

# Signaling Reduction in Idle Mode for Inter-Technology Mobility

Suresh Kalyanasundaram\*, Vinod Ramachandran\*, and Vijay Raman †

\*Motorola India Private Limited, Bangalore, India. E-mail: {Suresh.Kalyanasundaram, vinodkumar}@motorola.com

†Department of Electrical and Computer Engineering, University of Illinois, Urbana-Champaign, USA. E-mail: vraman3@uiuc.edu

**Abstract**—With the proliferation of air interface technologies, there are increasingly multi-mode user equipment devices (UEs) that can operate in more than one technology, although not at the same time. To save battery life, the UEs will camp in only one technology at any point in time even when there is coverage of multiple technologies. One key requirement is to limit the uplink signaling when UEs capable of operating in multiple radio access technologies perform inter-technology handovers in idle mode. In this paper, we propose a scheme that reduces this signaling by sending an inter-technology update to the network only when the UE loses coverage of the previously used technology. We also analyze the performance benefits of this scheme with that of the approach of camping on the preferred technology whenever coverage of that technology is available.

## I. INTRODUCTION

Every few years cellular standards organizations, such as, 3GPP (Third generation partnership project) and 3GPP2 (Third generation partnership project 2), standardize newer technologies that are capable of superior end-user performance and higher capacity. Some of the recent technologies that have been standardized include HSPA (High Speed Packet Access), CDMA 1X EV-DO (CDMA 1X Evolution-Data Optimized), and WiMAX. 3GPP is currently working towards standardization of Evolved-Universal Mobile Telecommunications System (E-UMTS) [1], which is expected to provide even higher data rates. While operators are rolling out these technologies, these technologies, in the near future, are not expected to provide the ubiquitous coverage provided by GSM and IS-95. Therefore, high-end user equipment devices (UEs) that are capable of these recent technologies need to invariably support the older technologies to provide ubiquitous coverage to users. We will refer to these UEs as multi-mode UEs.

UEs that are in the middle of an active data (or voice) session are said to be in *active mode*. In active mode, the network knows the exact cell in which the UE is located. When the UE is not performing an active data transfer, it is said to be in *idle mode*. In idle mode, the network does not know the exact cell in which the UE is currently camping. Instead it knows the location of the cell only to the granularity of a group of cells, known as a location area. Therefore, the network needs to page the UE in all the cells in the location area to deliver a UE-terminated call.

In this work, we consider the problem of idle-mode mobility of multi-mode UEs across different technologies and how a UE-terminated call can be delivered to such a multi-mode

UE. In general, a multi-mode UE will prefer to perform its active data transfers using the latest technology that provides coverage at the current location of the UE. We assume that this preference is static and does not depend on the current loading of the different technologies.

To reduce the battery consumption and the cost of the multi-mode UEs, they are expected to be using only one of the technologies, both in active and idle modes, at any point in time. As a result, when the UE is in idle mode, it will only listen to the paging channel of one of the technologies that it is capable of. Therefore, it is the task of the network to page for the UE in the technology in which it is camping.

An important factor to consider is that these technologies are being standardized by different standards bodies. Therefore a tight network-to-network co-ordination between them cannot always be assumed. Therefore it is preferable that any solution for inter-technology idle mode mobility does not assume a tight co-ordination between network elements of the different technologies.

Two types of signaling messages are required to handle idle-mode mobility: Location updates and paging messages. A number of papers have explored the trade-off between these two types of signaling messages when the mobility is within the same technology [2], [3], [4]. A similar type of trade-off exists when the mobility is across technologies. This topic has not received much attention from researchers so far. Minimization of "ping pong" effects within the same technology has received considerable attention, and a similar problem needs to be addressed when the "ping pong" effects are due to mobility between different technologies. In this work, we propose a scheme that minimizes signaling load due to idle-mode mobility without the need for a tight network-to-network coordination, while allowing the multi-mode UEs to perform their active data transfers in the best technology.

The rest of the paper is organized as follows: In Section II we propose a new scheme to reduce the signaling messages due to inter-technology mobility of multi-mode UEs. In Section III, we develop an analytical model and derive expressions for key metrics of interest. In Section IV, we present numerical results and compare the performance of our proposal with that of a baseline scheme.

## II. PROPOSED SCHEME

Before we describe our proposed solution, we point out that there are two fundamentally different philosophies for handling idle-mode mobility. In one approach, that we call the *multiple-paging approach*, the network does not always know the exact technology in which the UE is camping. Therefore, it may very often have to page in multiple technologies even in the same geographical area. The UE receives the paging message in the technology in which it is camping, and hence can respond to it appropriately. The other approach is for the network to know the exact technology in which the UE is camping. Therefore, each time the UE changes the technology in which it is camping, it is forced to send an inter-technology location update. Using this approach, paging only happens in the technology in which the UE is camping.

Of these two approaches, the latter approach of paging in only one technology is preferable from the point of view of minimizing the interactions between different technologies. Note that in the multiple-paging approach, the data meant for the UE will most likely get terminated in one of the technologies (typically, the technology in which the UE was last found), and the paging request then needs to be sent to other technologies in which the multi-mode UE may be potentially camping. And when the paging response is received from the UE, the data and the call control would then have to be transferred to the technology in which the UE was found. This type of complex network-to-network interaction is not required for the approach where the paging is only done in one technology. In addition, the multiple-paging approach suffers from the problem of multiple paging messages sent over different technologies even when the coverage areas of the different technologies may be identical. Because we would like to minimize the need for network-to-network interaction, we focus our attention only on the scheme where the network knows the exact technology in which the UE is camping. A detailed comparison of the multiple paging and the single paging approaches is not the focus of this paper. We note that the approach of paging in only one technology may suffer from "ping-pong" effects when there are a lot of seams between the coverage areas of different technologies. Therefore, we focus on means of minimizing the inter-technology update signaling load when we restrict our attention to the scheme that knows the exact technology in which the UE is camping.

We describe our solution assuming that UMTS and E-UMTS are the two technologies that the multi-mode UE is capable of, but it applies equally well with any other technology and with any number of technologies. The main idea behind our proposed solution is that the multi-mode UE continues to remain camped in the technology in which it last sent a location update, unless it enters a region where there is no coverage of that particular technology. For example, if the UE sent its last location update in UMTS, it continues to remain in UMTS and makes its location updates as per UMTS location areas for as long as there is UMTS coverage. Even if it enters E-UMTS coverage areas, and if there is

still UMTS coverage, it continues to remain in the UMTS technology. When the UE needs to be paged, it is paged in UMTS. However, if there is also E-UMTS coverage in that area, and if operator and UE policies are such that E-UMTS is the preferred technology, then an active mode handover is carried out to E-UMTS.

The main advantage that our proposed technique offers is that the inter-technology update signaling load is reduced, while still allowing the network to know the exact technology in which the UE can be reached. This benefit is obtained by postponing any inter-technology handovers in idle mode until it is actually required, i.e., when it loses coverage in the technology in which it made its last location update, or when it needs to move to active mode and the other technology is the preferred technology for active data transfers. It should however be noted that inter-technology handover in active mode during call setup may involve additional call setup delay, or the UE operating in a non-preferred technology for a short period of time.

We next compare the performance of our proposed scheme (called scheme 2) with that of scheme 1, where the multi-mode UE always performs an inter-technology update whenever it finds a technology whose preference is higher than that of the current technology in which it is camping.

## III. ANALYTICAL MODEL

In this section we obtain an analytical expression to compare the performance of our proposed solution with that of scheme 1. We consider a deployment where there is ubiquitous coverage of UMTS, and spotty coverage of E-UMTS. We consider that this type of deployment would be quite common, to provide ubiquitous coverage that users have come to expect. Deployments where none of the technologies have ubiquitous coverage are unlikely to be used in practice because that would imply that the only way to obtain ubiquitous coverage is by using a multi-mode UE. We study the impact of the percentage of E-UMTS coverage and the average area of a single contiguous E-UMTS coverage pocket on the inter-technology update signaling load.

For our analysis, we consider a region of area  $S$ , consisting of two distinct kinds of coverage areas as shown in Fig. 1. Area 1 contains cells with UMTS coverage only and area 2 has coverage of both UMTS and E-UMTS. Area 2 occupies a fraction  $\alpha$  of the total area  $S$ , and is distributed as circular pockets. We will refer to these as E-UMTS pockets.

Let  $\alpha$  be the fraction of the total area served by both UMTS and E-UMTS,  $\gamma$  be the average rate of cell handovers per UE,  $\eta$  be the average area of each E-UMTS pocket, and  $\lambda$  be the average call-activity rate per UE (both incoming and outgoing), and  $A$  be the area of each cell. We assume that each cell is circular in shape and that the area of each E-UMTS pocket can also be approximated by a circle.

If we consider a multi-mode UE in area 1, then the UE can be in any of the cells within area 1. We assume that, when the UE moves out of a cell, the point at which it leaves the cell is uniformly distributed over the circumference of the

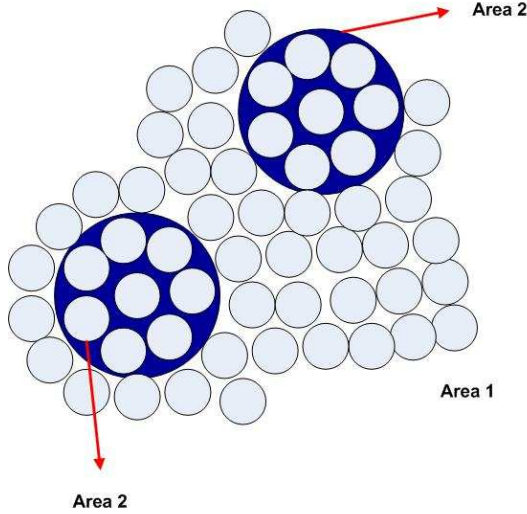


Fig. 1. Sample coverage scenario

cell. Given a UE in area 1, and that it is leaving a particular cell, the probability with which this cell-to-cell movement turns out to be mobility from area 1 to area 2 is given by

$$p_{1 \rightarrow 2} = \frac{\text{total circumference of E-UMTS pockets}}{\text{total circumference of all cells in area 1}} = \frac{2\sqrt{\pi\eta} \frac{\alpha S}{\eta}}{2\sqrt{\pi A}(1-\alpha)(S/A)} = \frac{\alpha\sqrt{A}}{\sqrt{\eta}(1-\alpha)}, \quad (1)$$

where the average circumferences of each cell and each E-UMTS pocket are given by  $2\sqrt{\pi A}$  and  $2\sqrt{\pi\eta}$  respectively. There are  $(1-\alpha)S/A$  cells in area 1 and  $\alpha S/\eta$  E-UMTS pockets.

Similarly, the probability that a given UE in area 2 will move to area 1 in its next cell-to-cell movement is given by

$$p_{2 \rightarrow 1} = \frac{\text{total circumference of E-UMTS pockets}}{\text{total circumference of all cells in area 2}} = \frac{2\sqrt{\pi\eta} \frac{\alpha S}{\eta}}{2\sqrt{\pi A}\alpha(S/A)} = \frac{\sqrt{A}}{\sqrt{\eta}}, \quad (2)$$

where  $\alpha S/A$  is the number of cells in area 2.

Let the number of cell-to-cell handovers made by a UE be a Poisson process with rate  $\gamma$ , and let the call activity (both making outgoing calls and receiving incoming calls) for a UE be a Poisson process with rate  $\lambda$ . In other words, the cell residence times are exponentially distributed with a mean of  $1/\gamma$  and the time between call activities is exponentially distributed with mean  $1/\lambda$ . Given that the average rate of cell-to-cell handover is  $\gamma$ , and that the probability with which a cell-to-cell handover is a handover from area 2 to area 1 is given by  $p_{2 \rightarrow 1}$ , the average rate of handover from area 2 to area 1 is given by  $\gamma\sqrt{A}/\sqrt{\eta}$ . The probability that a call arrives before a transition from area 2 to area 1 occurs is thus

given by the ratio of the call activity rate to the sum of the call activity rate and the average rate of cell handovers, i.e.,

$$p_{\text{call arrival}} = \frac{\lambda}{\lambda + \frac{\gamma\sqrt{A}}{\sqrt{\eta}}} \quad (3)$$

For scheme 1, the rate of inter-technology updates per UE is given by the weighted sum of the rate of transitions between areas 1 and 2, where the weights are the probabilities that the UE is present in the corresponding areas. This can be written as follows:

$$R_1 = (1-\alpha)\gamma p_{1 \rightarrow 2} + \alpha\gamma p_{2 \rightarrow 1} = \frac{2\alpha\gamma\sqrt{A}}{\sqrt{\eta}} \quad (4)$$

However, for scheme 2, the rate of inter-technology updates will be scaled by the probability that a call arrives before the UE moves from area 2 to area 1.

$$R_2 = \frac{2\alpha\gamma\sqrt{A}}{\sqrt{\eta}} p_{\text{call arrival}} = \frac{2\alpha\gamma\sqrt{A}}{\sqrt{\eta}} \frac{\lambda}{\lambda + \frac{\gamma\sqrt{A}}{\sqrt{\eta}}} \quad (5)$$

This expression can be obtained by observing that, if a call arrives when the UE is in area 2, it needs to make two updates, once to transition to E-UMTS to do the active data transfer and again when it moves from area 2 to area 1. If a call does not arrive when the UE is in area 2, then the UE does not make any inter-technology update. Half the number of updates for scheme 2 happens when the UE receives the call in area 2. The rest of them happen when the UE transitions from area 2 to area 1. Hence, the fraction of calls undergoing call setup delay can be given by:

$$\frac{(R_2/2)}{\lambda} = \frac{\alpha\gamma\sqrt{A}}{\lambda\sqrt{\eta} + \gamma\sqrt{A}} \quad (6)$$

From our expressions it is easy to see that the metrics of interest in Eqs. (4), (5), and (6) only depend on the ratio of  $\eta/A$ , i.e., the average number of cells in area 2, and not on the individual parameters themselves. All the results in the remainder of this paper are for the scenario with cells of unit area i.e.,  $A = 1$ .

## IV. RESULTS AND DISCUSSION

### A. Impact of rate of cell handovers and call activity rate

Figure 2 shows the rate of inter-technology updates as a function of the rate of cell handovers for both the schemes. Scheme 2 clearly offers a lower rate of updates than scheme 1. The rate of update messages increases for both schemes as the rate of cell handovers increases. As  $\gamma$  increases, the rate of update messages increases linearly for scheme 1, and it is independent of the call-activity rate. As the call activity rate increases, the rate of inter-technology updates also increases for scheme 2. As expected, we find that the benefits from scheme 2 occur when the UEs traverse all of area 2 without any call activity, and the likelihood of this event is higher when the call activity rate is lower. In the figures  $\lambda$  is given in units of calls per second.

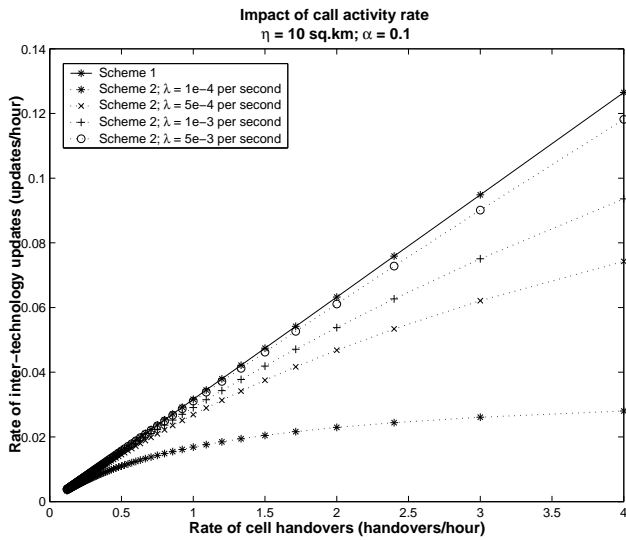


Fig. 2. Impact of call activity rate and rate of cell handovers

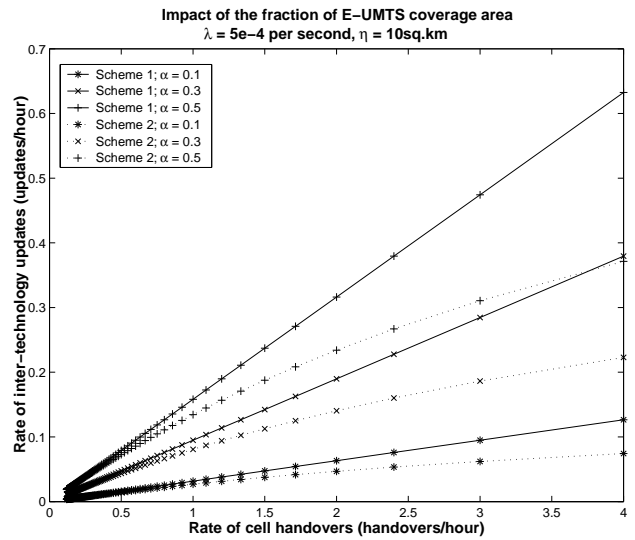


Fig. 4. Impact of the fraction of E-UMTS coverage area

### B. Impact of average area of an E-UMTS pocket

Figure 3 shows the impact of the average area of one E-UMTS pocket on the rate of inter-technology updates, for a fixed fraction of E-UMTS coverage. For a fixed  $\alpha$ , the number of E-UMTS pockets decreases as  $\eta$  increases. As a result, the rate of updates comes down for scheme 1. A similar trend of decreasing rate of inter-technology updates with increasing average pocket size is seen for scheme 2 as well. The difference between the two schemes is larger for smaller  $\eta$  because of the increased number of inter-technology boundary crossings. The updates are made at every such crossing for scheme 1 but the updates for scheme 2 depend on the call activity. This shows that when E-UMTS pockets are contiguous, it is less important to take measures to reduce inter-technology updates.

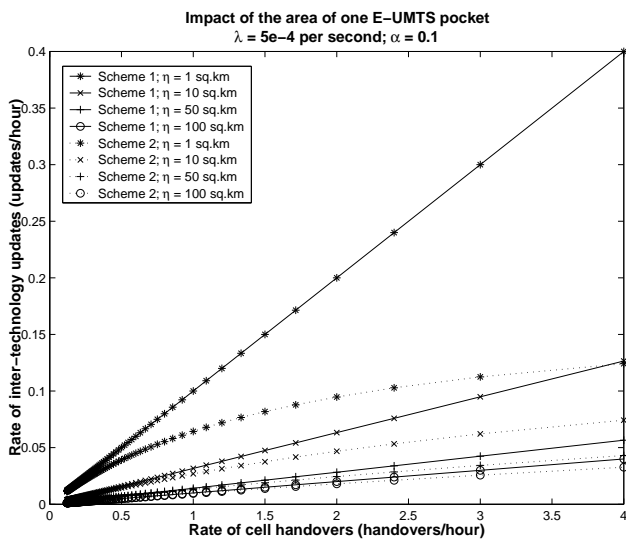


Fig. 3. Impact of the area of one E-UMTS pocket

### C. Impact of the percentage of area covered by E-UMTS

The effect of the fraction of the area covered by E-UMTS is shown in Figure 4. When the fraction  $\alpha$  increases for a fixed  $\eta$ , the number of E-UMTS pockets increases and hence the number of inter-technology updates also increases. This is true for both the schemes. The difference between the two schemes is larger when  $\alpha$  is larger because there are more seams between the two technologies.

### D. Calls incurring call-setup delay

The impact on the fraction of calls incurring call setup delay in scheme 2 due to different parameters is shown in Figures 5, 6, 7, and 8. From Figure 5, we can see that for a fixed per E-UMTS pocket area, the fraction of calls impacted increases linearly with the fraction of E-UMTS coverage  $\alpha$  because the number of E-UMTS pockets increase. As expected, when the number of E-UMTS pockets increase without being contiguous, scheme 2 will introduce call setup delays for a higher fraction of calls.

Figure 6 shows the effect of average call activity rate, and we observe a reduction in the number of calls incurring delay as  $\lambda$  increases. This is because more calls fall under the category of second or more calls made/received inside the E-UMTS coverage area. Note that only the first call inside an E-UMTS area will have to do an active mode handover to E-UMTS and hence incur the additional delay.

As shown in Figure 7, the number of calls that undergo additional delay decreases as the average area of one E-UMTS pocket increases. As before, as  $\eta$  increases for a fixed  $\alpha$ , the number of E-UMTS pockets decreases and hence more calls will come under the category of second or more calls inside the E-UMTS area. As the rate of cell handovers increase, the fraction of calls incurring delay will increase and saturate at the fraction of E-UMTS coverage area  $\alpha$ . This is shown in Figure 8, and the asymptotic value can be obtained from

Eq. (6). One important observation is that the fraction of calls that are impacted by our proposed solution is less than or equal to 20% in all our results.

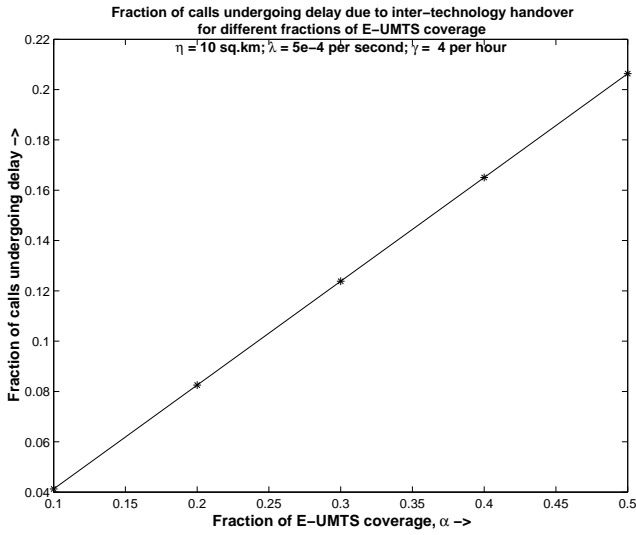


Fig. 5. Impact of fraction of E-UMTS coverage on the fraction of calls undergoing call setup delay in scheme 2

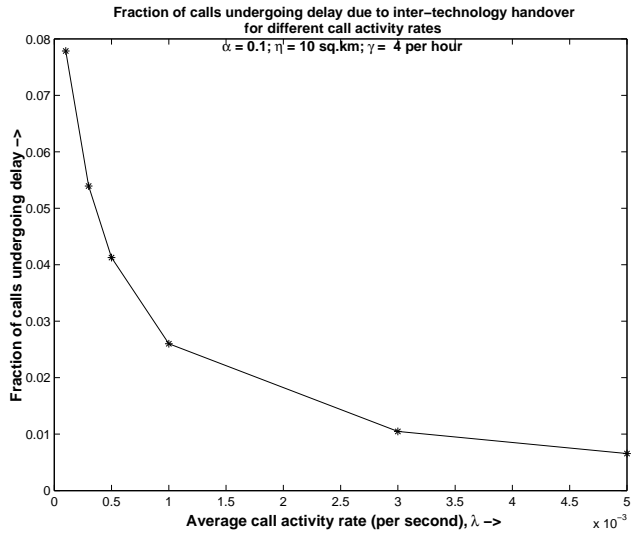


Fig. 6. Impact of call activity rate on the fraction of calls undergoing call setup delay in scheme 2

## V. CONCLUSIONS

In this paper, we have proposed a solution to reduce inter-technology update signaling and presented an analytical model and results that quantify its advantages. We have shown the impact of different modeling parameters on the rate of inter-technology updates. The results indicate the magnitude of benefits that can be obtained by using better techniques to reduce inter-technology updates compared to the "do-nothing" solution. For future work it would be interesting to compare

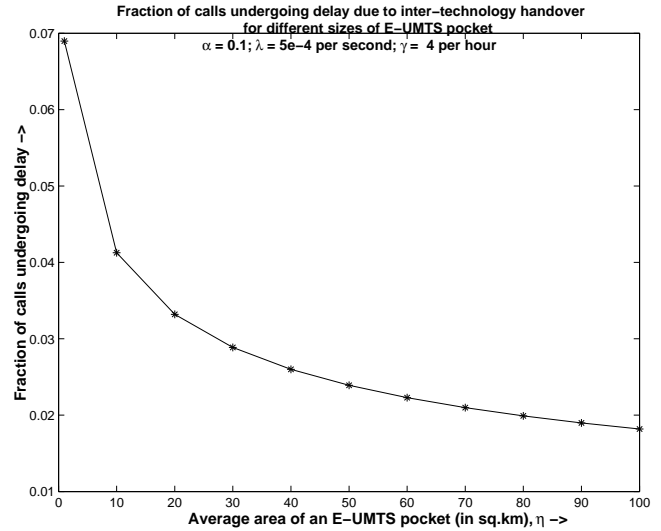


Fig. 7. Impact of average area of one E-UMTS pocket on the fraction of calls undergoing call setup delay in scheme 2

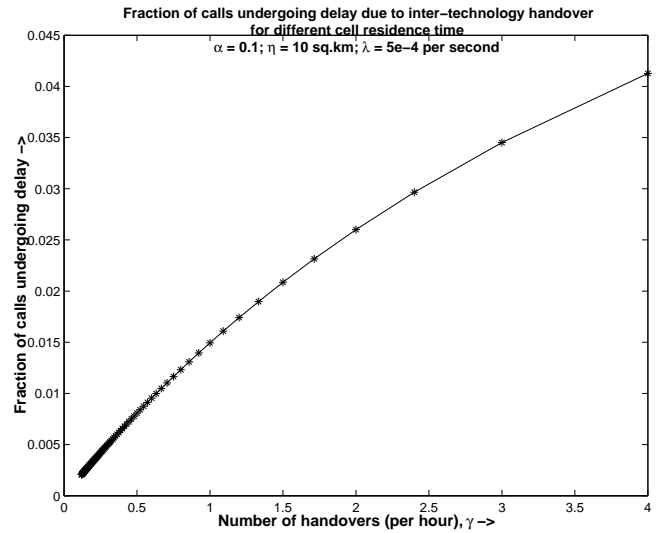


Fig. 8. Impact of rate of cell handovers on the fraction of calls undergoing call setup delay in scheme 2

the results of the scheme proposed in this paper with that of the multiple-paging scheme outlined in Section II.

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