will move to the first cell. In the broad Focus case, the user may move into any one of the three cells with the same probability. However, whether a user really follows this probability distribution depends on the Accuracy of the statistical data. In the narrow Focus case, it may turn out that, in reality, the user goes to the first cell only 60% of the time.

The rest of this paper is structured as follows. In Section 2, we present our model and previous work. In Section 3, we examine the effect of Focus and Accuracy on the reliability of the network by way of simulations. This is followed by the results and discussion in Section 4. In Section 5, we present the conclusions from our work.

2 Background and Model

In this section we elaborate on the concepts of selective reservations and mobility profile, and discuss how selective reservations can use a mobility profile. We also discuss how these issues are addressed in our model. We conclude the section by defining some performance metrics to determine the effectiveness of the selective reservations scheme.

2.1 Selective Reservations

Selective reservations is a mechanism that attempts to decrease the number of calls that are dropped. It is clear that reserving resources in all the neighboring cells for every mobile user will lead to a severe under utilization of resources, which impacts the network in several ways. Firstly, it limits the number of new users that can be admitted into the network, leading to more calls being *blocked*. The second problem arises due to the fact that the existing mobile users could find it impossible to move into any other cell due to a lack of resources, which can lead to an immediate premature termination of an ongoing call, which we refer to as a *drop*. Alternatively, instead of an immediate termination, the host could continue to receive

[2] Resources refer mainly to bandwidth, in this paper. Each cell has a maximum amount of bandwidth which the users share.

[3] The current cell for a user is the cell in which it is at that instant.

[4] Mobility profile is the movement probabilities of the users. We use these two terms interchangeably.

service from its present cell and try to move again later. We refer to this event as *second try*. Depending on the availability of resources, the move can be successful the second time, or it can fail. We refer to the termination of the call as a *drop*. A second try represents the flexibility of a hand-off between two cells. For example, we can think of an overlapping area where both cells could provide service.

Several researchers have studied how selective reservations can be employed in a wireless network. Advance reservations can facilitate on-going calls, but they consume resources. The issue is two-fold: a) estimate the probabilities of the movement, and b) have a policy to decide which cells to make reservations in. Levine et al. [8] propose a shadow cluster model, wherein there is a cluster of cells that are the most likely next destinations for the current cell. They propose making reservations only in that shadow cluster. Aljadhai et al. [1] propose a path predictability model. This is supposed to give an indication of which path a mobile host would take, enabling reservations only in those cells that lie in the host's most likely path of movement. Both these describe methods to compute the probabilities of movements. A selective reservation scheme could focus more on the second question: how we can use mobility profile [2].

2.2 Mobility Profile

A mobility profile contains information about the probabilities of the host moving from one cell into another. The current base station of a mobile host could consult the mobility profile and make advance reservations accordingly. The reservations would be made if the probability of movement into a cell exceeds a certain threshold. It could be specified by the mobile host as part of the service charge, or it could be governed by a network management policy. The mobility profile can vary by user, by cell, by the class of users, and it can vary with the time (morning versus evening). Several researchers have examined different aspects and dependencies of the mobility profile and how we can predict the movement of a user [8, 1, 2]. In our work, we assume that the mobility profile is an estimate of the probabilities of movement. Our goal is to study the properties, Accuracy and Focus, of the profile and how these properties affect the usefulness of the mobility profile.

2.3 Performance Metrics

There are many ways to define the effectiveness of the service that a network provides. In our work, we focus on the following the performance metrics.

- *blocked calls:* This indicates the total number of calls blocked. This would happen when a host wants to enter the network for the first time, but it cannot due to lack of resources.
- *dropped calls:* A call is dropped if it can not be accommodated by the cell. A host is dropped from the system, when it can not move to a cell even after its second try.
- *successful hand-offs or visits:* This is the total number of successful hand-offs, that is, movement of a mobile host from one cell to another. Note that we count as successful even the hand-offs of a host that eventually gets dropped from the system.

- *percentage of calls that succeeded on the second try:* A host cannot move into a new cell due to lack of reservations as mentioned earlier. The mobile host waits for a random time, and then tries again. We count the number of such successful second attempts.

3 Simulation Experiments

We conducted simulations to quantify the effect of the mobility profile on the effectiveness of selective reservations. The simulation in mobile networks depend on a large number of different parameters. Our goal is to isolate the effect of the mobility profile. For this reason, we preferred to keep the model simple, so that the results could lend themselves to a straightforward interpretation.

3.1 Network Model

The network environment consisted of 19 cells. Some of our initial results suggest that the number of cells does not seem to affect the performance. The results we show here correspond to 19 cells, which is comparable to the values (13,37,19 cells) that are usually used in similar simulations [2] [1] [10]. We set the cell capacity to 10,000 units each. Each cell is hexagonal in shape with six neighbors each.

We let hosts enter the network one at a time. The host enters a random cell if there are resources in that cell. If there are no resources available at that instant, then the call is blocked. If a call is admitted, the mobile user moves around in the system until it is dropped or its call duration ends. Each time a host moves into a new cell successfully, it constitutes a successful visit. Sometimes, it might happen that a host tries to move into another cell but finds no available resources. In this case, it tries for a second time. If it fails again, it is dropped.

When a host successfully enters the system, it submits its mobility profile to the base station of the cell. The base station reads the profile and makes the reservations accordingly if there are enough resources available. The host will stay in the cell for a some time (depending upon the cell latency specified) and then try to move into another cell. When a host moves into another cell, all its previously held reservations are released. A host finally exits the system at the end of its call.

3.2 The Mobility Profile: Focus and Accuracy

We assume that we are given a mobility profile for each host. The reservations are done based on this mobility profile. We consider the Focus of each profile to decide on the number of cells to make a reservation in. We say that a mobility profile has *Focus P%* when we need to make reservations in P% of the neighboring cells,

The Accuracy of the mobility profile expresses the validity of the probability movements. The host moves to a cell with reservations only A% of the time. This probability A% quantifies the Accuracy of the estimated probabilities that we use to make our reservations. We experiment with accuracies of 70%, 80% and 90%. Unless specified otherwise, the accuracy is 90%. For implementing the Accuracy, we ensure that, A% of the time, the host moves into a cell that has reserved resources on its behalf.

3.3 Simulating Selective Reservations

We examine four different mobility profile qualities with respect to their focus:

- *No-Focus* or *all reserve*: it is in effect a non selective reservation approach that corresponds to a very broad Focus. We request reservations in all neighboring cells.
- *Focus 80%*: it corresponds to low Focus; we request reservations five out the six neighboring cells on average.
- *Focus 50%*: it corresponds to medium Focus; we attempt to reserve in three out of the six neighboring cells on average.
- *Focus 15%*: it corresponds to very *ideal* Focus where we always know exactly which cell we want to reserve.

Note that *Focus 15%* corresponds to an ideal case in our simulations. If we have only six neighboring cells, with Focus 15% we select often only one cell for reservations. This corresponds to the ideal case that the host always follow the expected trajectory.

4 Results and Discussion

4.1 Focus and Accuracy

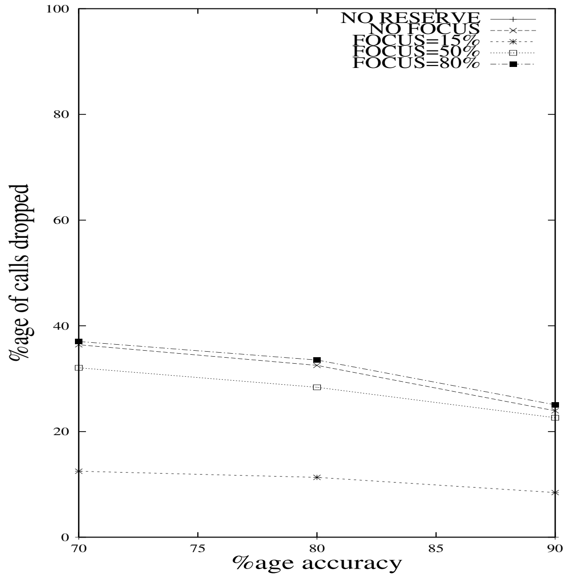


Figure 1: **Percentage of dropped calls versus accuracy**

Figure 1 shows how the Accuracy of the profile affects performance. As seen in the figure, the percentage of dropped calls decreases as the accuracy increases. The best performance among the reservations scheme is with Focus of 15%. This indicates that for the optimal performance, Focus as well as Accuracy is important.

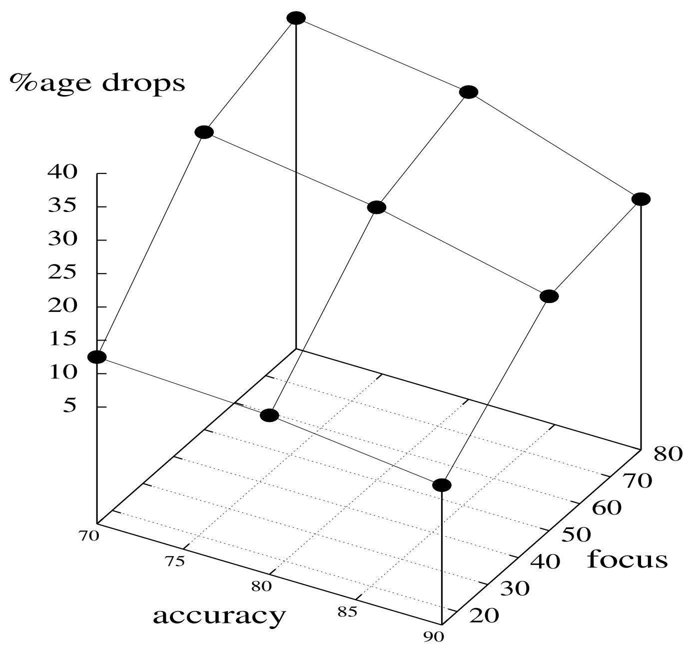


Figure 2: **Variation of dropped calls with focus and accuracy**

Figure 2 shows how the number of dropped calls varies with focus and accuracy. The drops decrease in number as the Focus becomes narrower (i.e., tending towards 15%), and also as the Accuracy increases (i.e., from 70% to 90%). The best performance (i.e., the least number of drops) is seen when Focus is 15% and Accuracy is 90%. The largest number of drops is seen when the accuracy is only 70% and focus is 80%. As we mentioned earlier, Focus 10% corresponds to making reservation in one cell, 50% corresponds to three cells, and 80% corresponds to 5 cells.

4.2 Blocked Users

Narrow Focus can significantly decrease the number of blocked users. Figure 3 shows the number of blocks versus the interarrival time [5]. As expected, *Focus 15%* experiences the least number of blocks. This can be attributed to the minimal reservations made in this case which leaves more resources free to be utilized by new calls. Accuracy is an important determinant in the effectiveness of these reservations. In this specific case we are assuming 90% accuracy. Later, we will show how the performance is affected when accuracy drops to 80% and 70%.

As the *Focus* broadens, the number of blocked calls starts increasing. This can be explained by the fact that broader Focus implies more reservations which means fewer resources for new

[5]Note that the plot for no reservations scenario is not seen in the graph. This is because it is so close to zero that it coincides with the x-axis. This comment is applicable to any other graph where the plot is mentioned but not seen.

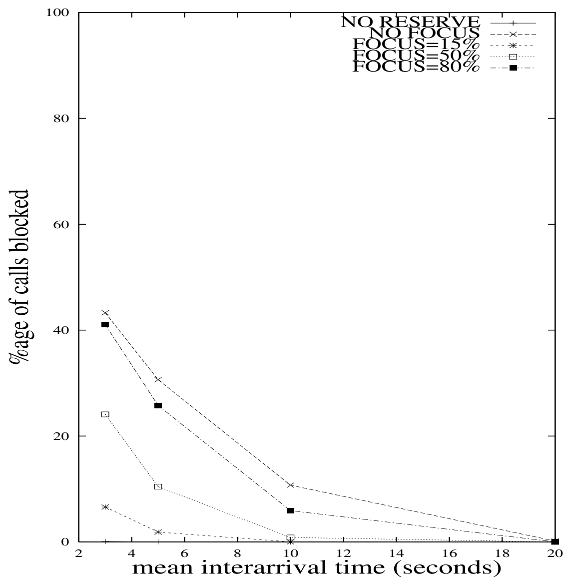


Figure 3: **Blocked users versus interarrival time**

calls. Therefore, we see an increase in the number of blocks. Indeed, *Focus 80%* offers only marginally better performance than *No Focus.* Note that no-reservations outperforms any kind of reservation scheme.

Figure 3 also shows how the number of blocks decreases as the load decreases. Here, the load is determined by the interarrival time which is shown on the x-axis. Smaller interarrival time implies higher load.

4.3 Reliability: The Dropped Users

A network is said to be reliable if the users do not get dropped in the middle of their calls. Indeed, dropping probability is an important metric of the network performance. Focus has a dramatic effect on the number of dropped hosts. Figure 4 shows the dropping probability versus the interarrival time. *Focus 15%* turns out to be the best in terms of the least number of calls dropped. The reason is the same as in the case of blocked calls - fewer reservations. *Focus 15%* seems to drop more than 10% fewer calls as compared to *No Focus.*

No-reservations has the lowest number of dropped calls since the users do not have to contend with reserved resources. As the interarrival time increases, the load on the system decreases and consequently, the number of dropped calls also decreases.

4.4 Successful Hand-offs

Narrow Focus can significantly increase the number of successful hand-offs. Figure 5 shows the number of successful hand-offs versus the interarrival time. As we can see, the narrower the Focus, the better the performance as compared to *No-Focus.* More specifically, *Focus 15%* is the best, and allows about twice the number of visits compared to *No Focus.* On the other hand, *Focus 80%* is about the same as as *No Focus.*

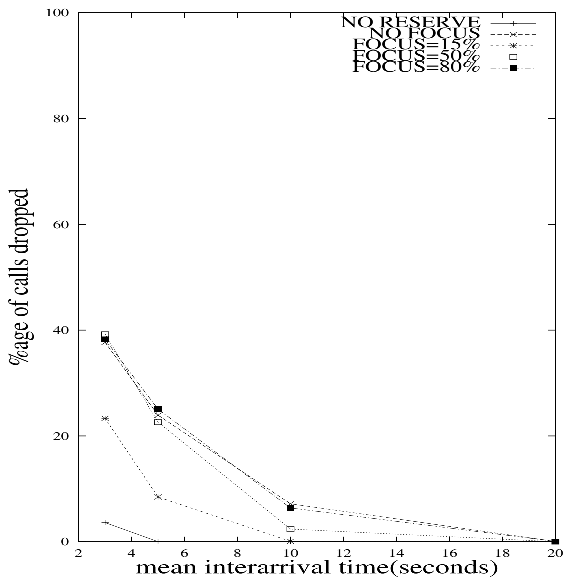


Figure 4: **Dropped users versus interarrival time**

4.5 The Importance of Flexibility During the Handoff

Flexibility during the hand-off can greatly increase the reliability of the network. In addition, narrow Focus significantly facilitates the success probability of the second attempt for movement. Figure 6 shows the percentage of successful hand-offs on a second try versus the interarrival time. As seen in the figure, *Focus* offers significant advantage over the *No Focus*.

For low load (i.e., larger interarrival time), almost 100% of the second tries succeed. This implies that the mobile hosts are able to find resources, if they try again. However, as the load increases, the success rate decreases. Intuitively, this is because when the load is high, there is more contention for resources. Even if someone from the cell in question leaves, it is more likely that its position will be filled with an existing host or a new arrival.

Flexibility can be provided if there is overlap between adjacent cells. In such a case, if a host wants to move into a cell but finds no resources the first time, it can still continue to stay on in the current cell and then try again for resources in the new cell. This can be facilitated by overlapping cells.

4.6 Burstiness

We introduce burstiness in the arrival pattern. Intuitively, the more burstiness the system experiences, the worse the performance. We experiment with 0%, 10%, 20%, 30% and 40% levels of burstiness. (The percentages refer to the fraction of the total calls that were bursty arrivals.)

Figure 7a shows the effect of burstiness on blocked calls. As we expected, the number of blocked calls increases for all cases i.e., with or without reservation. So, for example, we have more blocked calls in the case of selective reservations with Focus 15%, when the burstiness increases from 10% to 30%. Also note that the relation between reservations and no-reservations still holds. So, we still have no-reservations experiencing the least number of

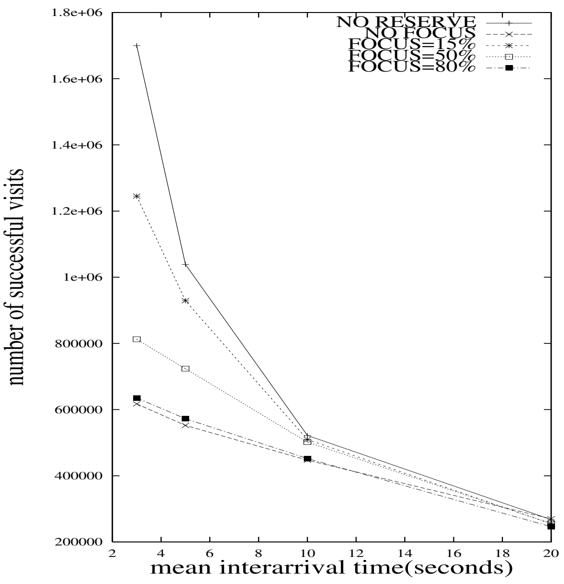


Figure 5: **Successful handoffs versus interarrival time**

blocked calls and *No Focus* experiences the most. Reservations with some *Focus* do better than *No Focus* but not as well as no-reservations. Among selective reservations, blocked calls are less when the Focus is 15% as compared to 80%. Figure 7b shows that dropped calls exhibit similar behavior: the drops are fewer in number when the Focus is narrower.

Figure 8a shows how the number of successful visits varies with the burstiness. Interestingly, the number of visits seems to go up as the burstiness increases. This can be explained by the fact that as burstiness increases, blocks and drops increase as seen in Figure 7. This implies that the system will be less loaded for the rest of the users that exist. Consequently, the existing users find themselves having more room to move about and thus make more number of successful visits. Note that new arrivals do not count as successful visits. Thus, long lived calls contribute more to an increase in the number of successful visits as opposed to many short lived calls.

Figure 8b shows how second try calls are affected by burstiness. The number of second try successes drop a little. This seems to indicate that even though there is more loss due to increased burstiness, the existing users are substantial enough that there is no corresponding increase in the fraction of second try successes. Nevertheless, the relative relationship between the different cases of reservation still holds, with no-reservation outperforming all others.

4.7 Other Results

The above set of results was for the case where the interarrival time and the cell latency were exponentially distributed. We also performed the entire set of experiments for three other cases:

1. exponentially distributed cell latency; constant interarrival time

2. constant cell latency; exponentially distributed interarrival time

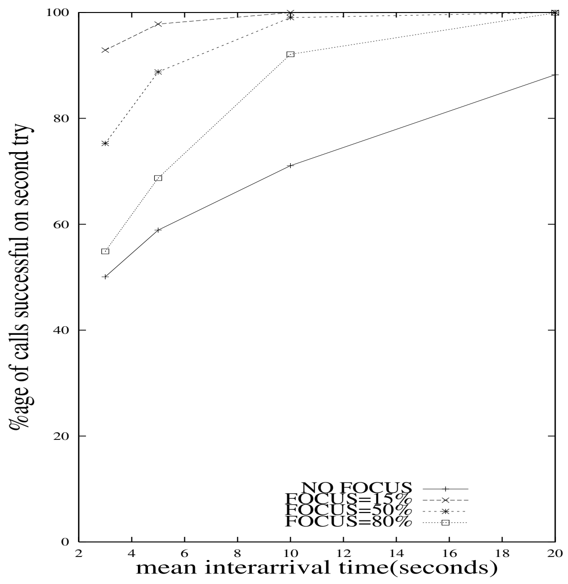


Figure 6: **Percentage of hand-offs that succeeded on a second try versus interarrival time.**

3. constant cell latency; constant interarrival time

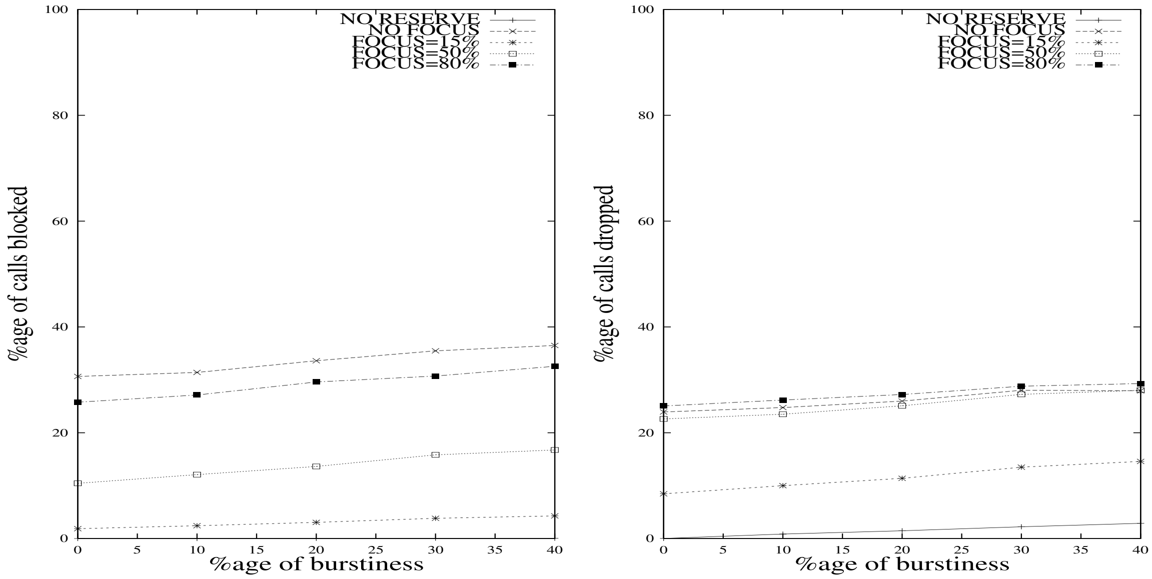
The graphs are shown in the appendix. They exhibit similar behavior to what we have seen in the graphs so far, i.e., no reservations seem to be better as compared to reservations with any Focus, and Focus of any kind is better than No Focus.

5 Conclusions

In this paper, we examined how the mobility profile can affect the reliability i.e., improve the dropping probability of a wireless service. We introduced two parameters to describe the quality of the mobility profile: Focus and Accuracy. The Accuracy of the prediction quantifies the validity of the statistical data, while the more subtle Focus parameter quantifies the behavior of the user. In other words, it represents the number of cells in which we need to reserve resources. We utilized the concept of a mobility profile to implement a selective reservations scheme, where the mobile host reserves resources only in those cells to which it is likely to move. The performance metrics for the system include the number of blocked calls, the number of cells each user can visit successfully, the number of calls that have to be terminated prematurely or dropped, and the number of users that can move successfully on a second try. We performed simulations for *Focus 15%*, *Focus 50%*, *Focus 80%* and *No Focus* for Accuracy of 70%, 80%, and 90%. Our results indicate that Focus and Accuracy are crucial parameters for the effectiveness of selective reservations.

Our results can be summarized in the following points:

- We introduced the concept of Focus that captures concisely how the user behavior lends itself to the case of reservations.



(a) Effect of burstiness on blocked calls

(b) Effect of burstiness on dropped calls

Figure 7: **Blocks and drops versus burstiness**

- Narrow Focus gives better performance as compared to broad Focus. As expected, *Focus 15%* is much better than *Focus 50%* and *Focus 80%*. Our results suggest that for Focus of 50-80% (3-5 cells) reservations hurt the performance of the network.

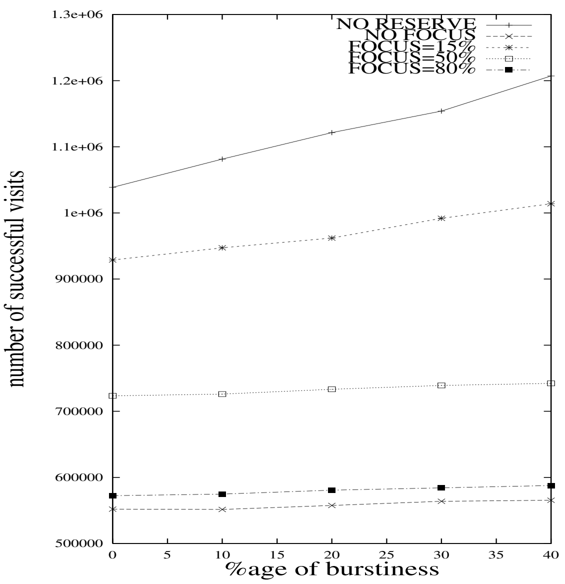
- Focus alone is not effective in extracting the optimum out of a system; Accuracy is also very important. Thus, Focus and Accuracy capture our Ability to do selective reservations in an effective manner.

- Hand-off flexibility can significantly decrease the dropping probability. In practice, we want to give hosts a large time interval in which they can do the hand-off between cells. For example, one way to encourage this is to have large areas of overlap between cells. This was studied by introducing the idea of second tries. We observed that second tries can improve the performance significantly. Even with high loads, more than 50% of second attempts were successful.

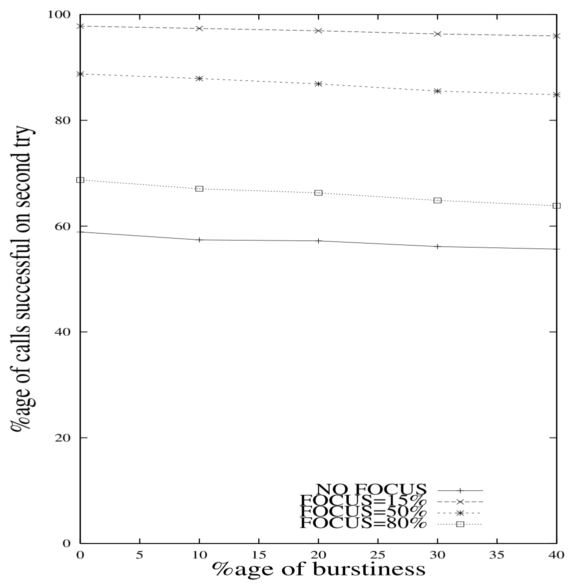
Our results also show that no reservations seem to be relatively better than reservations in terms of performance. We plan to investigate this in more detail and study the conditions which would be ideal for making reservations. We believe that the introduction of Focus and Accuracy is a first step in understanding and modeling this problem.

References

[1] A.R.Aljadhai and T.F.Znati. *A Framework for Call Admission Control and QoS Support in Wireless Environments.* Proceedings of IEEE INFOCOM '99. pp.1019-1026



(a) Effect of burstiness on number of visits



(b) Effect of burstiness on second try successes

Figure 8: **Visits and second tries versus burstiness**

[2] V.Bharghavan, J.P.Mysore *Profile Based Next-Cell Prediction in Indoor Wireless LANs.* IEEE Singapore International Conference on Networking, 1997

[3] Kevin Brown, Suresh Singh. *A Network Architecture for Mobile Computing.* IEEE INFOCOMM '96

[4] Guohong Cao, Mukesh Singhal. *Distributed Fault-Tolerant Channel Allocation for Mobile Cellular Networks.* Proceedings of IEEE INFOCOMM '99. pp.584-591

[5] Rohit Ghai, Suresh Singh *An Architecture and Communication Protocol for Picocellular Networks.* IEEE Personal Communications Magazine. Vol1(3). 1994, pp.36-46

[6] Tomasz Imielinski, B.R.Badrinath *Mobile Wireless Computing: Challenges in Data Management.* Communications of the ACM, vol.37, issue 10. 1994

[7] Rahul Jain, Edward Knightly *A Framework for Design and Evaluation of Admission Control Algorithms in Multi-Service Mobile Networks.* Proceedings of IEEE INFOCOM '99. pp.1027-1035

[8] David Levine, Ian Akyildiz. *A Resource Estimation and Call Admission Algorithm for Wireless Multimedia Networks Using the Shadow Cluster Concept.* IEEE/ACM Transactions on Networking. Vol.5. No.1. Feb.1997

[9] Sanket Nesargi, Ravi Prakash *Distributed Wireless Channel Allocation in Networks with Mobile Base Stations.* Proceedings of the IEEE INFOCOM '99. pp.592-600.

[10] Parameswaran Ramanathan, Krishna M. Sivalingam, Prathima Agrawal, Shalini Kishore *Resource Allocation during handoff through dynamic schemes for mobile multimedia wireless networks.* Proceedings of IEEE INFOCOM '99. pp.1204-1211

[11] Suresh Singh *Quality of Service Guarantees in Mobile Computing.* Journal of Computer Communications 1996 Vol.19.pp.359-371

[12] Anup Talukdar, B.R.Badrinath, Arup Acharya *MRSVP: A Reservation Protocol for an Integrated Services Packet Network with Mobile Hosts.*

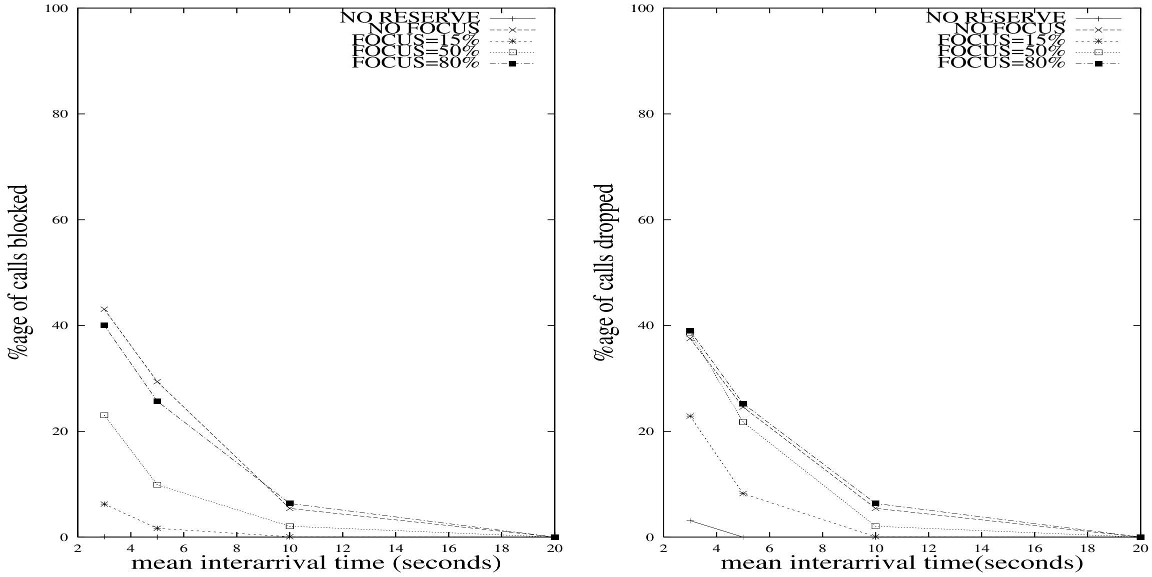
[13] Andreas Terzis, Mani Srivastava, Lixia Zhang *A Simple QoS Signaling Protocol for Mobile Hosts in the Integrated Services Internet.* Proceedings of IEEE INFOCOM '99. pp.1011-1018

A Appendix

The set of results shown in Section 4 was for the case where the interarrival time and the cell latency were exponentially distributed. We also performed the entire set of experiments for three other cases:

1. exponentially distributed cell latency; constant interarrival time
2. constant cell latency; exponentially distributed interarrival time
3. constant cell latency; constant interarrival time

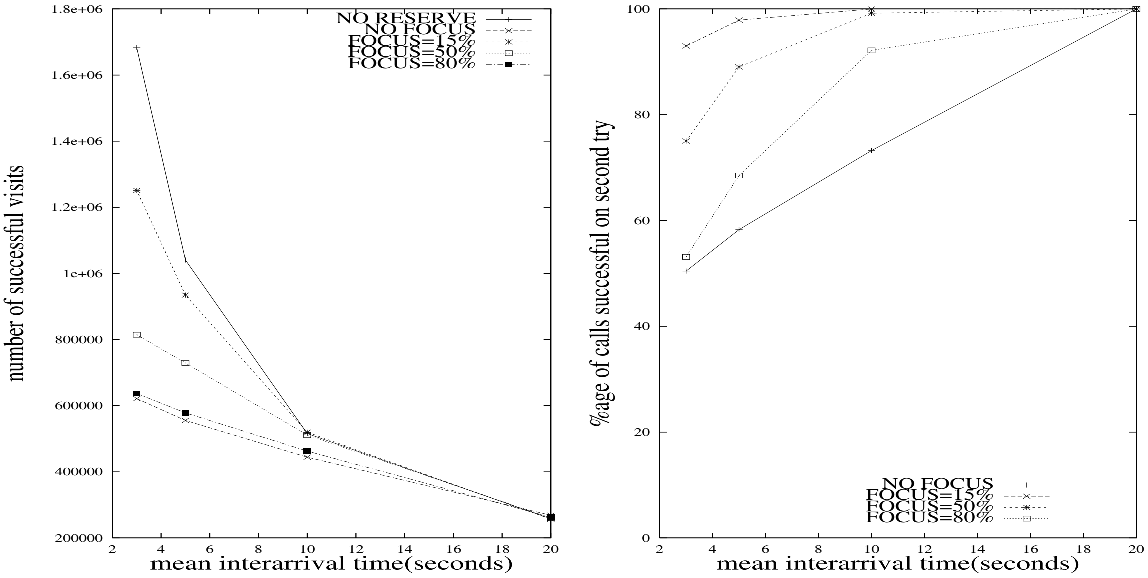
The results are shown in Figures 9 and 10 for Case 1, Figures 11 and 12 for Case 2, and Figure 13 and 14 for Case 3. These graphs show that Focus of any kind is better than No Focus in that that it blocks fewer users, drops fewer users, allows more successful visits, and allows more successful second tries. Narrower the Focus, better the performance; Focus 15% in our case outperforms Focus 50% and Focus 80% by far. No reservations still continues to be better than Focus and No Focus.



(a) Blocked users versus interarrival time

(b) Dropped users versus interarrival time

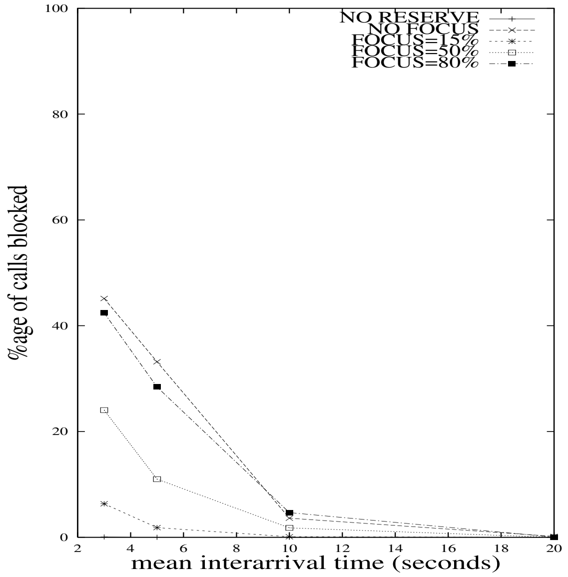
Figure 9: **Blocks and drops versus interarrival time - constant interarrival time**



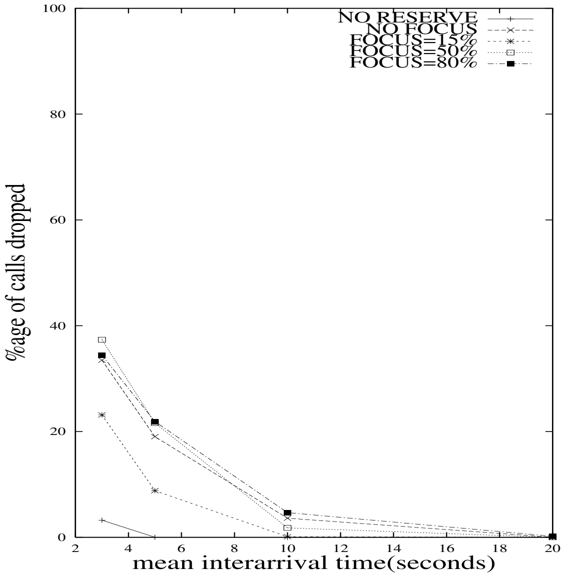
(a) Successful visits versus interarrival time

(b) Second tries versus interarrival time

Figure 10: **Visits and second tries versus interarrival time - constant interarrival time**

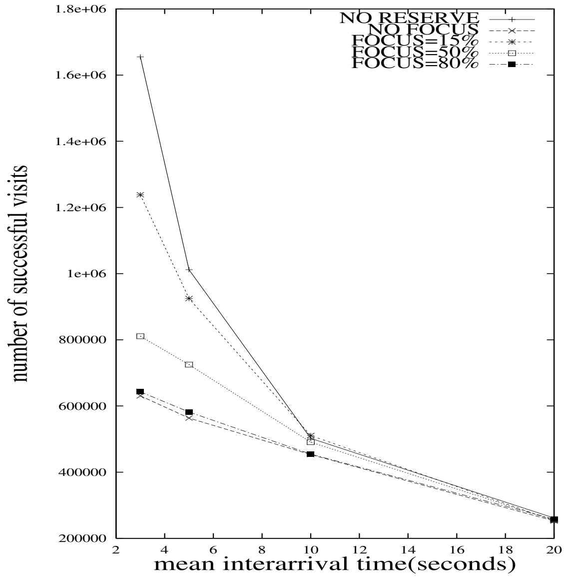


(a) Blocked users versus interarrival time

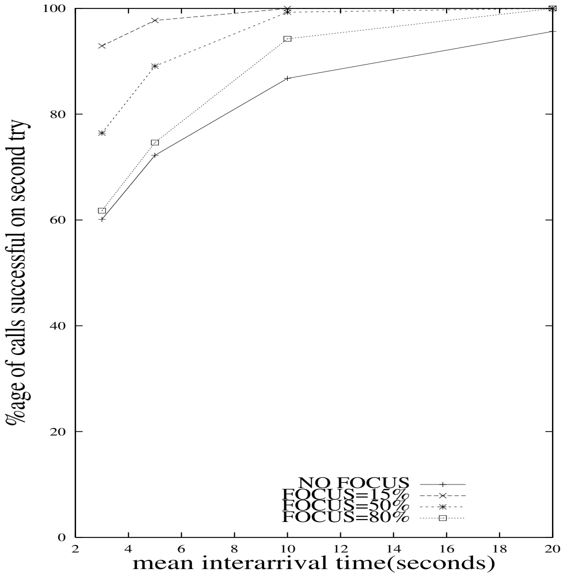


(b) Dropped users versus interarrival time

Figure 11: **Blocks and drops versus interarrival time - constant cell latency**

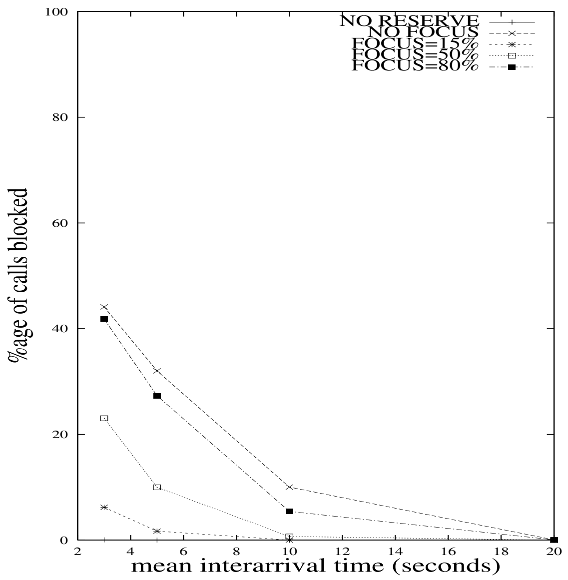


(a) Successful visits versus interarrival time

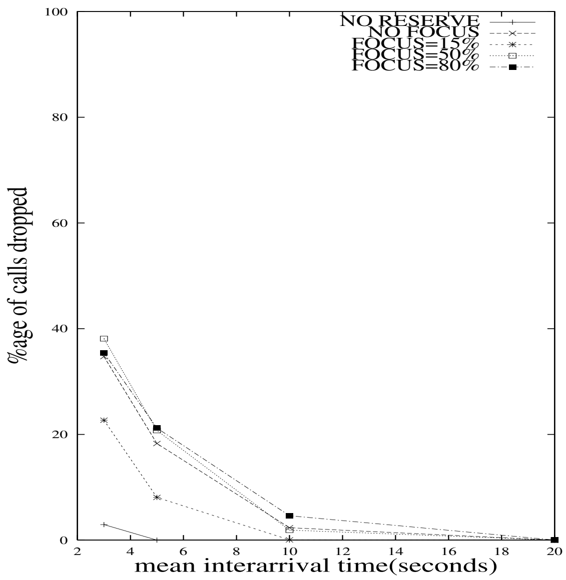


(b) Second tries versus interarrival time

Figure 12: **Visits and second tries versus interarrival time - constant cell latency**

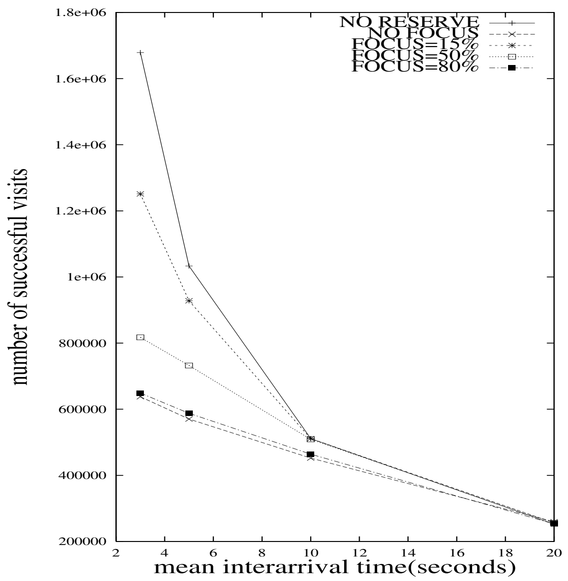


(a) Blocked users versus interarrival time

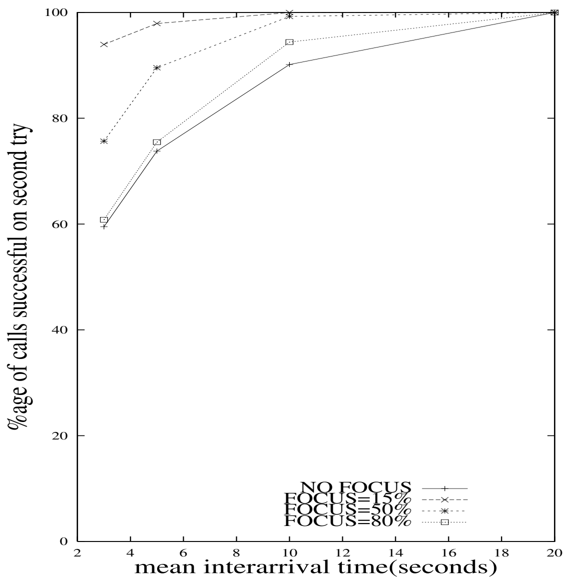


(b) Dropped users versus interarrival time

Figure 13: **Blocks and drops versus interarrival time - constant interarrival time and constant cell latency**



(a) Successful visits versus interarrival time



(b) Second tries versus interarrival time

Figure 14: **Visits and second tries versus interarrival time - constant interarrival time and constant cell latency**