Enhanced Mobile Internet Protocol Based on IPv6 Addressing Scheme for Third Generation Wireless Network

PAPER *Special Issue on Mobile Multimedia Communications*

Enhanced Mobile Internet Protocol Based on IPv6 Addressing Scheme for Third Generation Wireless Network

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SUMMARY The rapid growth of mobile systems and the exponential spread of the Internet have requested technologies for efficient and seamless delivery of IP data to mobile users. However, the Mobile Internet Protocol and the IETF Mobile IPv6 proposal are not scalable and capable of handling real time applications. The Mobile Internet Protocol employs mobility agents to support Internet-wide mobility, and mobile node employs the concept of *care-of address* to communicate with its correspondent node when it changes its point of attachment to the Internet. This paper proposes a new addressing scheme for mobile node based on IPv6. The concept of Mobile Internet is introduced, which is a logical subnet of IPv6 Internet and supports IP layer mobility. Mobile Internet is geographically overlaid on the Internet. It has a fixed subnet prefix, and each mobile node in it is only identified by its home IP address, regardless of its current location. Some new kinds of mobility agents (LRPC, LRPS/FLR) are defined. The proposed scheme is considered as a long-term solution for the Internet with mobile computers, several defects in the current Mobile IP protocol are solved.

key words: *mobile Internet, location resolution, mobile IP, IPv6, third generation wireless network*

1. Introduction

Recent initiatives to add mobility to the Internet and packet data services to third generation cellular systems are being considered by mobile service providers as possible candidate technologies for the delivery of IP data to mobile users. Both of these candidate technologies have shortcomings, however, the *Mobile Internet Protocol* (MIP) [1] and the *IETF Mobile IPv6* (MIPv6) proposal [2] represent a simple and scalable global mobility solution but lacks support for fast handoff control, real-time location tracking, authentication and distributed policy management found in cellular networks today. In contrast, third generation cellular systems offer seamless mobility support but are built on complex and costly connection-oriented networking infrastructure that lacks the inherent flexibility, robustness and scalability found in IP networks. Future wireless networks should be capable of combining the strengths of both approaches without inheriting their weaknesses.

The development of IP-centric mobile telecommunications networks present a number of challenges that go beyond the existing capabilities of Mobile IP and third generation networks. A number of new initiatives have been addressing these challenges as well as proposing enhancements to *Enhanced Data rate for GSM Evolution* (EDGE) and *General Packet Radio Service* (GPRS) technologies to more readily support wireless IP services. For example, the IETF Mobile IP Working Group is responding to new requirements being placed on Mobile IP by cellular telecommunications companies. In addition, cellular telecommunications providers and carriers have established new forums (e.g., 3GPP, 3GPP2 and 3GIP) that are revisiting the design of third generation networks with the goal of enhancing IP mobility-related solutions to deliver seamless mobility without losing the cost effectiveness, application flexibility and transparency of IP technologies. One of the important parts in these Technical Specifications is the wireless IP network standard (TSG-P) stating the requirements for supporting wireless packet data networking capability on 3rd generation wireless systems such as *Universal Mobile Telecommunications System* (UMTS). Among the requirements, MIP is the recommended key technology and needs to be improved. In this paper, we introduce a new architecture based on IPv6 addressing scheme to combine mobility and the Internet effectively.

In Sect. 2, we consider the problems of current MIP, and how it has been improved in some related work. Then in Sect. 3, we present our scheme, Mobile Internet. It stems from another standpoint rather than *care-of address* (COA) in current Mobile IP. In Sect. 4, we present some analysis to show how different in performance between our proposal and current MIP. Conclusion and some open issues follow in Sect. 4.

2. Mobile IP Overview

The basic elements in the basic MIP are *Mobile Node* (MN), *Home Agent* (HA), *Foreign Agent* (FA) TSG-P calls it *Packet Data Serving Node* (PDSN) and *corre-*

Manuscript received August 24, 2000.

Manuscript revised November 3, 2000.

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spondent node (CN) TSG-P calls it *End Host* (EH).

The MN performs a registration with the HA. In advanced location management systems, the registration may include the use of *authentication, authorization*, and *accounting* (AAA) protocols, such as RADIUS [3], or DIAMETER [4]. While away from home, MN uses COA to communicate with its CN.

The HA is a router on an MN's home network that tunnels datagrams for delivery to the MN. It thus maintains current location information, such as COA, for the MN. The location information is stored in a data structure called a mobility binding. The IP forwarding part of the router takes care of the data tunneling typically by using IP-IP encapsulation [5].

The FA is a router on an MN's visited network, or foreign network, which provides routing services to the MN while it is away from home, and registered to the mobility management system. Each MN uses its corresponding HA, while the FA just acts as an intermediate router. In this way, several MNs can use their corresponding HAs simultaneously over the same FA. The FA just delivers datagrams tunneled by the MN's HA to the MN. For datagrams sent by an MN, the FA may also serve as a default router for registered MNs.

Once the MN has registered with the system, the location management is handled with a location update message. The search for location occurs through the interplay of the MN and the FA so that the FA broadcasts or multicasts advertisements that tell about existing access points. When the MN moves, it sends registration requests telling the system its current location. The update part is composed of upgrading the mobility bindings in the HA and the routing information in the system.

The above is overview of Mobile IPv4. Compare with it, the most contribution of Mobile IPv6 is routing optimization. As each CN in IPv6 is assumed to be aware of mobility, routing optimization allows direct routing from any CN to any MN, without be forwarded by MN's HA, and thus eliminates the notorious "triangle routing" in the base Mobile IPv4. Additionally, overhead introduced by advertisement for fast handoff is another problem. To alleviate the problems and improve the performance of MIP, some related work has been done, which can be largely divided into two categories: micro-mobility for fast handoff and macro-mobility for route optimization. HAWAII [6] and Cellular IP [7] are two representative approaches of micro-mobility. HAWAII is a domain-based approach that adopts specialized path setup schemes to install host-based forwarding entries in specific routers; Cellular IP chooses hop-by-hop shortest path routing for uplink and chain of cached mappings for downlink. Both of them store location information as soft state and operate locally to reduce mobility related disruption to user applications and the number of mobility updates. However, such algorithms have little, if any, role to play in handoff within 3rd generation radio access networks (RANs). Their utility is lessened in the presence of link-layer mobility like that offered in today's TDMA and CDMA systems. Especially, for the macrodiversity [8] characteristic of CDMA RANs, the assumption of one-to-one mapping entries is not true. And so it is more important to improve macro-mobility rather than micro-mobility for applying MIP to 3rd generation mobile system. D. Forsberg [9] considered hierarchical mode to improve the performance of macro-mobility. Such a hierarchical scheme that reduces the signaling load of mobility management, by all means, is more appropriate to the enormous Internet. It's conceivable that combining hierarchical scheme with MIPv6 will bring better performance, but we found that it would inherit some problems from MIPv6 itself.

(a) In MIPv6, the packets destined for an MN is sent to either the MN's home network or the foreign network where the MN is currently in. The former case occurs while the CN does not detect whether or not the MN is roaming, thus results in the packets tracing a triangle path. The later case occurs if and only if there exists, in the CN's binding cache, an entry associated with the MN. However, because of the large number of MNs will be presented in the 3rd generation mobile system, it is a problem to update binding entries. For example, when many MNs visit a "hot" web site, such as www.yahoo.com, simultaneously, there must be a trade-off between the size of binding cache and the frequency of overwriting binding entries. Anyhow, the burden is heavy on the hot site.

(b) In MIPv6, when sending a packet while away from home, the MN may use its home address or its COA as the source address of a packet. In the former case, it means that a host belongs to the home network is permitted to access the home network from outside. In the later case, it means that a visitor's host is permitted to access the foreign network as if it is a member of the foreign network. Both cases leave vulnerable points that conflict with most current security policies.

(c) Frequent change of COA makes network management to MNs complicated. For example, many current Internet accounting systems work based on IP address and the accounting signaling is the main AAA signaling. Each time when an MN switches to a new COA for sending/receiving packets, relative accounting information must be reported to network management system in time for real time applications. Otherwise the accounting information will be lost or delayed. Moreover, frequent change of COA complicates QoS support. Recently, C.N. Yap presented IIP [10], in which each CN is aware of mobility and queries MN's location to its location registry before sends packets to it. This proposal can only solve the problem of the former case in (a) and can be taken as a special scenario in our proposal.

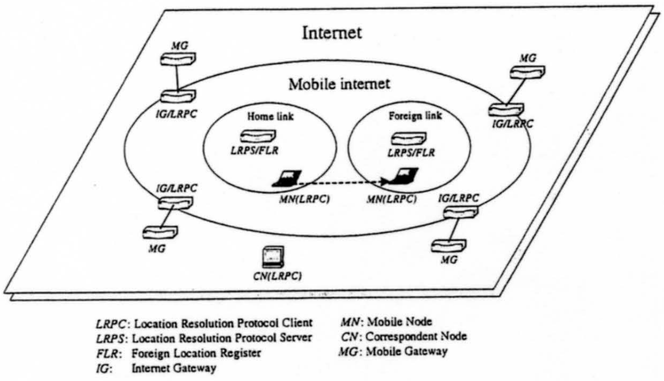

Fig. 1 The architecture of mobile internet.

3. Mobile Internet

All the approaches mentioned in Sect. 2 stemmed from a full-distributed idea, the core network has few functions in supporting node mobility except for forwarding packets, that is why COA came out. The idea is simple and is proved to go well with the current Internet, where users are mostly fixed users. However, along with the rapid growth of mobile systems, the simple idea will not go well with mobile users. We propose a new address scheme based on IPv6, Mobile Internet, in which home address is the only address to MN. The idea of Mobile Internet is to establish a mobile core network and give the core more functions to manage mobile users. In this paper, IPv6 is adopted as an example, but is not limited, for solving the problem that the address space of IPv4 is running to be exhaust, other ways such as *multiprotocol label switching* (MPLS) plus private address space of IPv4 may serve the same function as IPv6.

3.1 Network Architecture

Figure 1 shows the network architecture of Mobile Internet. Mobile Internet is a logical subnet of Internet, which is geographically overlaid on the Internet. The logical subnet is a root aggregation, which has a fixed IPv6 subnet prefix. The root aggregation will be divided into sub-aggregations assigned to different wireless network operators. Each sub-aggregation may be gradually divided into smaller ones to form an aggregation tree. Leaves on the tree are site-level aggregations, defined in IPv6, associated with only one local site. One can see our scheme is naturally a hierarchical scheme. To compare with MIPv6 easily and fairly, we neglect the hierarchical characteristic in the following sections. If our scheme is better than MIPv6, the result keeps the same even both deploy hierarchical architecture.

Mobile Internet consists of the following components: MN, *location resolution protocol server* (LRPS), *location resolution protocol client* (LRPC), *foreign location register* (FLR), and *Internet gateway* (IG). The interface between Mobile Internet and Internet is IG and *Mobile Gateway* (MG).

LRPS is an entity that resides on the router of an MN's home site. LRPS maintains a database of the MN's home address and its current location. While away from home, the MN must register its current location to its LRPS. While received a *location resolution query* (LR-query) for querying the current location of an MN from a LRPC, LRPS searches its database and answers the IP address of the MN's current FLR in *location resolution reply* (LR-reply) packet.

LRPC is an entity that originates the procedure of resolving the current location of an MN. It may reside on CN, IG or MN. While sends (for CN and MN) or forwards (for IG) a packet destined for an MN whose current location is unknown, LRPC starts location resolution by sending an LR-reply to the LRPS of the MN. After received LR-reply corresponding to the LRP-query, the current location of the MN is resolved and LRPC delivers following packets, destined for the MN, directly to the current location by IPv6 routing header [11] or other means, such as label switching if MPLS is deployed. An LRPC usually maintains a cache of bindings of MN's home address and its current location similar to the binding cache in MIPv6.

FLR is an entity that resides on the router of an MN's foreign site. FLR maintains a database of the MN's home address. It acts as the last hop while LRPC delivers packets destined for the MN.

IG is a router that forwards packets between Mobile Internet and Internet. IG is located in Mobile Internet side and directly connected to at least one MG. The administrators of mobile networks can define their policies here.

MG is a router that forwards packets between Internet and Mobile Internet. MG is located in Internet side and directly connected to at least one IG. Routing policies will be set at MG too.

While a router in the Internet detects a packet whose destination address is with the prefix of Mobile Internet, it forwards the packet to the nearest MG. The MG then forwards the packet to one of its directly connected IGs. While IG detects a packet destined for an MN whose current location is unknown, LRPC on the IG resolves the current location and then forwards packet to the foreign site where the MN is currently in.

While a router in Mobile Internet detects a packet whose destination address is not with the prefix of Mobile Internet, it forwards the packet to the nearest IG that will forwards the packet to one of its directly connected MG. Finally, MG routes the packet to the Internet according to its routing table.

3.2 Protocol Overview

This section gives an overview on the *location resolution protocol* (LRP) protocol, which is in charge of location management in Mobile Internet.

Register

While an MN is in its home site, it registers with its LRPS as a state of "at home." While moving to a foreign site, an MN first discovers an FLR attached to the foreign site by listening on beacons or sending solicitations, and asks to register with the FLR. If permitted, the MN then updates its location information to its LRPS and active LRPCs as "being away from home and visiting a foreign site associated with the FLR." As described above, an MN needs to do two kinds of registration: the first is registration to FLR, and the second is registration to LRPS. The former we call as forward registration and the later as location registration. LRPS/FLR is a distributed location database, and has similarities to HLR/FLR in GSM network.

Location Resolution

The current location of an MN is resolved due to LRPC queries the distributed location database formed in register stage. As shown in Fig. 1, LRPC usually resides on IG or CN. LRPC is triggered only when the current location of the destination (an MN) is unknown. And LRPC on CN will be triggered when the CN begins to send packets, while LRPC on IG, called proxy LRPC, will be triggered when the IG begins to forward packets. LRPC sends an LR-query packet to the LRPS located on the MN's home site and receives LR-reply packet that contains the MN's current location. The destination address of LR-query packet is a subnet-router anycast address pointing to the LRPSs on the MN's home site, see [12] for details of IPv6 anycast address. The context of LR-query packet contains the IP address of MN, and perhaps information such as the IP address or ID of the sender. The positive LR-reply packet contains IP address of the FLR currently serves the MN. With positive LR-reply, LRPC subsequently adds an entry of the pair, the MN and its current location (FLR), in its binding cache, and delivers packets destined for the MN to the associated FLR in accordance with the entry. The entry will be expired while timeout and be changed while the MN transfers to another FLR. A LRPC that has a valid entry of an MN is called active LRPC corresponding to the MN.

Packet Delivery

In Mobile Internet, the IP address of MN is the MN's home IP address; there is no COA. Packet delivery only occurs when the packet destined for a known location of an MN, that is, there is a valid entry of the MN in the binding cache of the delivering node, namely CN or IG, otherwise LRPC will be invoked. IPv6 routing header of type 0, see [11] for the definition, is adopted as delivery strategy.

Step1: The delivering node is actually the node the LRPC is triggered, so that the address of the delivering node is the address of active LRPC corresponding to the destined MN. When delivers a packet, the delivering node rebuilds the header of the packet.

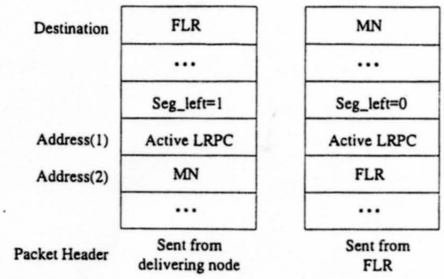

Fig. 2 Handling routing header.

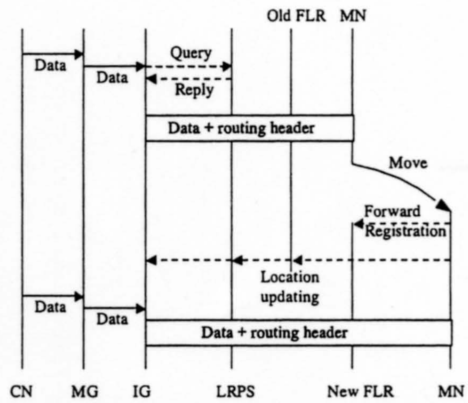

Fig. 3 An example scenario of location updating.

- Searches the binding cache and sets Destination Address = address of the FLR currently serves the MN.
- A routing header of type 0 is inserted: Routing header Length = 4 (2 segments), Segments left = 1, Address(1) = active LRPC's address, Address(2)=the MN's address.

Step 2: The packet is delivered to the FLR and further to the destination, Address(2), due to the function of routing header. Figure 2 depicts the procedure. While the MN received the packet at last, it knows its active LRPC from the routing header, which will be cached and used for updating location information when the MN changes its point of attachment. Figure 3 shows an example scenario an MN moves from one site to another. After the MN moved and registered with new FLR, it should updates the change of its location to its LRPS, all its active LRPCs, and previous FLR to avoid data loss before handoff completed. The updates here have similarities to Binding Update (BU) in MIPv6, such as retransmitting mechanism and rate limiting for sending updates.

4. Performance and Consideration

Performance of Mobile Internet is mainly dependent on LRP. However, Proxy-LRPCs are, in fact, intended to perform location resolution, and do increase burden to the mobile core network, although some caching function can be prepared on the LRPCs to enhance the

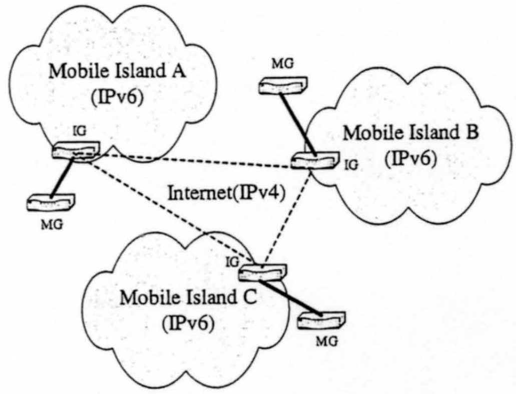

Fig. 4 Deployment of mobile internet.

performance of LRP. If the burden is affordable, our scheme will reach the best performance. If not, defining routing policies to hand over some deliveries to LRPC on CN will relieve burden added to the mobile core network. [10] gave the analysis of LRPC on CN. In order to show the advantages of our proposal, we assume the mobile core network has enough capability to deliver packets, but it doesn't mean our proposal lose flexibility when heavy burden results in network congestion.

Routing performance

As described in Sect. 3, Mobile Internet is a logical aggregation, which is comprised physically by many aggregations, such as many wireless network operators. Such architecture needs to be built step by step. Originally, each wireless network operator provides delivery of IP data to mobile users only in its own coverage, which we call a mobile island. Packets destined to an operator are distinguished from others through the unique prefix of its sub-aggregation. To support interconnectivity, dedicated lines connect these mobile islands to form a logical aggregation, see Fig. 4, where IPv6 mobile islands communicate with other such IPv6 domains by 6 to 4 [13] mechanism and IGs implement translator [14] to communicate with the Internet. The following analysis is based on the model of Fig. 4.

To compare the routing performance of MIPv6 and Mobile Internet, we define two mobility types in Mobile Internet: intra-island mobility, where MN moves within a mobile island, inter-islands mobility, where MN moves among different islands. In mobile IPv6, packets follow the shortest path from the CNs to the MN, except for the first packets which have to go through the MN's HA. In Mobile Internet, the route is always optimum for intra-island mobility at the cost of the latency of querying location information for the first packets. Triangular routing merely occurs in inter-islands mobility. Along the way dedicated lines are being widely deployed to well connect islands, inter-islands mobility will tend to be intra-island mobility due to there is, in fact, only one island, the Mobile Internet itself, at last.

Signaling Load

In both schemes, MIPv6 and Mobile Internet, a mechanism is provided to smooth out transitions in both schemes. After switching to a new agent (FA or FLR), an MN may send a BU to its previous default agent, asking him to redirect all incoming packets to its new location.

According to MIPv6, an MN sends BU to:

- its HA, each time it switches to another site (the HA must acknowledge this BU). We denote f_{HA} the BU and its acknowledge frequency from the MN to its HA.
- each of its CNs, each time it switches to another site and then periodically to refresh the CN's cache entries. After sending M consecutive BUs at a frequency of f_{fast} to a particular node with the same COA, the MN should reduce its frequency of sending BUs to that node to f_{slow}. We denote f_{CN} the average BU frequency from the MN to its CNs.
- its previous agent, each time it switches to another site. We denote f_{pre} the BU frequency from the MN to its previous agent.

f_{HA}, f_{CN} and f_{pre} are dependent on the mobility frequency of an MN, f_{mov}:

$$f_{HA} = 2 \times f_{mov} \tag{1}$$

$$f_{CN} = \begin{cases} (\lceil f_{slow}/f_{mov} \rceil + (M-1)) \times f_{mov} \\ \text{for } f_{slow} > f_{mov} \\ M \times f_{mov} \\ \text{for } 1/M \times f_{fast} \geq f_{mov} \geq f_{slow} \\ \lceil f_{fast}/f_{mov} \rceil \times f_{mov} \\ \text{for } f_{mov} \geq 1/M \times f_{fast} \end{cases} \tag{2}$$

($\lceil n \rceil$ is the minimum integer that isn't less than n)

$$f_{pre} = f_{mov} \tag{3}$$

According to Mobile Internet, an MN sends BU to:

- its LRPS at the frequency f_{LRPS}.
- each of its active LRPCs at the frequency f_{LRPC}.
- its previous FLR at the frequency f_{FLR}.

As described in Sect. 3.2, the location updates in Mobile Internet have similarities to BUs in MIPv6, and so f_{LRPS}, f_{LRPC} and f_{FLR} are in the same form as f_{HA}, f_{CN} and f_{pre} respectively. Figure 5 displays f_{HA}, f_{CN} and f_{pre} as a function of f_{mov} with $f_{fast} = 0.5$, $f_{slow} = 0.01$ and $M = 5$.

In order to compare the performance of MIPv6 and Mobile Internet, we introduce "signaling load" that is defined as the signaling bandwidth generated by a scheme on the Internet. Signaling load depends directly on the location updates, generated due to MNs perform handoffs. Handoffs are handled locally in both schemes. In Mobile Internet, local handoffs, which occur under intra-island mobility, are handled within the mobile island. In MIPv6, location updates have to cross the

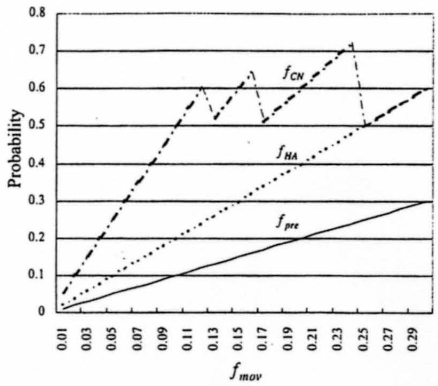

Fig. 5 f_{HA}, f_{CN} and f_{pre}.

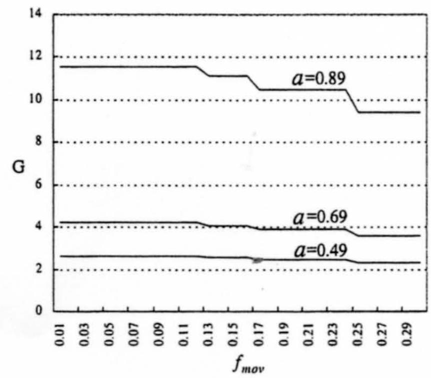

Fig. 6 Gain vs. f_{mov}.

whole Internet to reach the MN's CNs. Additionally, we assume the sizes of location updates in both schemes are the same, $Size_{BU}$, and consider two scenarios, local mobility and inter-sites mobility.

Local mobility in MIPv6, that is an MN is moving within its home site, generate signaling load:

$$L_{MIPv6,local} = Size_{BU} \times f_{CN} \times N_{CN} \quad (4)$$

N_{CN} is the number of CNs that are not in the MN's home site. However, local mobility in Mobile Internet is, in fact, intra-island mobility, and does not generate signaling load to the Internet: $L_{MI,local} = 0$.

Inter-sites mobility in MIPv6 is the mobility that an MN is moving across foreign sites, it generates signaling load:

$$L_{MIPv6,inter} = Size_{BU} \times (f_{CN} \times N_{CN} + f_{HA}) \quad (5)$$

Inter-sites mobility in Mobile Internet is inter-islands mobility and generates signaling load:

$$L_{MI,inter} = Size_{BU} \times (f_{LRPC} \times N_{LRPC} + f_{LRPS}) \quad (6)$$

N_{LRPC} is the number of the MN's active LRPCs, normally $N_{LRPC} < N_{CN}$.

As the results established in [15] that $\alpha = 0.69$ of an MN's mobility is local, we also use α to represent the probability of local mobility, so that the average of signaling load of each scheme is defined as below:

$$L_{MIPv6} = \alpha \times L_{MIPv6,local} + (1-\alpha) \times L_{MIPv6,inter} \quad (7)$$

$$L_{MI} = \alpha \times L_{MI,local} + (1-\alpha) \times L_{MI,inter} \quad (8)$$

We define the gain achieved by Mobile Internet over MIPv6 as: $G = L_{MIPv6}/L_{MI}$. Figure 6 shows the gain as function of f_{mov} with different α ($f_{fast} = 0.5$, $f_{slow} = 0.01$, $M = 5$, $N_{CN} = 3$ and $N_{LPRC} = 2$). The gain is larger for larger α. On the way to build Mobile Internet, the better mobile islands are well connected, the larger α is, and at last $\alpha = 1$ to reach the goal of Mobile Internet.

5. Conclusion and Open Issues

This paper introduces the concept of Mobile Internet and demonstrates an addressing scheme for MNs in Mobile Internet based on IPv6. The advantages are:

- MN roams freely in Mobile Internet and is only identified by its home IP address, regardless of its current location. This supports location privacy.
- Routing inside Mobile Internet is optimal. Routing between Mobile Internet and the Internet is near optimal. Signaling load is lower than MIPv6.
- Service providers can decide the LRPC is deployed on network side (proxy LRPC) or user side. It's flexible for network management.

The disadvantage is that, because Mobile Internet is completely a new network, it will be built from zero. However, as a long-term solution, this disadvantage is acceptable. The cellular telephone network is a successful example. In addition, the scheme is applicable to routing in some special networks such that the network includes unidirectional data links or the network itself is in movement. There are some open issues currently over investigation that would effect our proposal.

- The load for LRP processing is high on proxy LRPC, if the number of its serving MNs is large. Some methods should be considered to make proxy LRPC worked more effectively; otherwise the performance of LRP would be degraded.
- AAA information is necessary for mobile service. However, authentication and authorization need only once at the point MN transits to another site, so that accounting information is the most signal. On the other hand, most accounting software is based on IP address, if take this point into consideration, our proposal will provide more gain on signaling load.
- While Mobile Internet expands largely, polices must be imposed for routing between Mobile Internet and the Internet. As depicted in Fig. 1, Mobile Internet is connected to the Internet almost

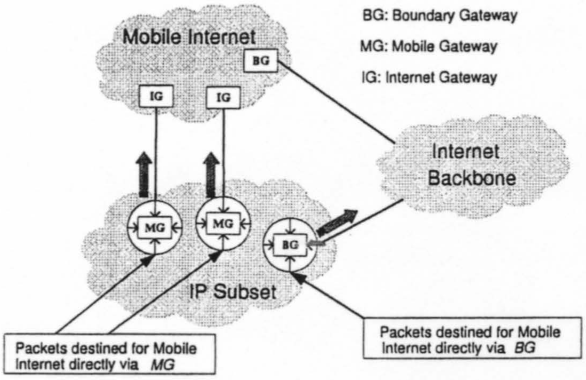

Fig. 7 Traffic between mobile internet and internet.

everywhere. Figure 7 shows the traffic flow between Mobile Internet and Internet. In the future Mobile Internet may grow with MNs up to tens of millions. There exist many routing domains in such a large-scale Mobile Internet. Common interior gateway protocols, such as OSPF [16], and exterior gateway protocols, such as BGP [17], may be employed as routing protocols for Mobile Internet. However, because of the special architecture of Mobile Internet as shown in Fig. 1, new rules must be introduced for routing within Mobile Internet domains and for routing between Mobile Internet and the Internet.

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