PERFORMANCE COMPARISON OF MOBILITY MANAGEMENT IN MOBILEIP NETWORKS

RAJASEKHAR.SWARNA(*)
Dept.of.Computer Science,
GIET,Rajahmundry.
swarnarajasekhar@gmail.com

K.H.VIJAYAKUMARI
Dept.of.Computer Science,
GIET,Rajahmundry.
vijaya.kotari@gmail.com

Abstract—**In wireless networks, efficient management of mobility is a crucial issue to support mobile users. The Mobile Internet Protocol (MIP) has been proposed to support global mobility in IP networks. Several mobility management strategies have been proposed which aim reducing the signaling traffic related to the Mobile Terminals (MTs) registration with the Home Agents (HAs) whenever their Care-of-Addresses (CoAs) change. They use different Foreign Agents (FAs) and Gateway FAs (GFAs) hierarchies to concentrate the registration processes. For high-mobility MTs, the Hierarchical MIP (HMIP) and Dynamic HMIP (DHMIP) strategies localize the registration in FAs and GFAs, yielding to high-mobility signaling. The Multicast HMIP strategy limits the registration processes in the GFAs. For high-mobility MTs, it provides lowest mobility signaling delay compared to the HMIP and DHMIP approaches. However, it is resource consuming strategy unless for frequent MT mobility. Hence, we propose an analytic model to evaluate the mean signaling delay and the mean bandwidth per call according to the type of MT mobility. In our analysis, the MHMIP outperforms the DHMIP and MIP strategies in almost all the studied cases. The main contribution of this paper is the analytic model that allows the mobility management approaches performance evaluation.**

Index Terms—Mobile IP, mobility approach, performance evaluation

I.INTRODUCTION

IP multimedia applications are becoming popular in the packet-based wireless networks. The integration of these applications in wireless networks requires the support of seamless terminal mobility. Mobile IP (MIP) has been proposed by the Internet Engineering Task Force (IETF) to provide global mobility in IP networks [1]. It allows maintaining mobile terminals ongoing communications while moving through IP network. In the MIP protocol, Mobile Terminal (MT) registers with its home network from which it gets a permanent address (home address). This address is stored in the Home Agent (HA). It is used for identification and routing purpose. If MT moves outside the home network visiting a foreign network, it maintains its home address and obtains a new one from the Foreign Agent (FA). This Foreign address is called Care-of-Address (CoA). To allow continuity of ongoing communications between the MT and a remote end point, the MT shall inform the HA of its currentlocation when it moves outside the home network. The HA delivers to MT the intercepted packets by tunneling them to the MT's current point of attachment.

IP mobility in wireless networks can be classified into macro- and micromobility. The macromobility is the MT mobility through different administration domains. The micromobility is the MT movements through different subnets belonging to a single network domain. For micromobility where the MT movement is frequent, the MIP concept is not suitable and needs to be improved [3]. Indeed, the processing overhead related to location update could be high specifically under high number of MTs and when MTs are distant from the HAs yielding to highmobility signaling delay [4]. Hierarchical Mobile IP (HMIP) has been proposed to reduce the number of location updates to HA and the signaling latency when an MT moves from one subnet to another [5], [6]. In this mobility scheme, FAs and Gateway FAs (GFAs) are organized into a hierarchy. When an MT changes FA within the same regional network, it updates its CoA by performing a regional registration to the GFA. When an MT moves to another regional network, it performs a home registration with its HA using a publicly routable address of GFA. The packets intercepted by the HA are tunneled to a new GFA to which the MT I belonging (e.g., GFA_2 following MT handoff from FA_3 to FA_5 in Fig. 1). The GFA checks its visitor list and forwards the packets to the FA of the MT (FA_5 in Fig. 1). This regional registration is sensitive to the GFAs failure because of the centralized system architecture [7], [8].Moreover, ahigh traffic load on GFAs and frequent mobility between regional networks degrade the mobility scheme performance [4]. In order to reduce the signaling load for interregional networks, mobility dynamic location management approaches for MIP have been proposed: A Hierarchical Distributed Dynamic Mobile IP (HDDMIP) and Dynamic Hierarchical Mobile IP (DHMIP). In the HDDMIP approach, each FA can act either as an FA or GFA according to the user mobility. The traffic load

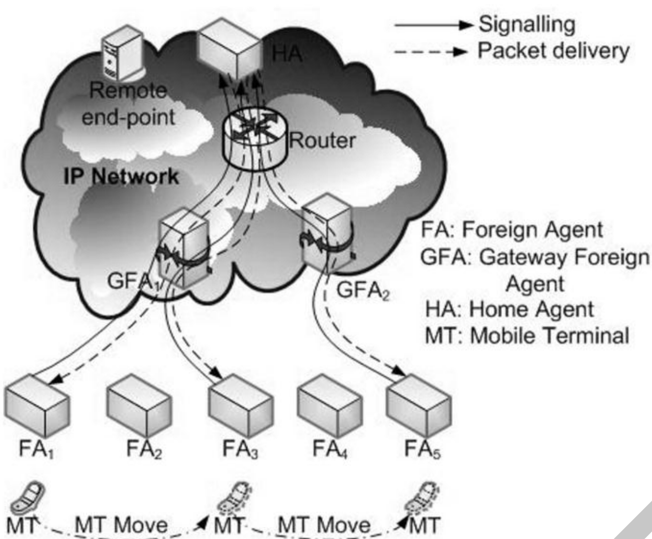

Fig. 1. MIP and DHMIP mobility approaches.

in a regional network is distributed among the FAs. The number of FAs attached to a GFA is adjusted for each MT. Thus, the regional network boundary varies for each MT. This number is computed according to the MT mobility characteristics and the incoming packet arrival rate. This number is adjustable from time to time according to the variation of the mobility and the packet arrival rate for each MT. In [9] and [10], analytic models are proposed to compute this number such as the total signaling traffic for location update and packet delivery is transferred with minimal network resource and low delay, respectively. Nevertheless, this approach requires that each FA is able to act as an FA and a GFA. Moreover, it adds processing load on the MT to estimate the average packet arrival rate and the subnet residence time. Hence, the main advantage of this approach is the system robustness enhancement since the GFA failure affects only the packets routing to MTs belonging to this GFA. The disadvantages are the system infrastructure and MTs costs which could be high. The DHMIP approach has been proposed to reduce the location update messages to the HA by registering the new CoA to the previous FA and building a hierarchy of FAs . Hence, the user's packets are intercepted and tunneled along the FAs hierarchy to the MT. The hierarchy level numbers are dynamically adjusted based on mobile user's mobility and traffic

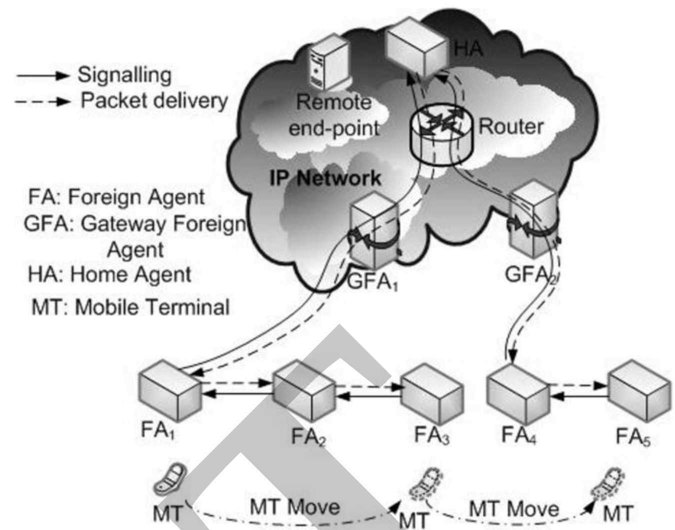

Fig. 2. DHMIP mobility approaches.

load information. Fig. 2 illustrates an example of DHMIP approach with a maximum of hierarchy level number equal to 3. When MT is attached to FA_2, FA_3, FA_5, or FA_6, the CoA update is sent to the previous FAs. If the MT becomes attached to FA_4 the level number reach the threshold and the MT will set up a new hierarchy. The MT registers its new CoA directly to the HA. In this approach, the location update to the new FA, which is close to the previous FAs, could be less expensive than that to the HA. In [11], authors propose an analytic performance model to evaluate the signaling transmission, the packet delivery, and the total costs of HMIP, HDDMIP, and DHMIP mobility approaches using a one-dimensional random walk model. The performance analysis shows that the DHMIP scheme outperforms compared to the HMIP and HDDMIP ones.

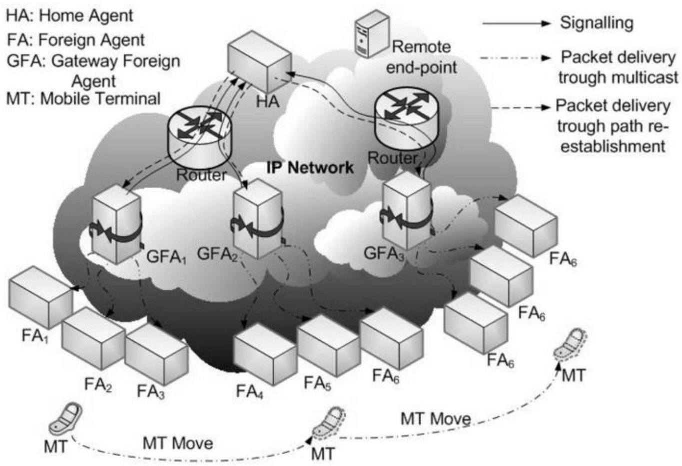

Fig. 3. Hierarchical handoff scheme.

2 MULTICAST-BASED MOBILITY APPROACHES

2.2 MULTICAST HIERARCHICAL MOBILE IP

In this approach, we propose to build hierarchical multicast groups. In each group, FAs are connected to each other through a GFA. A set of GFAs are connected to an HA. When an MT moves through FAs belonging to the same group, the GFA of this group multicasts the received packet (coming from the HA) to the MT. When the MT moves outside a group, the new CoA is registered to the GFA of the new group to which the MT is currently belonging. This GFA sends this CoA to the HA. This latest tunnels the packet to the new GFA which will multicast the received packets within the new FAs group. This approach reduces the frequency of the location update to the HA. This update is performed every inter-GFAs mobility rather than every inter-FAs mobility limiting the location update processing only at the GFA. In this example, the group creation is static in the sense that the numbers of groups and FAs do not change and remain fix. In Fig. 3, when the MT moves from FA2 to FA5, the location registration is performed between HA and GFA2. GFA2 multicasts packets to FA4, FA5, and FA6.

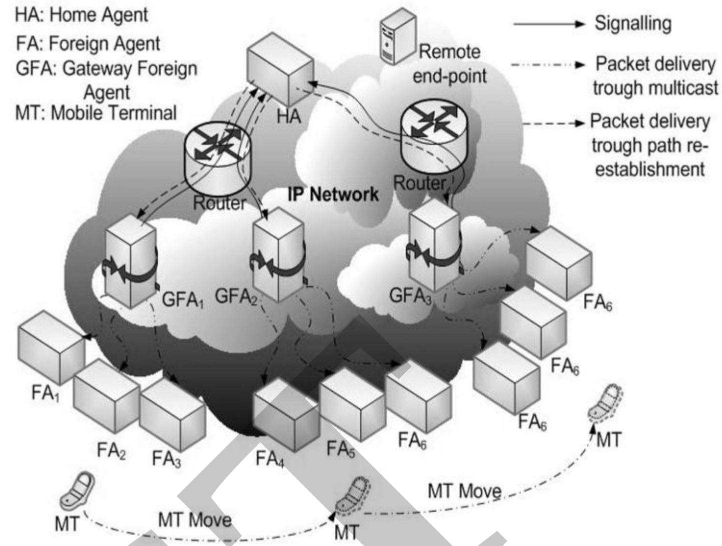

Fig. 5. Symmetric hierarchical IP network architecture

Thus, when MT moves to FA6 or FA4 there is no need for the MT location registration. Hence, this approach allows reducing the mobility signaling delay compared to the HMIP and DHMIP mobility approaches specifically for high-mobility MTs. However, it is network resources consuming approach due to multicast protocol use. Consequently, it is required for comparison purpose to evaluate the performance not only in term of handoff signaling delay but also in term of bandwidth use. This latest is the bandwidth used for signaling transfer and packet delivery. If we take the same MIP network architecture for the three mobility management approaches, the bandwidth used by MHMIP signaling is smaller than that of MIP or DHMIP approaches because the path reestablishment is performed only between HA and GFAs. However, the bandwidth used by an MT for packet delivery is high because several connections are used for packets' transfer to the MT. It is clear that the total bandwidth used for signaling and packet delivery in MHMIP approach is higher than that used by the other approaches. Nevertheless, in case of MTs with high mobility (high handoff requests), the multicast resource in the GFA groups are reused by the MT every handoff event that occurs during its call holding time. Consequently, we expect that the MHMIP mean bandwidth per call for MTs with high mobility is no greater than that of the DHMIP and MIP mobility approaches. We also expect that the MHMIP mean handoff delay (including signaling and packet delivery delays) is smaller than that of the DHMIP and MIP mobility approaches. Hence, we propose to derive an analytic model that allows computation of mean bandwidth and mean handoff delay per call for MIP, DHMIP, and MHMIP mobility approaches. These performance measurements are computed according to the MTs mobility type (high or low) and the call holding time duration. The

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model description and the performance comparison of the three mobility approaches are discussed in the following sections.

3 ANALYTIC MODEL

This section describes the analytic model and the set of established assumptions

3.1 ASSUMPTIONS

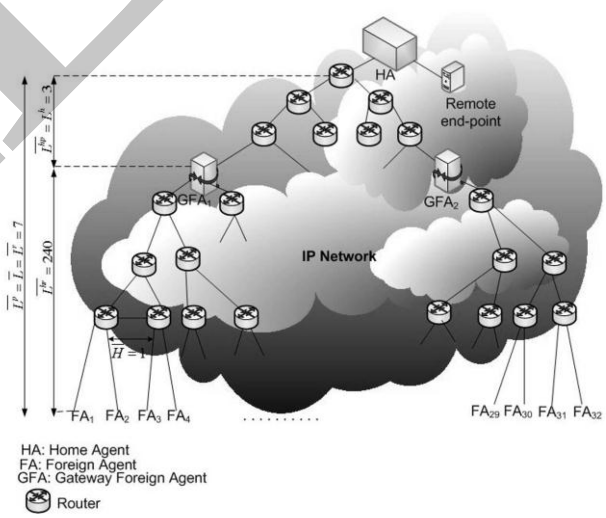
Generally, during each handoff, a path reestablishment is required to maintain or to improve call quality. This reestablishment uses signaling messages and involves a change in the number of links of the mobile connection. Note that the three mobility approaches described here are based on a mobile connection path reestablishment which leads to perform the following operations:

- CoA update with the HA,
- new path establishment from HA to FA for DHMIPand MIP, and from HA to GFA for MHMIP,
- user data traffic transfer from the previous path tothe new one,
- previous path discard.

The DHMIP uses also path extension which requires additional signaling messages to establish the path part that extends the mobile connection from the previous FA to the new one when the mobile move and becomes attached to this latest. Each connection is subjected to a certain number of handoffs through its life duration (call holding time). This latest is divided into n time intervals enough small to allow the occurrence and the end of only one handoff during this interval. In each time interval, we define . qa as the probability that an FAs handoff (handoff between two FAs) occurs and ends in this interval and . qf as the probability that the call ends in this interval. The number of handoffs that could occur during a call holding time depends on the MT dwelling time in a radio cell and the traffic type: voice or data. Several voice traffic researches have supposed that the dwelling time in a radio cell is an exponential distribution [24], [25]. In fact, this assumption depends on the shape of the radio cell and the specific distributions of the mobile's speed and direction which are difficult to characterize. In [26], [27], [28], [29], [30], authors have demonstrated that the exponential distribution for the dwelling time in radio cell is not appropriated. They propose to replace it with complex distributions such as Phase-Type, Lognormal, Hyperexponential, and HyperErlang requiring the identification of several parameters related to the selected traffic model. In order to simplify the computation of the mean bandwidth and mean delay per call, we consider that the time between the handoff events and the call duration is a geometric distribution of mean 1=qa 1 and 1=qf , respectively.

3.2 DHMIP ANALYTIC MODEL

The DHMIP mobility approach combines the path reestablishment and the connection extension protocols. The path reestablishment protocol is invoked to set up a new FAs hierarchy. This protocol allows a path establishment between the HA and a new FA in the new hierarchy. In this latest, the path extension is used to maintain the mobile connection when mobile moves through the Fas belonging to this hierarchy. The path reestablishment may occur after each new FAs hierarchy setup. Events that may occur at each time i ¼ 1; 2; . . . are 1) path reestablishment, 2) path extension, and 3) call termination. Let . p be the probability that a new FA hierarchy is set and consequently a path reestablishment is performed, . L be the number of links between the FA to which the MT is attached and the remote end point with which the MT communicates, . Lp be the number of links between the HA and the initial FA through which a new hierarchy is set (e.g., FA1 and FA4 in Fig. 2), and . H be the number of links of the path extension (e.g., in Fig. 2, this number is equal to 1 when MT moves from FA1 to FA2 and becomes connected to FA2). L, Lp, and H are random variables with general distributions and with mean L, Lp, and H, respectively.



3.3 MIP ANALYTIC MODEL

The MIP mobility approach is based only on the path reestablishment protocol. This latest allows maintaining the call connectivity when the MT moves between FAs. In this case, events that may occur at each time i ¼ 1; 2; . . . are 1) path reestablishment and 2) call termination. Let . qa be the probability that there is an inter-FAs handoff and thus a partial reestablishment, . L be the number of links between the FA to which the MT is attached and the remote end point with which the MT is communicating, and . Lr be the number of links between the HA and the new FA to which the MT moved (e.g., the number of links between the HA and the FA3 following the handoff from FA1 to FA3 in Fig. 1). L and Lr are random variables with general distributions and with mean L and Lr, respectively.

3.4 MHMIP ANALYTIC MODEL

The MHMIP mobility approach is based on the path reestablishment and the multicast protocols. When the MT moves within a GFA group, the mobile connection is maintained using the multicast protocol. When the MT moves outside this hierarchy, a combination of the path Re establishment and the multicast protocols allows maintaining the call's connection. Events that may occur at each time i ¼ 1; 2; . . . are

1) path reestablishment and
2) 2) call termination.
   We define q0a as the probability that there is an inter-GFAs handoffs and thus path reestablishments such as q0a ¼ _qa with 0 _ _ _ 1. _ is the fraction of inter-GFAs MHMIP handoffs on the whole possible handoffs qa (intra and inter-GFAs).

The inter-GFAs handoff arrivals are modeled using a Bernoulli process. For each mobile connection, we define . Lh as the number of links between the GFA to which the mobile is currently attached and the remote end point with which the MT is communicating, . Lhp as the number of links between the HA and the GFA to which the mobile is currently belonging, and . Lhr as the total number of links in the GFAhierarchies. Lh, Lhp, and Lhs are random variables with general distributions and with means Lh, Lhp, and Lhs, respectively.

4 RESULTS ANALYSIS

In this section, we compare the performance in terms of mean bandwidth and mean handoff delay per call of the three mobility management approaches MHMIP, DHMIP, and MIP.

4.1 NUMERICAL DATA

The mean call holding time is a random value chosen between 60 and 120 seconds for voice traffic and between 900 and 1,200 seconds for data traffic. For simplification purpose of the mean number of links computation (Lr, Lp, L, H, Lh, Lhp, and Lhr), a symmetric hierarchical IP network architecture is considered (Fig. 5). Symmetric architecture means that the number of links between the HA and each FA is the same (e.g., there is five links between the HA and each FAi; fi ¼ 1; . . . ; 32g in Fig. 5). The example given in Fig. 5 shows an architecture with Lp ¼ Lr ¼ 7, Lhp ¼ 3, and Lhr ¼ 240. For comparison purpose, we take the number of links between the HA and the end point the same for the three mobility management approaches. For a fixed remote end point, the number of links between the HA and this end point do not change for an ongoing call of an MT. Then, we consider that the end point is directly connected to HA (e.g., Lh ¼ Lhp ¼ 3 and L ¼ Lp ¼ Lr ¼ 7 for the example given in Fig. 5). Two types of configurations are considered for the network given in Fig. 5: .

Configuration 1: the average number of links are Lh ¼ Lhp ¼ 3 and Lr ¼ Lp ¼ L ¼ 7. These values result in the number of link where the resources were allocated Lhr ¼ 240. .

Configuration 2: the average number of links are Lh ¼ Lhp ¼ 1 and Lp ¼ Lr ¼ L ¼ 7. From these values, we obtain Lhr ¼ 252. For each configuration, two cases are analyzed: realistic and critical. In the realistic case, the inter-GFAs handoffs may occur less frequently than the intra-GFAs handoffs (q0a ¼ 0:1 _ qa). In the critical case, the intra- and the inter-GFAs handoffs may occur with the same probability (q0a ¼ qa, where qa and q0a are variables). For both cases, the path extension for the DHMIP mobility management approach should occur after each handoff and the path reestablishment should occur after each two consecutive handoffs (p ¼ qa=2). For p > qa=2, the mean bandwidth and mean delay is higher than that get with p ¼ qa=2 (see Section 4.2). We suppose that the MT handoff to a new FA involves a path extension of mean length H ¼ 1. For length greater than this value, the mean bandwidth and the mean handoff delay are high.

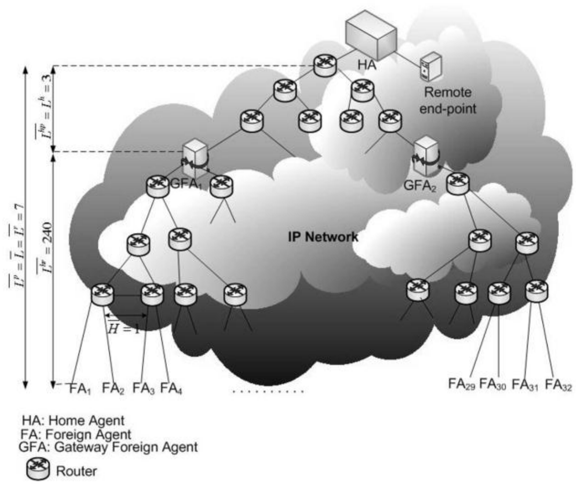


Fig. 5. Symmetric hierarchical IP network architecture.

4.2 NUMERICAL RESULTS

We propose to compare the performance of the MHMIP handoff approach with those obtained with DHMIP and MIP approaches in terms of mean bandwidth and mean handoff delay per call. For summarization purpose, we compute the ratios Bp PR=Bh PR, Br PR=Bh PR, Dp PR=Dh PR, and Dr PR=Dh PR. These ratios allow a simple and direct reading of the different performance between the tree mobility management approaches. Figs. 6 and 7 give an example of mean bandwidth variation per call Bp PR and Bh PR for the DHMIP and MHMIP handoff approaches. Fig. 6 illustrates the mean bandwidths per call for MHMIP and DHMIP mobility management approaches. It shows that the MHMIP mean bandwidth per call is smaller than that obtained with the DHMIP approach. This mean bandwidth represents a performance measurement that an IP network operator can use to determine the needed resources to be deployed in the network to service a certain number of MTs. The MHMIP mobility management approach is the method that allows cost reduction in terms of resources usage compared to the DHMIP approach. Fig. 7 illustrates the Bp=BPR ratio variation for different values of the probability p. We note that lower is p higher is the mean bandwidth per call. Moreover, we note a different behavior of this bandwidth between the intervals qa _ 0:3 and 0:3 _ qa _ 1. For 0:3 _ qa _ 1, the mean bandwidth value decreases while it increases in the interval qa _ 0:2 for different values of p (p ¼ qa=6; qa=4; qa=2) and still increasing in the interval 0:2 _ qa _ 0:3 for p ¼ qa=6. This is in fact due to the low probability of path reestablishment p and the frequent use of path extension in the interval qa _ 0:3. Hence, less frequent path reestablishment usage for DHMIP mobility management approach involves a high mean bandwidth per call consumption.

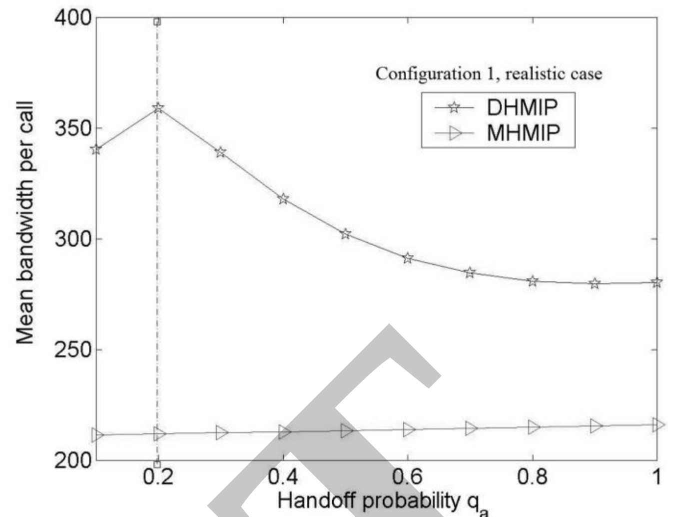


Fig. 6. Mean bandwidth per call $B_{p\ PR}$ and $B_{h\ PR}$ for voice traffic with $1=q_f$ ¼ 60 seconds, $B_{PD}=B_{PR}$ ¼ 0:5.

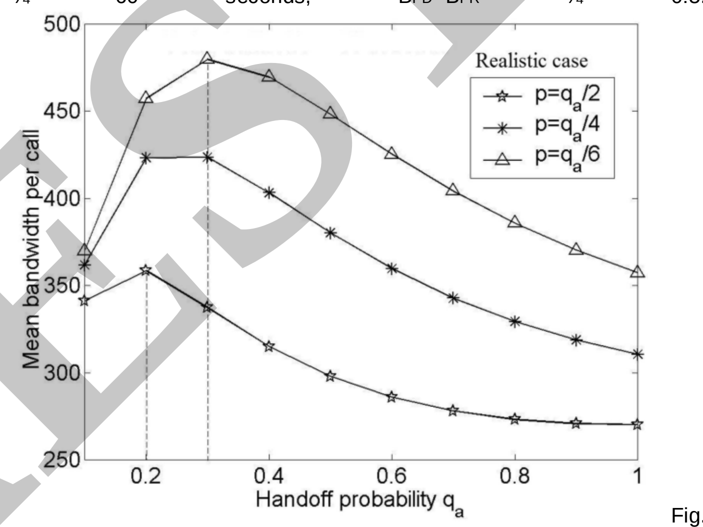


Fig. 7. Mean bandwidth per call variation $B_{p\ PR}$ for voice traffic with $1=q_f$ ¼ 60 seconds, $B_{PD}=B_{PR}$ ¼ 0:5.

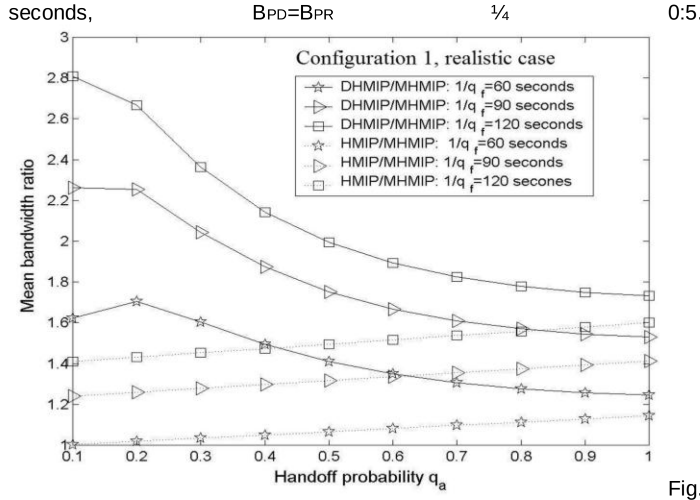
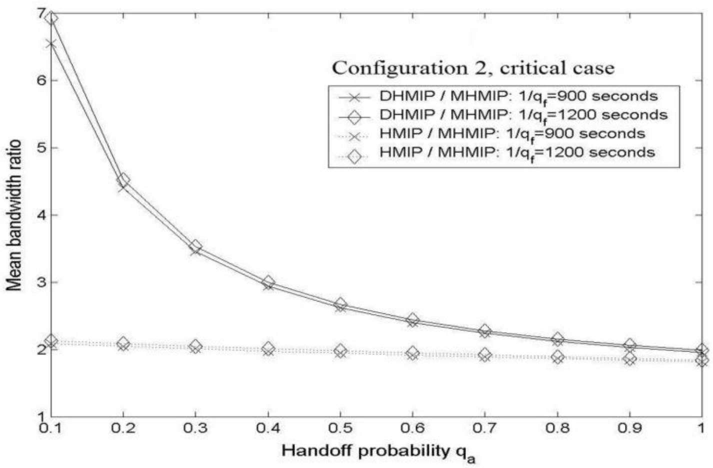


Fig. 8. Mean bandwidth ratio $B_{p\ PR}=B_{h\ PR}$ and $B_{r\ PR}=B_{h\ PR}$ for voice traffic with



ToC	Delay ratio	Delay			
		Voice and data traffic for			
		$D^{PD}/D^{PR} = 0.5$		$D^{PD}/D^{PR} = 0.8$	
		RC	CC	RC	CC
1	$\overline{D^p_{PR}}/\overline{D^h_{PR}}$	8.00	0.72	8.48	0.76
	$\overline{D^r_{PR}}/\overline{D^h_{PR}}$	20.00	1.80	21.57	1.94
2	$\overline{D^p_{PR}}/\overline{D^h_{PR}}$	13.33	1.20	16.00	1.44
	$\overline{D^r_{PR}}/\overline{D^h_{PR}}$	33.33	3.00	40.74	3.66

Fig. 9. Mean bandwidth ratio $B_{p\ PR}$=$B_{h\ PR}$ and $B_{r\ PR}$=$B_{h\ PR}$ for data traffic with p ¼ q_a=2;B_{PD}=B_{PR} ¼ 0:8.

5 CONCLUSION

In this paper, we have proposed an analytical model which evaluates the mean handoff delay per call and the mean bandwidth per call of three mobility management approaches: MIP, DHMIP, and MHMIP. Numerical results show that the MHMIP mobility approach compares very favorably with the previously considered mobility approaches. More specifically, our analysis gives in almost all cases a lower mean handoff delay per call and a mean bandwidth per call than those offered by the DHMIP and MIP approaches. It also shows the robustness of the MHMIP approach in the sense that for critical scenario corresponding to the extreme situation where all handoff events are localized at the multicast group borders, this approach essentially yields to 1) a lower mean bandwidth per call than the DHMIP and MIP approaches; 2) a lower mean handoff delay per call than that offered by the MIP approach; 3) a lower mean handoff delay than that offered by the DHMIP except in case of frequent inter-GFAs handoffs with a network configuration having a high number of links involved in MHMIP path reestablishment such as the configuration 2. Since we expect a diversity of multimedia applications for future IP mobile networks, we recommend using the MHMIP approach in networks parts carrying delay sensitive and/or low mean bandwidth consumption type of applications and this according to the mobility type.