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Virtual Agent Clustering Based Mobility Management Over the Satellite Networks

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ABSTRACT Due to the high dynamic characteristics of the low-orbit satellite networks, the frequent handovers of the users led to heavy mobility management load and large handover delay. To solve these problems, one mobility management mechanism based on the virtual agent domain (VAD) is proposed. In this mechanism, a virtual agent cluster (VAC) is designed to co-manage the network architecture of users in the corresponding VAD. With the on-board processing and switching capabilities, the architecture of the distributed mobility management mechanism is adopted to support the information sharing between the VACs, which reduces the performance requirements for single satellite and improves the system scalability. Then, we construct the home mobile-agent-anchor (HMAA) and the local MAA. In this way, the MN triggers a binding update to the HA only when the home MAA is lost, and the MN's switching within the VAD only needs to update its intra-domain relations, which reduces the overhead of mobility management and switching delay. Furthermore, the proposed scheme is theoretically evaluated in terms of the signaling overhead and handover latency. Finally, the numerical simulation results are presented to verify the efficacy of our scheme. The experimental platform also demonstrates the availability and efficiency of the new mechanism.

INDEX TERMS Low-orbit satellite network, mobility management protocol, virtual agent domain, information sharing, home mobile agent anchor, simulation platform.

I. INTRODUCTION

Since the low-earth-orbit (LEO) satellite network has the characteristics of supporting global communication, short propagation delay and high data transmission rate, it is considered as an effective extension of the terrestrial cellular system and would play an important role in the future mobile communication system. In addition, with the development of all-IP technology, it is necessary for LEO satellite networks to service IP-based communication applications [2]. However, due to the time-varying network topology structure, each ground node may frequently switch from one satellite to another one to maintain a continuous communication. Thus, proper mobility management schemes should be carefully examined to support Mobile IP over the next-generation LEO networks [3]. Obviously, we can adopt the MIPv6 protocol of the terrestrial system to implement the mobility management.

However, there still exist some problems. The first one is the mobility management overhead due to frequent switching. The second one is the feasibility of the network deployment. To overcome these bottlenecks, the author in [4] proposed a distributed mobility management scheme. The distributed network structure improves system performance to a certain extent, but introduces a large amount of signaling overhead in the terrestrial network. In addition, a great number of ground stations (GSs) are needed, and the switching delay is large. Multicast Hierarchical Mobile IP was proposed in [5], which adopted the layered multicast group scheme to reduce lots of binding updates to home agent (HA). Nevertheless, due to the use of multicast protocol, it consumed a large amount of network resources.

In this paper, considering the dynamic topology of the LEO networks, we construct a virtual mobility management

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scheme called as "VMIPv6" on the basis of the MIPv6 protocol. VMIPv6 is an optimized mobility management solution that adopts the layered idea and the distributed architecture of Distributed Mobility Management (DMM) [6]. In order to reduce the overhead of mobility management and switching delay, we formulate a virtual agent cluster (VAC) to co-manage the network architecture of users in the corresponding virtual agent domain (VAD). Specifically, we construct the home mobile-agent-anchor (HMAA) and the local MAA, which can share the user's location information through signaling interactions within the VAC. In this way, the mobile node (MN) triggers a binding update to the HA only when the associated home MAA is lost, while the MN's switching within the VAD only need to update its intra-domain relations, which avoids a large amount of binding update throughout the entire LEO satellite network. Then, we analyze the performance of the proposed VMIPv6 in terms of the signaling overhead and handover latency. Moreover, since the existing mobility management protocols for LEO satellite networks have not been standardized and are generally learned from the solutions for terrestrial networks, we choose to compare the efficacy of the VMIPv6 with the traditional MIPv6. Finally, an experimental platform is presented to verify the new protocol.

II. RELATED WORKS

In the packet-based wireless network, IP multimedia applications are becoming more and more popular [7]. In order to integrate these applications in wireless networks, we need to get seamless terminal mobility support [5], [8]. Mobile IP protocol is proposed by the Internet Engineering Task Force (IETF) to provide global mobility services in the IP networks [9]. When mobile nodes move in the IP network, it allows the communication to be maintained.

Most of the current solutions come from Mobile IPv6 (MIPv6) [10]. The first mobility management standard protocol was proposed by IETF for IPv6 networks [11]. In the MIPv6 protocol, a MN in the home network gets a permanent red address, i.e., the home address. This address is stored in the HA in the home network, and is used for the identification and the routing. When the MN is not in the home network, HA is responsible for maintaining the accessibility of the home address and redirecting the received data packets to the exact location of the MN. If the MN moves out of the home network and accesses a foreign network, MN needs to obtain a temporary IP address from the current network, i.e., Care-of-Address (CoA). In MIPv6 protocol, some routers need not be specially configured as Foreign Agent (FA). MN can get CoA through neighbor discovering or address auto-configuration. Therefore, the concept of FA is cancelled and access routers are taken as the functional entity. But, this paper still uses agent terms. In order to maintain an uninterrupted communication connection between MN and its communication counterpart, MN requires to inform HA of its current location by sending Binding Update (BU) information. HA intercepts the data packets distributed to MN, and transmits them to the current network access point of MN through tunnel mechanism.

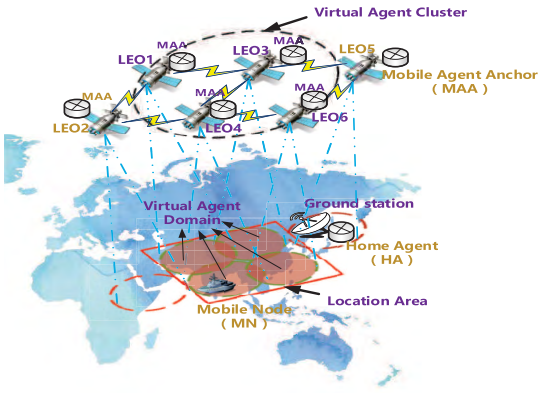


FIGURE 1. The network architecture for the LEO satellite network on basis of the VAD.

However, in the standard MIP, the handover and the location updating processes are closely coupled, and every handover needs to update the CoA at HA, which results in high handover delay and packet loss rate. Therefore, some improved protocols, such as Fast Handovers for Mobile IPv6 (FMIPv6) [12], Hierarchical Mobile IPv6 (HMIPv6) [13] and Proxy Mobile IPv6 (PMIPv6) [14] has been proposed.

Under the FMIPv6 framework, the next access point is predetermined by the bottom layer to reduce the handover delay. However, some interactive signaling messages between the access router and the new access router are introduced [15]. The HMIPv6 protocol introduces a proxy hierarchy mechanism, which adds a Mobile Anchor Point (MAP) to the network to handle local handover. The MAP divides the network into several areas and acts as a local HA in the visited network, which limits the number of mobility management signaling outside its domain and reduces the handover delay of location updates. But, within the dynamic network topologies, the advantages of HMIP have limitations, and the setting of network layering needs further exploration. The PMIPv6 protocol provides a network-based mobility management solution, and is different from the host-based protocol, where the MN initiates handover. The network replaces the MN to perform the mobile IP process, reduces the signaling interaction between the MN and the network access point, and optimizes the protocol workflow. However, there are also many limitations, such as the load balancing problem, the problem that the handover delay is long due to the handoff signaling need to pass the LMA which may be away from the MAG, etc [16].

III. SYSTEM MODE

The network structure for the proposed VMIPv6 is shown in Fig. 1, and the definitions of some terms are listed as follows. It is assumed that LEO satellites possess on-board processing and routing capabilities, and different satellites can exchange information with the IP technology.

- *Location Area* (LA): According to the topography, the latitude, the longitude and other factors, the ground area is divided into several LAs to facilitate the mobility management.
- *Virtual Agent Cluster* (VAC): The node set containing all the LEO satellites on the top of one specific LA is called as one VAC.
- *Virtual Agent Domain* (VAD): The whole coverage area of all nodes in VAC is defined as VAD.
- *Mobile Agent Anchor* (MAA): The MAA is an on-board router in each LEO satellite, and can provide routing services for the registered MN. The MAA is similar with the access router in IPv6, but it is mobile.

In our proposed scheme, the global ground area can be divided into multiple LAs, which can be covered and managed by several VACs. We assume that all the MAAs in the VAC can share the mobility information about one specific MN to cooperatively manage this node.

With the varying of the network topology, the satellite nodes in one specific LA may change. Nonetheless, once the network topology varies, we can reconstruct the VAC through two operations: adding the new satellites sliding into the LA and deleting the ones sliding out of the LA. For one given LA, the new satellites and the departing one will quickly learn and forget this LA's binding information, respectively. Specially, the reconstruction of the new VAC is only with small cost, that is, the information update of the MAA could be accomplished through little signaling interaction. Therefore, in the following performance analysis model, the reconstruction cost of the new VAC would be ignored without loss of generality.

IV. VIRTUAL MOBILITY MANAGEMENT

In order to reduce the burden of the mobility management, we define two types of MAAs, i.e., the home MAA and the local MAA. The home MAA maintains the connection between VAC and HA, and the MN registers its home MAA's subnet IP address at its HA. The local MAA is responsible for controlling the connection links between the MN and the VAC, and the MN binds its local MAA's IP address to each MAA of its related VAC.

Within our proposed scheme, the handovers happen in the following three cases. Scenario 1, the MN switches within one VAD; Scenario 2, the home MAA of the MN in one specific VAD slides out of the VAD's corresponding LA; Scenario 3, the MN switches from one VAD to another. The workflow of our proposed scheme is presented in Fig. 2. Each MN configures two care-of addresses within the VAD: the global care-of address and the local one. The former is constructed by the home MAA's IP address information, and the latter is formed by the local MAA's IP address. Only the local care-of address should be exchanged within the VAC to construct the routing entries at each MAA; the global care-of address will be adopted to dig the tunnel between the home MAA and the HA. In that way, there are two ways to address MN in the framework of the satellite network: host-specific routing addressing and tunnel addressing.

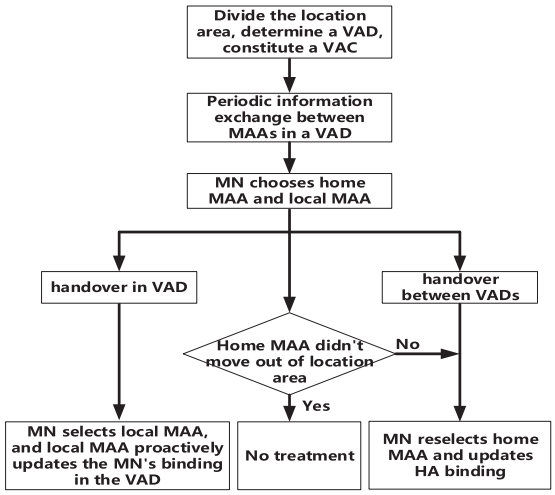


FIGURE 2. The workflow for the proposed mobility management scheme.

The former is similar to routing addressing in mobile ad-hoc networks.

A. SCENARIO ONE

The MN's handover in the VAD is caused by the mobility of the satellite. In order to reduce the amount of the transmission data along the long-latency path, the MN only exchanges control signaling with the new MAA, but does not need to update the binding information at the HA or correspondent node (CN). Following the basic operation flows of the IPv6, the MN implements the routing discovery, the configuration of the care-of address, and duplicate address detection (DAD), which will change the local care-of address.

The MN sends the binding updating message to the new MAA, i.e., the local MAA. Then, the other satellites establishes the binding information table through communication with the local MAA and creates a routing entry. Furthermore, the local MAA also sends the binding acknowledgement messages to the MN. The handover process does not ends until the routing entries are built successfully and the binding acknowledgement messages are received by the MN. Therefore, neither HA or CN needs to take part in MN's handover within one specific VAD. Fig. 3 represents the MN's signaling flow under this case.

Because this scenario is ubiquitous in satellite networks, the performance of this scenario can be improved greatly. As shown in Fig. 4, MN2 is in the coverage of MAA7, and MAA7 is a HMAA of MN2. The cache information in HA and VAC, i.e. binding relationship (IP_{MN2}, IP_{MAA7}), is established by binding updating and intra-domain sharing mechanism respectively. Fig. 5 represents the network connectivity state of MN2 after t-period, and it can be intuitively seen that the coverage satellites of MN2 and VAC have changed due to the motion of satellites. In this scenario, we need to first reconstruct VAC (adding MAA8 and MAA4, removing MAA2 and MAA6), then start the sharing mechanism to update the relationship in VAC, which is mapping

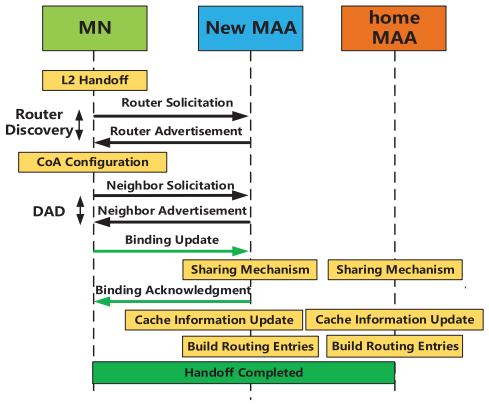


FIGURE 3. The workflow of the MN under the scenario one.

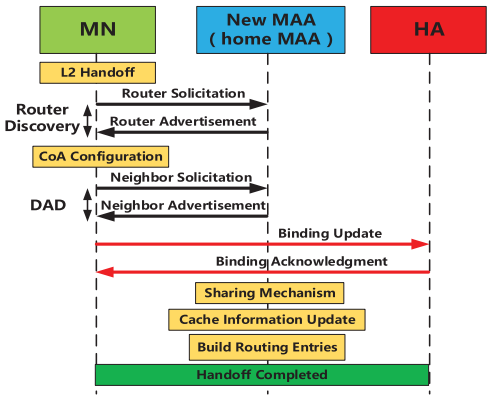


FIGURE 6. The signaling exchanging process if the home MAA is lost.

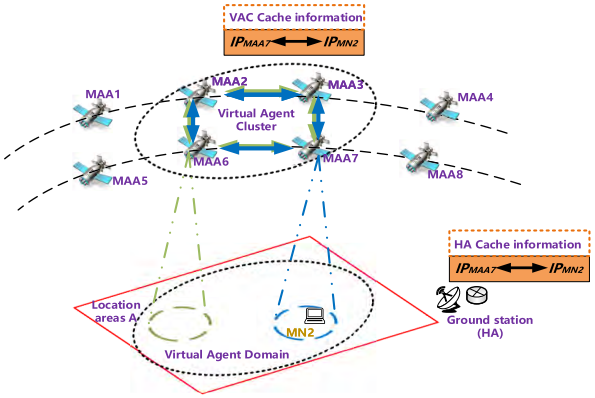


FIGURE 4. Mobile node connectivity at T1 time.

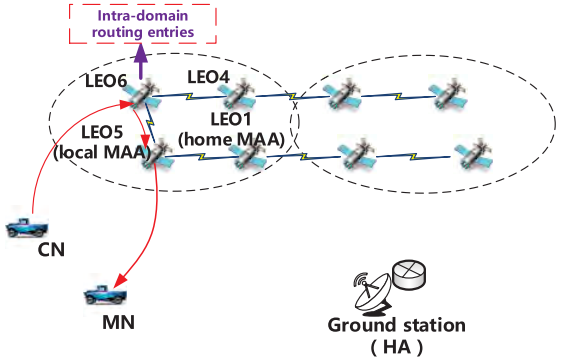


FIGURE 7. The data transmission path when CN and MN are in the same VAD.

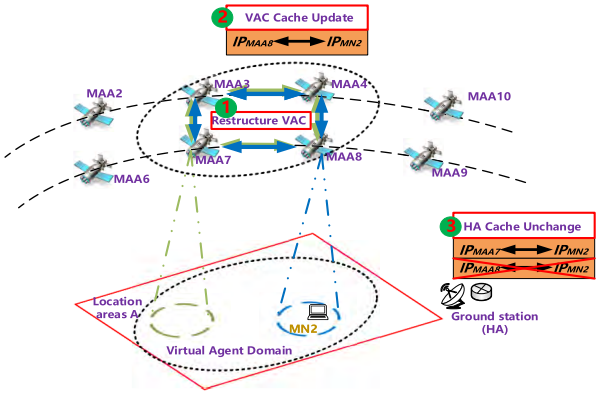


FIGURE 5. Mobile node connectivity at T2 time.

(IP_{MN2}, IP_{MAA8}). However, the cache information of HA does not require to be changed.

B. SCENARIO TWO AND SCENARIO THREE

Under the two cases, the home MAA of the MN is lost and the global care-of address is changed. Thus, the nodes in VAC should maintain the home MAA information of the MNs all the time. To deal with the above problem, the MN not only should re-choose a MAA in VAC as its new home MAA, but also needs to send the binding updating information to the HA/CN to inform its new global care-of address. Fig. 6 shows the signaling exchange process after the loss of home MAA, where the selected home MAA is the newly accessed MAA.

C. DATA TRANSMISSION LINK

As shown in Fig. 7, if the CN and the MN are located in the same VAD, the CN will first search the routing entries within this VAD, and then forward the data packets according to the achieved routing information. This way can improve the efficiency of data packet transmission.

Note that the routing optimization problem inside MIPv6 and its optimization protocol should be viewed from different perspectives. First, according to the introduction of the basic protocol, the improved protocol based on the MIPv6 protocol will support route optimization (RO). The route optimization process allows the MN to communicate directly between the two terminals by notifying the CN of its CoA. Transmitting data packets through the best path is one of the biggest differences between MIPv6 and MIPv4 and is one of the goals of the best protocol.

On the other hand, the RO process has also been raised with questions about location privacy [17]. In order to find the best path, all CNs will get the latest CoA of the MN, and the location information of the MN is exposed to the CN.

In addition, the RO process needs additional return routability (RR) procedures to ensure security, and significantly increases the signaling overhead [18]. Therefore, even though it can get the best route for data transmission, the system performance will degrade.

Because there are different opinions and views on the optimization of transmission routes, this section does not show the process of the subsequent route optimization, that is, the process of signaling interaction with the CN in the VMIPv6 protocol. We can further choose this part according to the actual use requirements. If there is no part of the route optimization, the essence of the policy based on the IPv4 protocol and the IPv6 protocol is basically the same for the verification of the policy itself. Therefore, in the simulation verification platform part of the following chapters, this paper adopts the implementation based on IPv4 protocol to reduce the complexity of platform construction.

For better differentiation and illustration, we define a new term, the Virtual Mobile IP Protocol (VMIP), which includes the IPv4-based VMIPv4 protocol and the IPv6-based VMIPv6 protocol.

V. PERFORMANCE ANALYSIS

In this section, we analyze the performance of the proposed VMIPv6 in terms of the signaling cost and handover latency. Moreover, we compare the VMIPv6 with the traditional MIPv6.

A. USER MOBILITY AND TRAFFIC MODELS

Generally, the user's mobility can be modeled by the user's residence time within one specific region, and different types of random variables [19]. Moreover, the traffic model should contain two levels, i.e., the session and data packet [20].

In LEO satellites network, the impact of MN speed can be neglected in user mobile modeling. Before proceeding, we present the following notations: μ_m and μ_d are the border crossing rate of an MN out of a MAA's subnet and out of the VAD, respectively; μ_h denote the rate of the MN's losing home MAA within the VAD; μ_l is defined as the border crossing rate of a MN out of a MAA, but its home MAA is still present at VAD. Then, taking the satellites' coverage and the MN's activity radius into consideration, we can set μ_d=0. Moreover, from the functions of the home MAA, its action scope can be equivalently described by the coverage of M MAAs. With this observation and the methods in [21], μ_h, μ_l and μ_m can be separately derived as

$$\mu_h = \frac{1}{\sqrt{M}}\mu_m, \quad \mu_l = \frac{\sqrt{M}-1}{\sqrt{M}}\mu_m. \tag{1}$$

Then, the residence time in a MAA and that in MN's home MAA are assumed to follow exponential distribution with parameters μ_m and μ_h, respectively. But, the session arrival process follows a Poisson distribution with rate λ_s. With the approach in [20], it can be obtained that

$$\mathbb{E}(N_m) = \frac{\mu_m}{\lambda_s}, \quad \mathbb{E}(N_h) = \frac{\mu_h}{\lambda_s}, \tag{2}$$

where N_m is the number of MAAs' boundary crossed by the MN during one session, N_h represents the number of the home MAA lost by MN during one session, and the notation $\mathbb{E}(\cdot)$ denotes the expectation operator.

Similarly, we can $\mathbb{E}(N_l)$ to represent the averaged location update number of the MNs, that slide out the MAA's coverage but still is associated with the home MAA.

B. SIGNALING COST

The signaling cost indicates the average signaling overhead for the binding update process during a session time interval. Specially, the binding update processes can be divided into two types: local update and global update. For MIPv6, all update belongs to global update. However, in terms of VMIPv6, two types of update both exist. In particular, the binding update process would transform its type according to the scenario, such as local update only occurs in scenario one. Specifically, local update accounts for a large percentage of the total update types in VMIPv6. Then, according to flows of the proposed scheme, we can express the signaling overhead during the session time interval as

$$C_{\text{MIPv6}} = \mathbb{E}(N_m)\, C^g_{\text{MIPv6}}, \tag{3}$$

$$C_{\text{VMIPv6}} = \mathbb{E}(N_l)\, C^l_{\text{VMIPv6}} + \mathbb{E}(N_h) C^g_{\text{VMIPv6}} + \mathbb{E}(N_m) C^s_{\text{VMIPv6}}, \tag{4}$$

where C^g_{MIPv6}, C^l_{VMIPv6}, C^g_{VMIPv6} and C^s_{VMIPv6} separately denotes the signaling overhead for the global update in MIPv6, that for the local update in VMIPv6, that for the global update in VMIPv6, and that for the information sharing within one specific VAC.

In the satellite networks, the transmission overhead for the data packets is proportional to the distance from the source node to the destination node [22]. So, we define the transmission overhead of the control signaling between nodes X and Y as $C_{X,Y} = \alpha d_{X,Y}$, where α is the unit transmission overhead value of a wireless link. Thus, with Fig. 3 and Fig. 6, the overheads in (3) and (4) can be listed as:

$$\begin{aligned} C^l_{\text{VMIPv6}} &= 6C_{\text{MN,MAA}}, \\ C^s_{\text{VMIPv6}} &= (M-1)C_{\text{MAA,MAA}}, \\ C^g_{\text{MIPv6}} &= C^g_{\text{VMIPv6}} \\ &= 4C_{\text{MN,MAA}} + 2C_{\text{MN,HA}} + 2NC_{\text{MN,CN}}, \end{aligned} \tag{5}$$

where N represents the number of CN.

C. HANDOVER LATENCY

The handover delay of the MN is defined as the time interval from triggering the switching of the link layer to the completion of the binding update. Carefully examining our proposed VMIPv6, the handover delay can be divided into the following parts: the handover delay of the link layer t_{L2}, the round-trip time of the route discovery t_{RD}, the delay of the duplicate address detection t_{DAD}, the information sharing delay t_s in the VAC, and the transmission delay $t_{X,Y}(S)$ for the packet of size S from X to Y. If X or Y is an MN, we can

derive [20]

$$t_{X,Y}(S)=\frac{1+q}{1-q}\Big[(\frac{S}{B_{ms}}+L_{ms})+(d_{X,Y}-1)(\frac{S}{B_{ss}}+L_{ss}+\varpi_q)\Big], \tag{6}$$

If X or Y are both satellite nodes, it follows

$$t_{X,Y}(S)=\frac{1+q}{1-q}*d_{X,Y}(\frac{S}{B_{ss}}+L_{ss}+\varpi_q), \tag{7}$$

where q is the probability of the wireless link's failure; ϖ_q is the average queuing delay for each routing node [23]; B_{ms} and L_{ms} are the wireless link bandwidth and time delay between MN and LEO satellites, respectively; B_{ss} and L_{ss} are the wireless link bandwidth and delay between LEO satellites respectively.

However, with respect to the traditional MIPv6, the handover delay does not contain the information sharing delay t_s, which is one important difference from the VMIPv6.

With the above analysis, the handover delay for the MIPv6 can be written as

$$T_{\text{MIPv6}}=t_{L2}+t_{RD}+t_{DAD}+2(t_{\text{MN,HA}}+t_{\text{MN,CN}}). \tag{8}$$

For VMIPv6, we derive its handover delays under the local update and the global one, respectively. The achieved handover delays are separately denoted as T^{l}_{VMIPv6} and T^{g}_{VMIPv6}. After some operations, we can obtain

$$T^{g}_{\text{VMIPv6}}=t_{L2}+t_{RD}+t_{DAD}+2(t_{\text{MN,HA}}+t_{\text{MN,CN}})+t_s, \tag{9}$$

$$T^{l}_{\text{VMIPv6}}=t_{L2}+t_{RD}+t_{DAD}+2t_{\text{MN,MAA}}+t_s, \tag{10}$$

where $t_s=(M-1)t_{\text{MAA,MAA}}$, and $t_{\text{MAA,MAA}}$ is the delay of information exchange between two MAAs.

VI. PERFORMANCE EVALUATION

In the simulation, to compare the efficacy of the VMIPv6 and MIPv6 protocols, we adopt the network topology which is similar to the design architecture of the OneWeb constellation system and with terrestrial gateways. Specifically, 720 satellites operate on 18 orbital planes, and there exist inter-satellite links. In our proposed scheme, the information sharing mechanism in the satellite cluster is the key to improve performance. Therefore, a constellation with a short inter-satellite link distance is required to clearly indicate the advantage. Of course, the Iridium system will also be improved to some extent. In addition, the constellation topology has large-scale characteristics, which is in line with the development trend of the emerging low-orbit constellation system.

The parameters and default values used in the performance evaluation are given in Table 1, and the remaining unknown variables in the formula are used as independent variables for the evaluation [24], [25]. We define a performance variable called session-to-mobility ratio (SMR), which represents the ratio of session arrival rate to user mobility rate [20]. In the simulation scenario, we assume that the distance between the two functional nodes is: $d_{\text{MN,MAA}}=1$, $d_{\text{MN,HA}}=5$, $d_{\text{HA,CN}}=5$, $d_{\text{MAA,MAA}}=1$, $d_{\text{MN,CN}}=3$. In addition, in order to simplify calculation, some parameter information follows the following principles: $L_{ss}=L_{ms}$.

As shown in Fig. 8, when the SMR is small, especially in the range of 0 to 1, we can see that the signaling cost of the VMIPv6 is significantly less than that of the MIPv6.

In Fig. 9, it is obvious that the VMIPv6 local update handover latency is much smaller than the others. In the LEO satellite network, since the MN mainly performs a local binding update, the VMIPv6 generally has a certain reduction in handover latency compared to MIPv6.

TABLE 1. System parameters.

Parameter	Symbols	Values
Number of MAA in the VAC	M	4
Weight value of the wireless link	α	10
Number of CN	N	4
Wireless link failure probability	q	0.5
Control packet size	S	96 bytes
Wireless link bandwidth	B_{ms} ,B_{ss}	30 Mbps
Queuing delay for routing node	ϖ_q	1 ms
DAD delay	t_{DAD}	200 ms
Router discovery delay	t_{RD}	100 ms
L2 handover delay	t_{L2}	50 ms

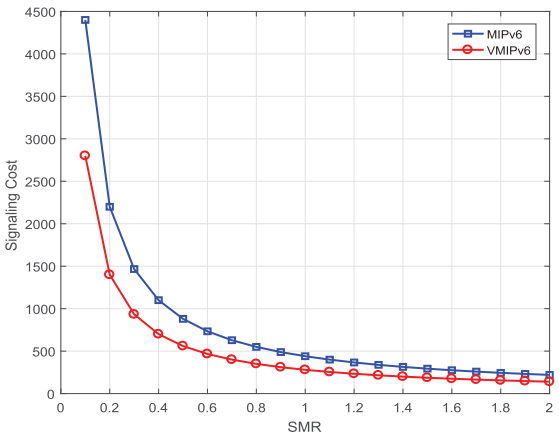


FIGURE 8. The curves of the signaling cost versus the SMR.

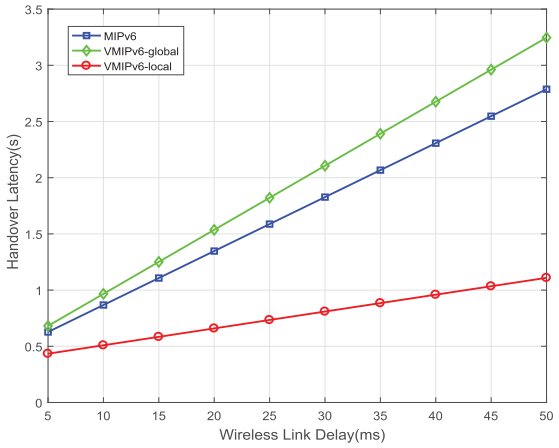


FIGURE 9. The curves of the handover delay with respect to the wireless link delay.

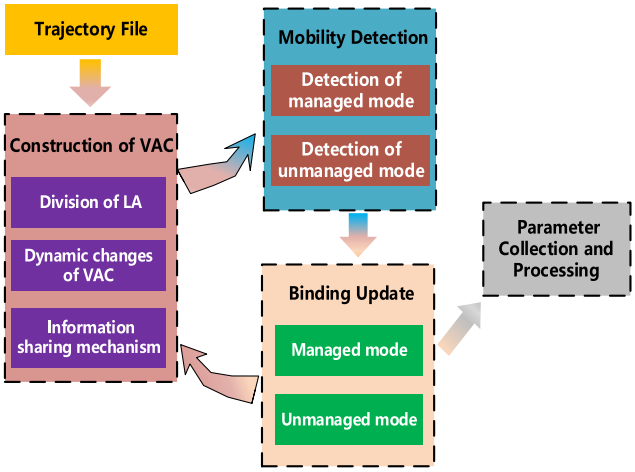


FIGURE 10. The platform module framework.

VII. TESTBED EVALUATION

As mentioned in the previous section, under different networks, such as IPv4 and IPv6, the VMIP protocol should have the same superiority. To decrease the implementation complexity of the protocol, we verify the VMIP within the standard IPv4 framework. Then, we illustrate the results of the platform from the aspects of functionality, protocol flow, and original statistical indicators.

As shown in Fig. 10, the platform module mainly includes construction of virtual agent cluster, mobility detection, binding update and parameter collection and processing. With the satellite trajectory file, construction of virtual agent cluster realizes the planning of satellite cluster and information sharing. The purpose of mobility detection is to determine whether the global CoA needs to be changed after the user changes the satellite access point. The binding update module is designed to implement different mode processing for different binding update requests by the satellite nodes and feeds back to the information sharing mechanism in the VAC construction module.

A. SCHEME IMPLEMENTATION

1) CONSTRUCTION OF VIRTUAL AGENT CLUSTER

Because of the high dynamic characteristics of satellites, the composition of VAC is also dynamic. For a new VAC, its direct expression is the formation of satellites. However, whether a satellite becomes a member of the VAC is determined by its own trajectory and division of LA.

The division of the ground location area is the basis for building a virtual agent cluster. In the scheme of LA based on ground division, accurate partition can be achieved according to many factors. And in the implementation of this platform, factors such as feasibility, population density and border population are considered. As shown in Fig. 11, the world is divided into eight locations, each one have its own area code. In order to identify the LA conveniently, we add the area code information to the IP prefix, such as area 2, whose IP segment address is 192.168.2.0.

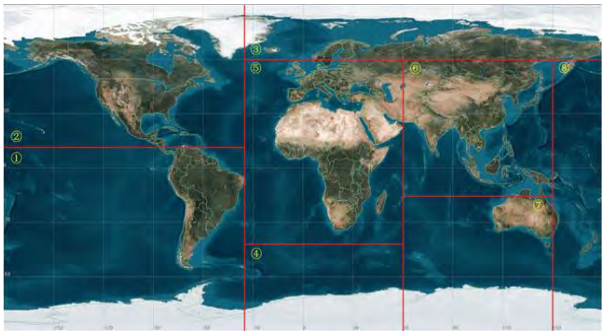


FIGURE 11. The division of location area.

After partitioning the LA, the LA can be obtained according to the longitude and latitude of the satellite, and then the VAC can be updated. For MN, whether IPv4 proxy discovery mechanism or IPv6 neighbor discovery mechanism, the way to identify a new VAC is based on the network address of the access router (satellite). Therefore, the satellite will need to update the IP address of the satellite to the ground after its constituting a new VAC.

When initializing the satellite network, each satellite has its own serial number. According to the area code of the location area, the corresponding port IP can be updated. For example, when the satellite node 2 enters the location area 3, its IP address to the ground port should be updated to 192.168.3.2. The IP address of the satellite to the ground port is represented by (11), which is determined by the area number and satellite number.

$$IP\ address = Area\ number + Satellite\ number. \quad (11)$$

The final part of constructing the VAC is to realize the information sharing mechanism within the cluster. As the periodic sharing scheme is a passive information interaction, there will be information loss at certain intervals. Therefore, we adopt an active strategy, that is, an active cluster information sharing mechanism is initiated by a LMAA, HMAA or a satellite which updates the network address of satellite to ground port. The specific implementation method is as follows:

- With the network address of star-to-ground port as the identification, if a new satellite node is added to the virtual agent cluster, the shared information request will be sent by multicasting; If it is a LMAA or HMAA, the binding relationship is shared directly with other nodes and the process is ended;
- After receiving the request for sharing information, the satellite storing the binding relationship of MN will reply its binding information to other satellite nodes;
- The new satellite node also replies its binding information;
- Establish the routing information of specific hosts in the domain according to the binding relationship after sharing information.

Since the number of satellite nodes in the cluster is small, information update does not occupy too much network resources. As far as the current form is concerned, the global population of users is around 600,000 for relatively mature satellite systems [26]. Therefore, it is reasonable to adopt specific host routing in the virtual agent cluster under the current network size.

2) MOBILITY DETECTION

In the low-orbit satellite network, since the satellite characteristics and the moving speed of the MN are much smaller than the rotational speed of the satellite, the moving bahavior of the MN is mostly passive. In addition, when a MN moves to a foreign network, it gets an Agent Advertisement, and an ICMP type router advertisement.

In this scheme, we use two modes: managed mode and unmanaged mode. If the MN gets a agent address in the agent advertisement message, the agent address is the same network segment as the CoA used previously. Then, it can be considered that the MN moves passively due to the movement of the satellite, and at this time, MN's HMAA does not move out of the LA, so the managed mode will be adopted. In the managed mode, the original CoA is used as the current CoA, that is, the global CoA remains unchanged and the agent address is used as the local CoA to trigger the local location update request. On the contrary, if the above situation is not satisfied, that is, the agent address is not in the same network segment as the previously used CoA, it can be determined that mobility management is caused due to the MN's inter-zone movement, or when the MN's HMAA moves out of the LA, the MN will be informed of the need which re-select HMAA. So the unmanaged mode will be adopted. At this time, the MN will acquire the new CoA as the global CoA, and finally send the binding update message containing the new CoA to implement global location registration. For the above two modes, it corresponds to the three scenarios of Section. IV.

Among them, the mode in which the MN obtains the CoA in the platform adopts the mode of the foreign agent's care-of address, and the transmitted binding update message only includes the global CoA.

3) BINDING UPDATE

After the network router (satellite node) is connected to receive the binding update message from the MN, different processing mechanisms are also adopted for the two different modes in the scheme.

We can extract the CoA of the MN from the binding update message. If it is found that the CoA is not allocated by the satellite node, then the mode is managed mode, and the satellite node is LMAA. In the managed mode, the network address of LMAA is used as the local CoA of the MN, and the CoA in the binding update message is used as the global CoA. In addition, the satellite node need to share information of the MN in the cluster and send binding acknowledgment information. Correspondingly, if the CoA is found to be allocated by the satellite node, it is an unmanaged mode. The satellite is both HMAA and LMAA, and it is registered and updated to the HA of the MN directly through the binding request message and binding acknowledgment message. Finally, the process of sharing information within the domain and establishing routing entries in the domain are also required.

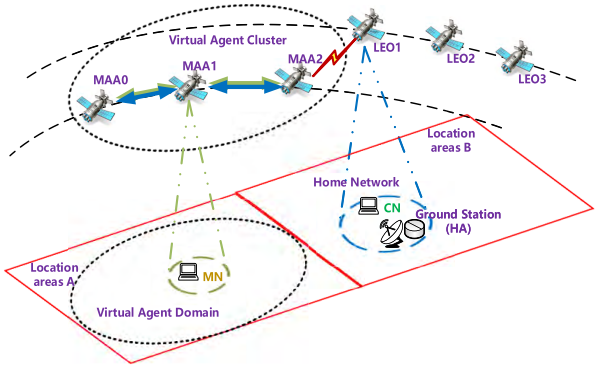


FIGURE 12. Schematic diagram of platform scenario.

Note that the binding update process for maintaining the life cycle of the binding relationship also uses the above workflow.

4) PARAMETER COLLECTION AND PROCESSING

After the MN or satellite node is collected and processed by the parameters, the interactive process information of the mobility management protocol will be restored. In the process of parameter collection and processing, raw data should be collected as much as possible to retain the authenticity of the data. At the same time, only the changed data can be collected through the repeated judgment process of the data to avoid adverse impact on the system.

B. TESTBED DESCRIPTION

This section intends to mimic a low-orbit satellite network system with inter-satellite links, and a small-scale scenario is used to characterize the availability and efficiency of the protocol.

As shown in Fig. 12, we built a demonstration and verification scenario based on two orbits and six stars. In this scenario, there are two location areas A and B, mainly including satellite nodes, mobile node, ground station and correspondent node. In location area A, the satellite node serves as the access router node of the foreign network. In the location area B, as a network access point of the home network, the satellite node realizes indirect communication between the user and the home agent by uploading and downloading datagrams or signaling. Therefore, the satellite in the area replaces the function of the home agent. In order to get closer to the real environment, we design the movement mode of MN, which is caused by the movement of satellite nodes. The home agent is deployed at the ground station node to

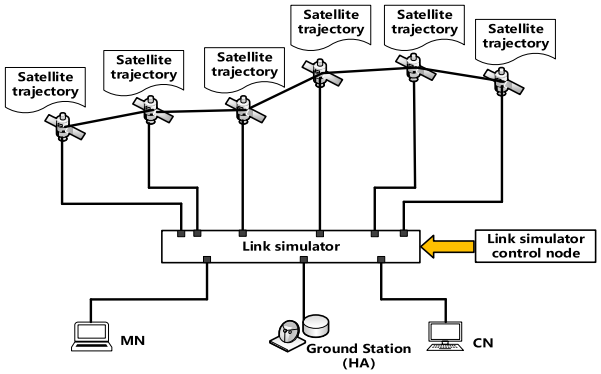


FIGURE 13. Verify the schematic diagram of platform construction.

maintain the binding information of the MN. In addition, we guarantee that communication between the satellites in different orbit will not be interrupted, that is, indirectly guarantee the accessibility of the station or the HA.

In fact, we also need to take the switching problem of the ground station into consideration. But, in order to ensure accessibility, dynamic host configuration protocol (DHCP) technology and dynamic routing protocol are adopted. Since this section is not the focus of this article, a brief description is given.

In order to realize the demonstration and verification platform in this scenario, we further design a low-orbit satellite simulation network based on link simulator, as shown in Fig. 13. In the link simulation section, the link simulator and link simulator control nodes are included. The control node is responsible for distributing and managing the satellite's running track file to the link simulator. By calculating and measuring the satellite's running track, the link simulator dynamically controls the changing state of link-on-off, representing the high dynamic nature of the satellite network. Among them, the satellite node also needs to have a preset running track, which can be completed by reading the track file. Of course, this trace file is consistent with the trace file distributed by the link simulator control node. The MN and CN reflect the status of the communication link through instant services such as video, voice or text. Finally, the demonstration verification platform can observe the communication status of the MN and the CN and the multi-dimensional indicators of the satellite nodes and the ground stations.

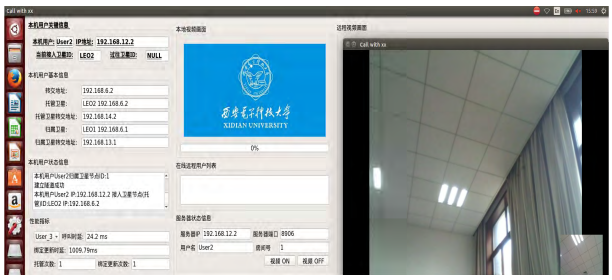
C. EXPERIMENTAL RESULT

1) FUNCTIONAL TESTING

For the mobility management protocol of satellite networks, in addition to providing mobility support, another important function is to guarantee the QoS of delay-sensitive services. In functional testing, the platform selects time-sensitive business, namely video business. As shown in Fig. 14 and Fig. 15, there are the screenshots of MN and CN status information display interface at time T1 (unmanaged mode) and time T2 (managed mode).

FIGURE 14. CN status information display in the time T1 and T2.

(a) MN in time T1



(b) MN in time T2

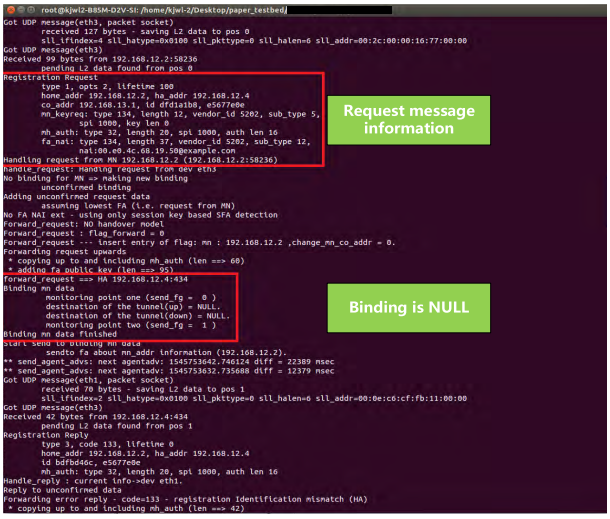
FIGURE 15. The state information of MN at different time.

According to the information displayed above, CN has always been located in the management scope of ground station, that is, in the home network. But, MN switches between MAAs. At time T1, MN is in the coverage range of MAA1 and adopts unmanaged mode. At time T2, MN is in the coverage range of MAA2, but MAA1 does not move out of the location area, so the managed mode is adopted. Two modes are the main features of VMIP protocol, and the verification of normal communication under different modes is the focus of the experimental platform.

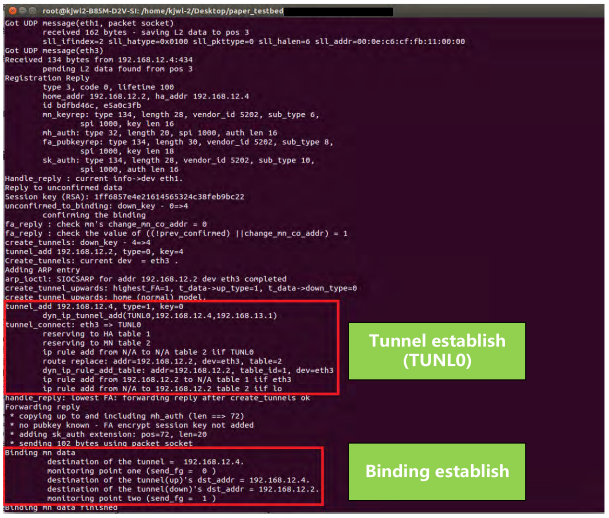
The experimental results show that video service generally operates normally in the process of conversion between the two mode and inter-satellite switching, but there is a slight packet loss phenomenon in the switching gap. The reason for packet loss is that the experimental platform only focuses on the network layer and does not implement the scheme for other layers. Therefore, as a whole, the functionality of the protocol proposed in this paper is normal.

2) PROTOCOL IMPLEMENTATION

In terms of observing protocol flow, we also focus on MAA presentation information in both modes, as shown in Fig. 16 and 17.

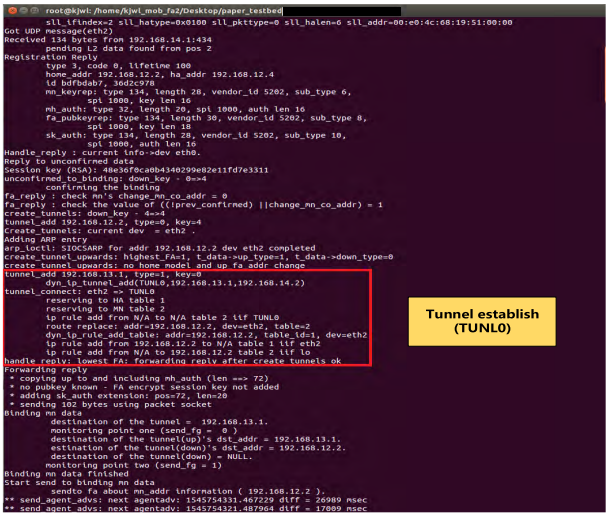


(a) MAA1 handle request in time T1

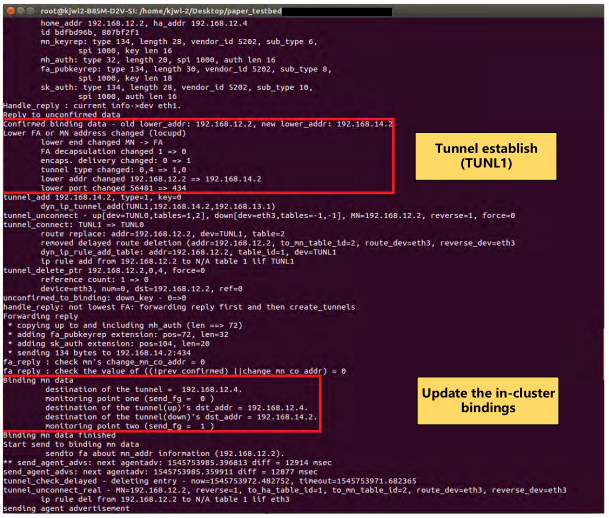


(b) MAA1 handle reply in time T1

FIGURE 16. The state information of MAA1 at unmanaged mode.



(a) MAA2 handle request in time T2



(b) MAA1 handle request in time T2

FIGURE 17. The state information of MAA1 and MAA2 at managed mode.

At time T1, Fig. 16 shows the status information of MAA1 in unmanaged mode. MAA1 receives MN's registration request, stores it as an unconfirmed binding table item, and forwards it to the GS for binding update. After receiving the registration reply of the GS, the unconfirmed binding table items in MAA1 are converted into the confirmation table items. Then, the registration reply is forwarded and TUNL0 tunnel is established. It can be seen from the figure that during the request arrival process, only the unconfirmed request information is recorded, and no tunnel establishment is made. But when dealing with replies, the main job is to add tunnels and routing rules.

At time T2, Fig. 17 shows the status information of MAA1 and MAA2 in the managed mode. At this time, MN is in the coverage range of MAA2, and MAA2 also receives MN's registration request and forwards it, but the forwarding object is not the ground station but MN's HMAA (MAA1). Then, the update content of MAA1 and MAA2 includes two points. The first point is that MAA2 establishes TUNL0 tunnel with MAA1, and the second point is that MAA1 modifies the confirmed information and establishes TUNL1 tunnel with MAA2. In addition, MAA2 interacts information with other MAAs in the cluster to establish host-specific routing table entries.

The VMIP protocol proposed in this paper establishes a specific host routing entry in a VAC. And establishing a secondary tunnel can implement data packet forwarding as well as establishing a specific host routing entry, but the former reduces the efficiency of data packet transmission. Considering that the user's data traffic is small, in order to simplify the implementation process, the LMAA (MAA2) and HMAA (MAA1) are set up to establish a secondary tunnel TUNL1 in the simulation platform, and the other MAAs in the cluster establish specific host routing entries.

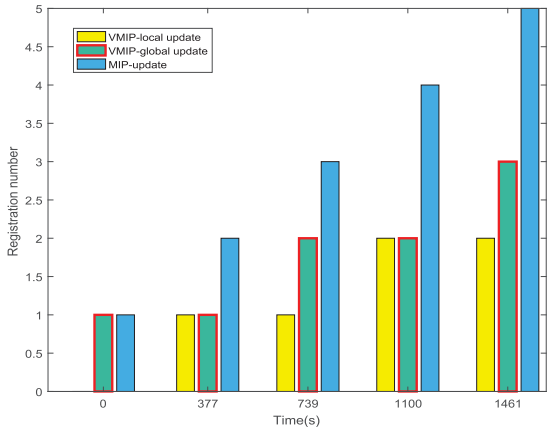


FIGURE 18. Registration times statistics in the experimental platform.

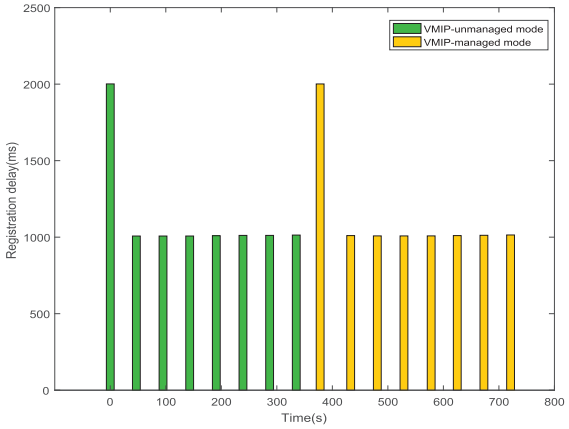


FIGURE 19. Registration delay statistics in the experimental platform.

MAA status information in the experimental platform shows that the VMIP protocol flow is basically implemented and running normally.

3) DATA STATISTICS

Regarding the raw data, we collected the registration times and registration delays of the platform system, as shown in the Fig. 18 and 19. The proposed registration delay characterizes the delay in executing the binding update process.

In the MIP protocol, the number of binding updates to HA increases linearly with time. However, in VMIP protocol, although the number of registration reaching HA is also increasing, it can be significantly reduced compared with MIP protocol, and the reduction is converted into binding update within the cluster, that is, local update and global update are carried out alternately. Binding updates within the cluster can significantly reduce the mobility management load compared to each HA update.

In terms of registration delay, we select two modes of registration delay. In unmanaged mode and managed mode, the first registration delay is about 2 seconds. while in each mode, the subsequent registration delay is about 1 second. The subsequent registration is mainly to maintain the life cycle of the binding relationship. In this experimental platform, because the link transmission delay of the registration delay accounts for a small proportion, the registration delay under the two modes is roughly the same.

The VMIP protocol has significant advantages in signaling overhead, and the effort in registering delay is primarily to reduce its link transmission delay. Therefore, the simulation platform fails to show the advantage of reducing the registration delay due to physical condition constraints.

VIII. CONCLUSION

In this paper, we proposed a mobility management scheme for LEO satellite networks with the help of the VAD. We compared our proposed scheme with MIPv6 in terms of the binding update signaling overhead and switching latency. The simulation results showed that our method is better than MIPv6. At the same time, the experimental platform also verified the availability and efficiency of the protocol.

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REFERENCES

[1] D. Li, H. Li, S. Zhang, and X. Zhang, "Virtual agent clustering based mobility management over the satellite networks," in *Proc. 10th Int. Conf. Wireless Commun. Signal Process. (WCSP)*, Oct. 2018, pp. 1–5.

[2] D. He, P. You, and S. Yong, "Comparative handover performance analysis of MIPv6 and PMIPv6 in LEO satellite networks," in *Proc. 6th Int. Conf. Instrum. Meas., Comput., Commun. Control*, Jul. 2016, pp. 93–98.

[3] S. Ayaz, C. Bauer, C. Kissling, F. Schreckenbach, F. Arnal, C. Baudoin, K. Leconte, M. Ehammer, and T. Graeupl, "Architecture of an IP-based aeronautical network," in *Proc. Integr. Commun., Navigat. Surveill. Conf.*, May 2009, pp. 1–9.

[4] W. Han, B. Wang, Z. Feng, B. Zhao, and W. Yu, "Distributed mobility management in IP/LEO satellite networks," in *Proc. 3rd Int. Conf. Syst. Inform.*, Nov. 2016, pp. 691–695.

[5] N. Kara, "Mobility management approaches for mobile IP networks: Performance comparison and use recommendations," *IEEE Trans. Mobile Comput.*, vol. 8, no. 10, pp. 1312–1325, Oct. 2009.

[6] B. Sarikaya, "Distributed mobility IPv6," *IETF Internet-Draft*, Feb. 2012.

[7] J. Du, C. Jiang, Z. Han, H. Zhang, S. Mumtaz, and Y. Ren, "Contract mechanism and performance analysis for data transaction in mobile social networks," *IEEE Trans. Netw. Sci. Eng.*, vol. 6, no. 2, pp. 103–115, Apr. 2019.

[8] C. Jiang, H. Zhang, Y. Ren, Z. Han, K.-C. Chen, and L. Hanzo, "Machine learning paradigms for next-generation wireless networks," *IEEE Wireless Commun.*, vol. 24, no. 2, pp. 98–105, Apr. 2017.

[9] C. E. Perkins, *IP Mobility Support for IPv4*, document IEEE RFC 3344, Aug. 2002.

[10] D. J. C. Perkins and J. Arkko, *Mobility Support for IPv6*, document IEEE RFC 6275, Jul. 2011.

[11] F. Giust, C. J. Bernardos, and A. De La Oliva, "Analytic evaluation and experimental validation of a network-based IPv6 distributed mobility management solution," *IEEE Trans. Mobile Comput.*, vol. 13, no. 11, pp. 2484–2497, Nov. 2014.

[12] G. Koodli, *Fast Handovers for Mobile IPv6*, document IEEE RFC 4068, Jul. 2005.

[13] K. E.-M. H. Soliman, C. Castelluccia, and L. Bellier, *Hierarchical Mobile IPv6 (HMIPv6) Mobility Management*, document IEEE RFC 4140, Aug. 2005.

[14] S. Gundavelli, Ed., K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, *Proxy Mobile IPv6*, document IEEE RFC 5213, 2008.

[15] K. N. Ashraf, V. Amarsinh, and D. Satish, "Survey and analysis of mobility management protocols for handover in wireless network," in *Proc. IEEE 3rd Int. Adv. Comput. Conf. (IACC)*, Feb. 2013, pp. 413–420.
[16] A. J. Jabir, S. Shamala, Z. Zuriati, and N. Hamid, "A comprehensive survey of the current trends and extensions for the proxy mobile IPv6 protocol," *IEEE Syst. J.*, vol. 12, no. 1, pp. 1065–1081, Mar. 2018.
[17] D. Liu, "Distributed deployment of mobile IPv6," *IETF Internet-Draft*, Sep. 2011.
[18] D.-H. Shin, D. Moses, M. Venkatachalam, and S. Bagchi, "Distributed mobility management for efficient video delivery over all-IP mobile networks: Competing approaches," *IEEE Netw.*, vol. 27, no. 2, pp. 28–33, Mar. 2013.
[19] Y. Fang, "Movement-based mobility management and trade off analysis for wireless mobile networks," *IEEE Trans. Comput.*, vol. 52, no. 6, pp. 791–803, Jun. 2003.
[20] C. Makaya and S. Pierre, "An analytical framework for performance evaluation of IPv6-based mobility management protocols," *IEEE Trans. Wireless Commun.*, vol. 7, no. 3, pp. 972–983, Mar. 2008.
[21] F. V. Baumann and I. G. Niemegeers, "An evaluation of location management procedures," in *Proc. IEEE 3rd Int. Conf. Universal Pers. Commun.*, Sep./Oct. 1994, pp. 359–364.
[22] J. Xie and I. F. Akyildiz, "A novel distributed dynamic location management scheme for minimizing signaling costs in Mobile IP," *IEEE Trans. Mobile Comput.*, vol. 1, no. 3, pp. 163–175, Jul. 2002.
[23] J. McNair, I. F. Akyildiz, and M. D. Bender, "Handoffs for real-time traffic in mobile IP version 6 networks," in *Proc. IEEE Global Telecommun. Conf.*, vol. 6, Nov. 2001, pp. 3463–3467.
[24] J. Ma, S. Zhang, H. Li, F. Gao, and S. Jin, "Sparse Bayesian learning for the time-varying massive MIMO channels: Acquisition and tracking," *IEEE Trans. Commun.*, vol. 67, no. 3, pp. 1925–1938, Mar. 2019.
[25] J. Ma, S. Zhang, H. Li, N. Zhao, and V. C. M. Leung, "Interference-alignment and soft-space-reuse based cooperative transmission for multi-cell massive MIMO networks," *IEEE Trans. Wireless Commun.*, vol. 17, no. 3, pp. 1907–1922, Mar. 2018.
[26] *E. Online*, Iridium Commun., McLean, VA, USA, Dec. 2015.

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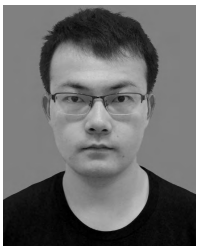

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