Population based Mobility Management in LEO Satellite Networks

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ABSTRACT
Low Earth Orbit satellite systems gained considerable interest towards the end of the previous decade for its some important characteristics that are showed with such low propagation delay, low power requirements and ability to communicate with handheld terminals. So LEO networks are considered to be complementary rather than competitive to terrestrial networks. But the higher relative speed than terrestrial mobile networks is the main disadvantage of LEO satellites. As a result, the frequency of handover is more which decreases the quality of service. To overcome this problem, many solutions are given by scientists. Here we have proposed a Population Based Mobility Management (PBMM) method where we have divided the total Earth's surface into three types of area and applied different mobility management method for each of the populated areas. Through mathematical analysis simulation results shows that this method is better than the standard mobility management methods and can successfully reduce the handover costs.

Keywords
Low Earth Orbit (LEO), Terrestrial Network, Population Based Mobility Management (PBMM), Mobile Node (MN).

1. INTRODUCTION
Satellite communication networks are utilized to co-exist with terrestrial networks in order to provide global coverage to a heterogeneously distributed over population. A LEO satellite takes about 100 minutes to orbit the earth, which means that a single satellite is in view of ground equipment for only a few minutes [1]. As a consequence, a LEO satellite system must hand over between satellites to complete the transmission if a transmission takes more than the short time period that any one satellite is in view,. In general, this can be accomplished by constantly relaying signals between the satellite and various ground stations, or by communicating between the satellites themselves using "inter-satellite links" (ISLs) [1], [2].

In addition, LEO systems are designed to have more than one satellite in view from any spot on Earth at any given time, minimizing the possibility that the network will lose the transmission. Because of the fast-flying satellites, LEO systems must incorporate sophisticated tracking and switching equipment to maintain consistent service coverage. The need for complex tracking schemes is minimized, but not obviated, in LEO systems designed to handle only short-burst transmissions [3].

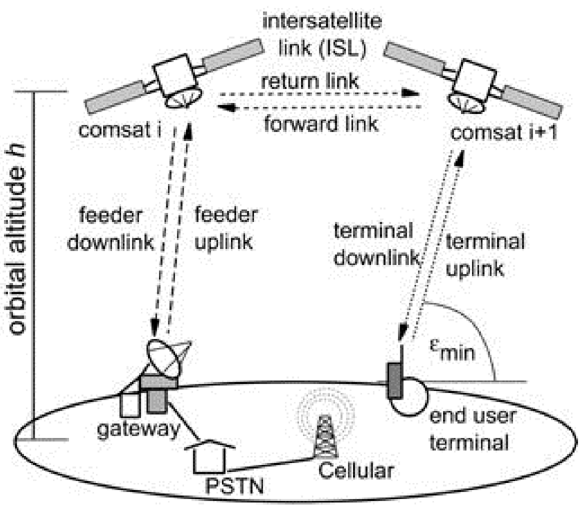

Fig 1: Satellite Communication System

Handover:
In the term handover or handoff refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another. In satellite communications it is the process of transferring satellite control responsibility from one earth station to another without loss or interruption of service. Handovers may degrade the system performance as an unsuccessful handover results call blocking and forced call termination. Forced call termination is less desirable than a new call blocking though both affect the performance of the system. A number of handover techniques have been proposed to solve this problem.

IP/LEO satellite networks are used to provide a wide variety of IP-based applications, such as teleconferencing and tele-education. Being totally independent of terrestrial networks, LEO satellite networks have a unique ability of supporting certain emergency communication systems, such as I Am

Alive (IAA) System [4]. To provide such applications, scalable mobility management and IP communication between end nodes are required.

Conventional IP mobility management protocols, typified by Mobile IP [5] and LIN6 (Location Independent Network architecture for IPv6) [7], require mobile nodes to send binding update requests to the Location Directory every time a handover occurs. Given the high-mobility of satellite networks, usage of these approaches will result in a large number of binding update requests and consequently affect the scalability of the mobility management schemes.

Now we will try to find an equation of rate of handover occurrence form the boundary crossing model.

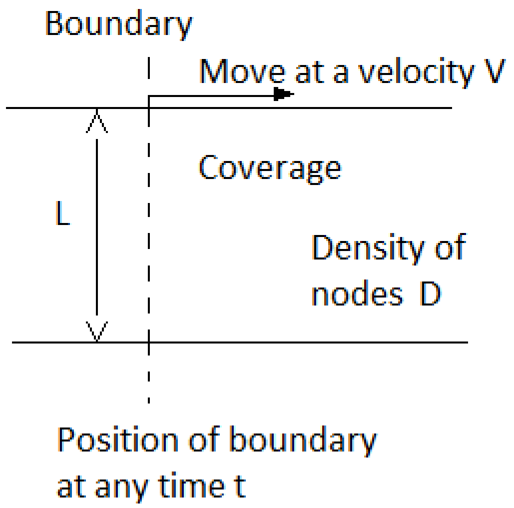

Fig: 2 Boundary crossing model

In the above figure, a coverage boundary of length L moves with velocity V from left to right during a period of time Δt. The nodes that belong to the area with surface L.V will be required to perform handover during time Δt. denoting the area density of nodes as D, the rate of boundary crossing event, R, can be expressed as:

$$R=V.L.D \quad (1)$$

Considering the fact that handovers are mainly due to satellites movement, V can be approximated to the ground speed of satellites. Let $D_L(V_{sat}.t)$ denote the linear density of nodes on the coverage boundary at time t. The rate of handover occurrence, $R_{HO}(t)$, is:

$$R_{HO}(t)=V_{sat}.L_{sat}\int_{Vsat(t-t\Delta)}^{Vsat.t} DL(Vsat.t)dt \quad (2)$$

Where, V_{sat} and L_{sat} denote the ground speed of satellite and the coverage boundary length, respectively.

Since satellites are assumed to cover wide areas and move fast, V_{sat} and L_{sat} are large. From Eq.2, it becomes evident that $R_{HO}(t)$ takes large values even for small values of Δt. Furthermore, this rate of handovers is likely to become even larger in a very populated area (large values of $D_L(V_{sat} \cdot t)$).

In this paper we have proposed a new mobility management method named Population Base Mobility Management (PBMM) in the basis of population of mobile nodes in different areas.

The rest of the paper is organised as follow: in the second section we have described the related mobility management methods available. In the third section we have described the details of PBMM method. In the forth section we have compared the handover management cost of standard IP protocols our proposed work. The simulation results of related mobility management methods and PBMM method based on handover cost is evaluated in section five. In the next section we conclude the whole paper and finally a future work is mention regarding this paper in section seven.

2. RELATED WORK

2.1. Mobility Management in Terrestrial Mobile Networks and LEO satellite Networks

2.1.1. *Outline of General Mobility Management*

In recent years the main concern in IP/LEO networks is the mobility management. The purpose of it is to locate MNs in the network and to guarantee a seamless data transmission upon change in node position. Mobility management mainly deals with two operations, namely binding update and data delivery [8].

- *Binding Update:* This operation aims to associate Reachability Identity (Reach.ID) and Routing Identity (Route.ID) of each node.
- *Reach.ID:* It indicates a unique name of the node and not subjected to change.
- *Route.ID:* It specifies position of the node in the network and changes in response to node movement. When a MN changes its position, the Route.ID changes as well as the old binding update is no longer valid. To update the binding, MNs are requested to send their new Route.ID to the Location Directory (LD) [10].

The main disadvantage of this procedure is when LD is geographically too far from the MNs. As a result, the cost of binding update becomes very expensive especially a high mobility environment such as satellite networks [9]. We all know that a handover is a local process which involves only the MN, the old AR, and the new AR where as binding update is a global process that may affect other network elements in addition to the three adjacent entities. We have two types of Location Management namely Precise Location Management and Loose Location Management.

- *Precise Location Management*: When Route.ID indicates the position of the MN, so data transmission can be done seamlessly with no further operations. This is called Precise Location Management. In this case the MN requires frequent update of MNs registration even upon a slight movement of nodes. Thus the required update cost can be very huge [11]
- *Loose Location Management*: When Route.ID is used to indicate the location of MN roughly, an additional operation called paging is done to find the position of MN. But in wide paging areas, the paging cost can be very high which the main disadvantage of it is.

So from this discussion we can conclude that Route.ID plays a very important role on the mobility management cost. More attention should be thus paid to the choice of Route.ID type that suites best mobility management in the underlying network.

2.1.2. *Mobility management in Terrestrial IP network*

The main drawback of mobility management in terrestrial IP networks is the fact that IP addresses that are originally designed for Route.ID's are also used as Reach.ID's in higher layers. As a result, a MN cannot be identified in the higher layers if its IP address changes at handover occurrence time.

The most useful protocol among existing mobility management is Mobile IP (MIP) which was proposed to tackle this problem. It uses two different IP addresses for two different identities of MN. First one is referred as Home address and acts as a Reach.ID and second one is Care of Address and serves as Route.ID. Home Agent plays the role of LD in MIP. In this case, locations of MNs are precisely managed by binding update for every handover occurrence.

Another mobility management protocol is LIN6 where LIN6 address are used to refer to the Route.ID of mobile nodes. LIN6 addresses are decided according to the AR that mobile nodes are connected to which is similar to CoA of MIP.

MIP and LIN6 uses a precise location management which necessitates a binding update whenever MN changes its position which is devoid of the condition that the MN is communicating or not. So it is better to use a precise location management to the active nodes. But for the inactive nodes a loose location management is sufficient where the no of binding update frequency can be reduced.

The most dominant loose location mobility management protocols are Paging in Mobile IP (P-MIP) [12] and Cellular IP [13]. Paging is a procedure that allows a wireless system to search for an idle mobile host when there is a message destined to it, such that the mobile user do not need to register its precise location to the system whenever it moves.

In P-MIP each paging area is consists of a certain number of ARs in the network. Whenever a packet data is destined to an idle node reaches at one of the AR in a paging area, that AR broadcasts a paging request to all the other ARs that subsequently send paging messages within own coverage areas. When an idle MN receives a paging request, it becomes active. But that MN is not required to perform binding update within its own paging area. The MN should only update its binding whenever it crosses the paging area boundary. Thus the frequency of binding update can be reduced.

2.1.3. *Mobility Management in LEO satellite networks*

The most widely used protocol for mobility management over satellite networks is again Mobile IP (MIP) which is proposed by the Internet Engineering Task Force (IETF) to handle mobility of internet hosts for mobile data communications. It is based on the concept of Home Agent (HA) and Foreign Agent (FA) for routing of packets from one point of attachment to other. It is basically completed by four steps.

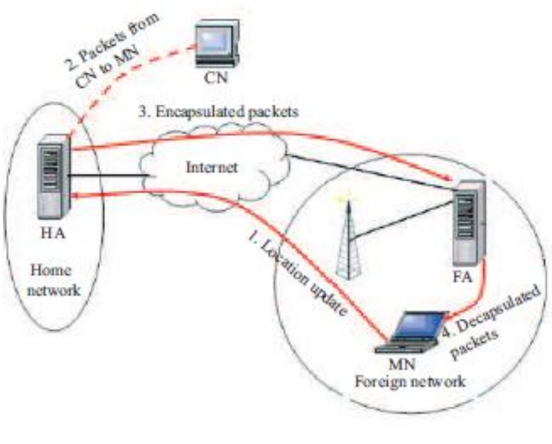

Fig 3 Handover Flow in Mobile IP

i) When handover begins MN registers itself in FA and waits for allocation of channels in FA and updates its location in HA directory.

ii) The packets are sent to HA and HA encapsulate it.

iii) Encapsulated packets are sent to The FA.

iv) FA decapsulate those packets and sent it to MN.

Applying MIP to LEO satellite networks will result in a precise location management of MNs and consequently an invocation of binding update upon each handover occurrence [14]. As discussed earlier, the number of binding update request will be huge in a single burst. To process all the requests, a massive amount of network bandwidth and computational load are required. This is a serious issue for scalability of mobility management in LEO satellite networks.

To reduce the binding update two loose location management schemes have been introduced; P-MIP and Handover Independent IP Mobility Management [16]. The design of P-MIP encompass, Paging area construction, Movement Detection, Registration, Paging, Data Handling

However since paging areas are formed from the coverage areas of a certain number of satellites which are constantly moving, so the ceaseless motion of the satellites makes the paging areas to keep changing. Meanwhile, bursting binding updates might occur as well when LEO satellites cross paging area boundary. So this loose location management method is not suitable for LEO satellite networks.

Another loose location management method is Handover Independent IP Mobility Management which uses the IP addressing on the basis of geographical location and is independent of logical locations.

In this method, the earth's surface is divided into a number of cells, and MN's Route.ID's are associated with the cell where MNs reside in. MNs are assumed to be equipped with GPS (Global Positioning System) receiver for finding their locations. A Route.ID changes and the corresponding binding update occurs only when a MN moves to neighbour cell.

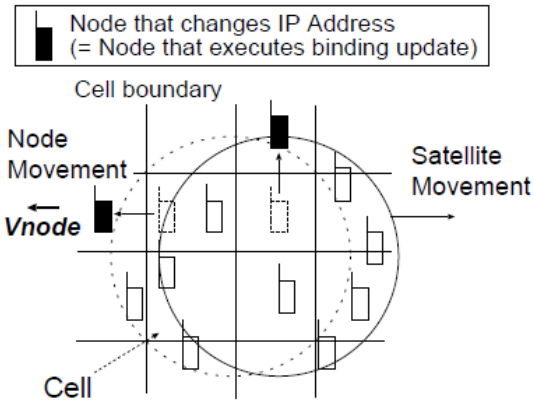

Fig 4 Handover Independent Mobility Management

This method has three steps.

1) Geographical Location mapping to Route.ID
2) Cell distribution in a satellite coverage
3) Connection setup and maintenance

The main disadvantages of this method are

- ➢ As the LEO satellites have high speed so it crosses the boundaries of the cells frequently which leads to less mitigation of the frequency of IP binding update
- ➢ This method needs centralised binding management, which causes huge location directory database and long distance transmission path for IP, address binding updates. This places a heavy burden on communication and storage resources in satellites.

3. PROPOSED WORK

Here we have proposed a new mobility management method named Population Based Mobility Management in LEO Satellite Networks based on the population of mobile nodes. We have used both precise location management method and loose location management method in the different area based on the population.

Our method is based on the following facts.

1. In LEO satellite systems we have covered the whole earth to have a global connection. Many research work shows that the population of mobile nodes is concentrated in a few areas not the whole world. So if we use same mobility pattern throughout the whole world it will be wasted of resources and also we will not able to serve the whole world simultaneously with the desired Quality of service. So we must use different mobility system in the different population to have the best result.
2. Another fact that these population area also changes with time. Suppose many workers come to the city in the office hours and they again back to home after that. So the population area of mobile nodes also changes with time. So we should use different mobility management not only in different population area but also at different time. Population areas are also dynamic and changes with time.

These two backlogs of modern mobility management systems are removed in our PBMM method.

1. ***Population Area Formation:*** In our proposed PBMM method we have divided the whole earth surface into three population area low populated area, medium populated area and high populated area.

A. *Low Populated Area:* Low populated area mainly covers oceans, mountains, forests, and deserts etc where the population of mobile node is very low. The parameter for selection such differentiation may vary for different satellite systems. Here we have specified that Low Populated Area must contain less than 100 mobile nodes per square kilometres. These low populated areas contain maximum percentage of the whole earth surface nearly equal to 60%.

B. *Medium Populated Area:* Medium Populated area mainly contains villages where the population of mobile nodes is in between 100-10000 mobile nodes per square kilometres. Medium populated area contains second highest percentage of whole earth surface nearly equal to 30%.

C. *High Populated Area:* High populated area contains mainly metropolitan cities, works places where the population of mobile nodes is more than 10000 mobile nodes per square kilometres. It contains the lowest populated area nearly equal to 10%.

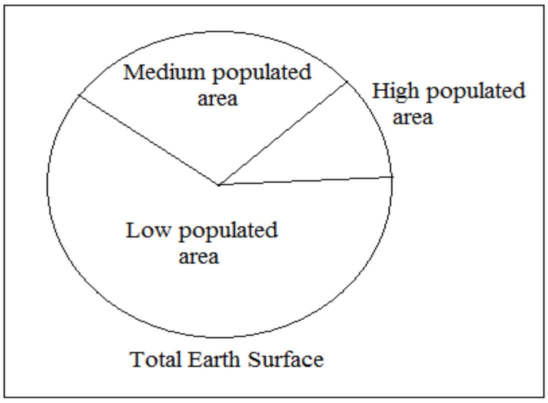

Figure 5 Different Populated Areas

2. EFFECT OF TIME PERIOD IN DIFFERENT POPULATION AREA

Most of the High populated areas are dynamic as the mobile nodes moves due to the working place variation. As said earlier that most of the mobile nodes have spends the entire day means 24 hours in two different zones. One is their residual place and another is their working places. Most of the people moves their working places at office hours and back return to home after that. This movement make some of the medium populated areas in to high populated area during office hours for example in metropolitan cities people moves for jobs and after that the high populated areas are again converted to medium populated area.

To accompany with these changes we have used a database which calculates the no of mobile nodes in each populated area and thus there will be two types of area one for office hours and another for the rest of time period.

A. **Dynamic Period:** The duration of dynamic period is to be selected by the database. It will be within 9am to 9pm. In between these time most of the mobile nodes moves and medium populated area is converted to high populated area. It may be different for different parts of the world where night worker are more.

B. **Static Period:** The rest o the time is the static period. Generally it will be within 9pm to 9am. These will also dynamic and will be selected by the database. In this time period the high populated area are converted to medium populated area.

In our proposed PBMM method we will use different mobility management method for the mobile nodes in different populated areas. The mobile node must register them while changing their respective populated area. For low populated area and medium populated area we have used loose location management method and for high populated area we have used precise location management method.

Population Based Mobility Management method:

In PBMM method we have used three types of mobility management method for three types of populated areas. Every mobile should register itself while changing their populated areas. So the mobile node IP address will be

Node IP address= Node ID + populated area ID

So there will be unique ID for each type of populated area.

A. **Mobility Management for Low Populated area:** for low populated area the number of mobile nodes is very less so we will use a very loose location management method. Among all the proposed loose location management method *Handover Independent method* suits best for this type of area. Here we have divided the total area in a number of cells and the cells are generally large in size. The mobile nodes are assumed to be equipped with GPS. The node IP address changes whenever the mobile node moves to the neighbouring cell and the update is kept in the location directory. Hence the node IP address will be

Node IP address for low populated area= node ID + cell IP

The cell ID is done such that it can easily be identified that that cell belongs to low populated area

Cell IP = Cell ID + low populated area ID. The other details of handover independent method are discussed earlier.

B. **Mobility Management for medium populated area:** For medium populated area the no of mobile nodes are more than low populated area. So we will use a less loose location management method. Among the available loose location management method *paging in mobile IP* suits best for medium populated areas. Here the overall populated area is divided into a number of paging areas. The total area of each paging area is much less than the cell area of handover independent method. So hence the node ID will be

Node IP address for medium populated area= Node ID + paging area IP

The paging area ID is also done such that it can be easily identified that it belongs to medium populated area.

Paging area IP = Paging area ID + medium populated area ID.

C. **Mobility management for High populated area:** For high populated area the no of mobile nodes is very high. So we need a precise location management method to handle this large number of mobile nodes. The most used precise location management method is mobile IP. The main disadvantage of mobile IP is its performance decreases for large areas but the cell size for the high populated area is smaller than others. So MIP suits best for high populated area.

Advantages:

The main advantages of this PBMM method is stated below

a) In PBMM method the earth's surface is divided into three parts according to the population of mobile node sand we have applied three different mobility management methods for three different parts. As earlier only one mobility management method is applied to the whole world which can act well for a specific part of world but not the whole world. But as we applied three different methods in three different parts so these methods results its best to their respective world.

b) As three different methods are used so it increases system scalability.

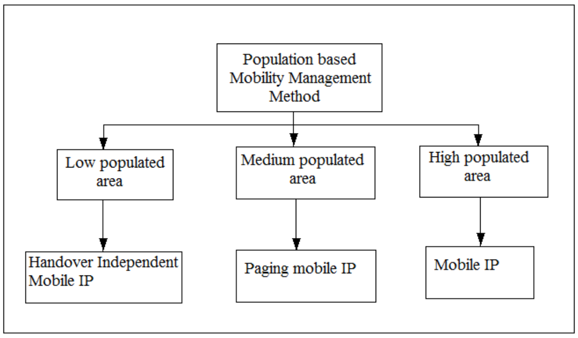

Figure 6: PBMM method

Cost analysis:

In this section we have evaluated the cost of PBMM method and compared it to that Mobile IP, P-MIP and Handover Independent Mobile IP.

Mobility Management Cost elements

As discussed earlier, the mobility management cost mainly consists of the binding update cost and data delivery cost. In precise location management method, the binding update cost is large as a large number of binding update request is generated. In loose location management, this cost is reduced but some additional cost such as local forwarding cost and paging cost are generated. So the overall cost rises.

Mobility Management Cost Definition

In [12] the mobility management cost is evaluated as the product of generated control message size, M and the number of hopes, H, required to deliver the message. If we apply such definition into the paging cost, it will be proportional with the number of receivers. Taking into account the broadcasting capabilities of satellites, however, the cost is also simply a product of the message size and the number of travelled hops.

$$Cost=M.H \quad (3)$$

Costs of different Mobility management events:

The following defines the cost required for each mobility management event; binding update, local forwarding, paging and GPS finding.

For each case, the Control messages generated are assumed to be equally sized (M) in all the four events. The number of control messages that are generated upon a handover occurrence between mobile nodes and the corresponding ARs, is assumed to be same for MIP, P-MIP, handover Independent Mobile IP and our proposed method. Thus we can neglect the number of control message in the cost evaluation.

1. *Binding Update Cost:* Let $H_{MN,LD}$ denote the number of hops between a mobile node and the Location Directory. The cost for binding update procedure can be expressed as:

$$M.H_{MN,LD}$$

2. *Local Forwarding Cost:* Denoting the number of hops between two adjacent satellites as $H_{AR,AR}$ the local forwarding cost is shown as follows:

$$M \cdot H_{AR,AR}$$

3. *Paging Cost:* The paging cost as mentioned in [16] is

$$M.H_{AR,AR}.(S-1) + M.1.S$$

Where *S* denotes the number of single-beam satellites that cover a single paging area.

4. *GPS Finding Cost:* The cost to find a MN by GPS method is G.

Management Cost of MIP, P-MIP, Handover Independent Mobile IP and our proposed method

The costs of Mobile IP, P-MIP, Handover Independent Mobile IP and our proposed method are as follows

A. Mobile IP: The cost of MIP is the product of binding update cost and rate of handover occurrence. The local forwarding, paging and GPS are not used here. So the MIP management cost, $C_{MIP}(t)$ can be expressed as

$$C_{MIP}(t)= M.H_{MN,LD}.R_{HO}(t) \quad (4)$$

B. Paging in Mobile IP: In P-MIP the active MN update their binding upon handover occurrence. The idle nodes perform their binding update only when they cross the paging area boundary. So using equation 1 the rate at which boundary nodes cross the paging area boundary at time t, $R_{p\_area}(t)$ is

$$R_{p\_area}(t)=V_{sat}.L_{p\_area}.\int_{Vsat.(t-t\Delta)}^{Vsat.t} DL(Vsat.t)dt \quad (5)$$

Where L_{p_area} denotes the boundary length of paging area.

So the P-MIP cost $C_{P\text{-}MIP}(t)$ is

$$C_{P\text{-}MIP}(t)=M.H_{MN,LD}.R_{p\_area}(t)+ M.H_{MN,LD}.\{R_{HO}(t)-R_{p\_area}(t)\}.\alpha + \{M.H_{AR,AR}.(S-1) + M.S\}.n(t).(1-\alpha).\lambda \quad (6)$$

Where $n(t)$ and α denote the total number of nodes per a coverage area at time t and the ratio of active mobile nodes to the total number of nodes, respectively. The rate of newly coming connections to a mobile node is denoted as λ. The first and second terms indicate the binding update cost, whereas the third one refers to the paging cost. Observe that $n(t)\cdot(1-\alpha)\cdot\lambda$ indicates paging the occurrence rate.

C. Handover Independent Mobility Management Cost: In this method, the local forwarding and paging scheme occurs as some additional cost. So the total cost $C_{HI}(t)$ is

$$C_{HI}(t)= M.H_{MN,LD}.R_{cc}(t))+ M._{HARAR}.R_{HO}(t).\alpha + \{M.H_{AR,AR}.(S-1) + M.S\}.n(t).(1-\alpha).\lambda \quad (7)$$

Where $R_{CC}(t)$ can be expressed as

$$R_{CC}(t)=C.V_{node}.L_{cell}.\int_{Vnode(t-\Delta t)}^{Vsat.t} Dn(Vsat.t)dt \quad (8)$$

Where C is the no of cells, V_{node} and L_{cell} denotes the velocity of nodes and the cell boundary length respectively.

The first term in Eq. 7 indicates the binding update cost. The second and third terms represent the local forwarding and paging cost, respectively.

D. Population Based Mobility management Cost : Now we will evaluate the cost of our PBMM method. As in PBMM we have used the MIP, Paging in MIP and handover independent MIP so the cost of PBMM will be the sum of these three costs.

I. Cost for Low populated area: In low populated area we have used handover independent MIP so the cost C_{LPA} (Low Populated area) will be same as equation 7

$$C_{LPA} = M.H_{MN,LD}.R_{cc}(t))+ M._{HARAR}.R_{HO}(t).\alpha + \{M.H_{AR,AR}.(S-1) + M.S\}.n(t).(1-\alpha).\lambda \quad (9)$$

II. Cost for Medium Populated Area: In medium populated area we have used the paging in mobile IP so the cost C_{MPA}(Medium populated area) will be same as equation 6.

$$C_{MPA} = M.H_{MN,LD}.R_{p\_area}(t)+ M.H_{MN,LD}.\{R_{HO}(t)-R_{p\_area}(t)\}.\alpha + \{M.H_{AR,AR}.(S-1) + M.S\}.n(t).(1-\alpha).\lambda \quad (10)$$

III. Cost for High populated area: In the high populated area we have used the MIP so the cost will be C_{HPA} (High Populated Area) same as equation 4.

$$C_{HPA} = M.H_{MN,LD}.R_{HO}(t) \quad (11)$$

Now the total cost for PBMM method is

$$C_{PBMM} = C_{LPA}*0.6 + \{ (C_{MPA}*0.3 + C_{HPA}*0.1) + (C_{MPA}*.35 + C_{HPA}*0.05)\}/2 \quad (12)$$

The first term in equation 4 indicates cost of the area for LPA. As it covers 60% of total earth's surface so it is multiplied by 0.6. The second term indicates the cost of dynamic period which is the sum of area of MPA and HPA. As in dynamic period the area covered by MPA is 30% and HPA is 10%. In the third term the cost of static period is shown where the area covered by MPA is 35% and HPA is 5%.

4. SIMULATION RESULTS

In order to evaluate the performance of PBMM method we compare it to MIP, P-MIP and Handover Independent Mobile IP. Each method is evaluated by handover costs. The simulation results were run on MATLAB 7.8 in a designed virtual environment.

The virtual environment is created by setting the following parameters.

Satellite coverage area radius	700[km]
Satellite Ground Speed	7km/sec
Low populated cell area	1000sq km
Medium populated cell area	500 sq km
High populated cell area	100 sq km
No of mobile nodes in low populated cell	10node/sq km
No of mobile nodes in medium populated cell	500 nodes/sq km
No of mobile nodes in high populated cell area	1000nodes/sq km
Area covered by LPA both in static and dynamic period	60%
Area covered by MPA in dynamic period	30%
Area covered by MPA in static period	35%
Area covered by HPA in dynamic period	10%
Area covered by HPA in static period	5%
α	15%
λ	0.0009
Δt	1sec
$H_{MN,LD}$	2
$H_{AR,AR}$	1
S	5

We assume the satellite coverage area to be hexagonal shaped and their surfaces are equal to that of a circle with a radius 700[km].

In figure 7 we have shown the simulation results. It shows that the cost of our proposed PBMM method is better than MIP, P-MIP and Handover independent MIP. As out method is the average of these three methods for different time and place so eventually the management cost of PBMM is lower than others.

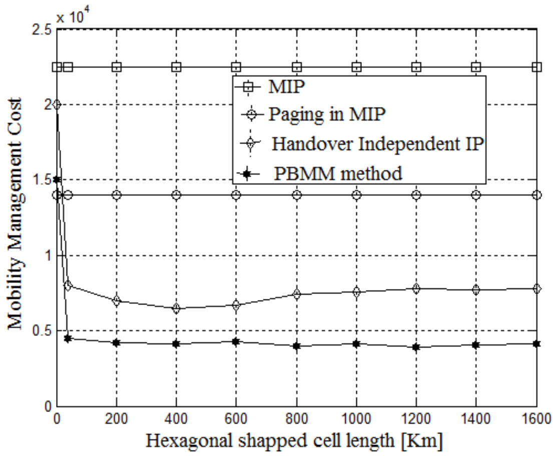

Figure 7: Handover cost of different methods

5. CONCLUSION

In this paper we have proposed PBMM method where we can successfully reduced the handover cost by dividing the total node population into three parts LPA, MPA and HPA.

We first described major aspects of satellite communication and the advantages of satellite communication. Then we introduce the term 'handover' and the problems of handover on satellite communication. Then we described various IP protocol management methods such as MIP, P-MIP and Handover independent MIP. After that we have described our proposed work PBMM method and mentioned its advantages. The cost analysis of different mobility management methods with comparison with our proposed work is given in the next part of this paper. Based on the cost analysis, a simulation result of these mobility management methods with our proposed works is also given. It shows that the PBMM method is better than other IP protocols. So we can use it in our IP networks as a mode of future satellite communications.

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