Proxy Home Agents for Route Optimization in HAP Networks

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Abstract: - Proxy Home Agent (PHA) functionality is proposed for platform nodes in High Altitude Platform (HAP) networks. The solution enables more efficient backhaul link utilization due to path optimization capabilities in an environment with mobile routers. The existing route optimization function of Mobile IP (MIP) cannot solve this problem, while Hierarchical MIP based route optimization does not map well on the HAP network architecture. Optimal inter-platform routes may be achieved even when mobility management for mobile routers does not include support for route optimization. The solution can be rewarding in network architectures where access network is separated from global network through bottleneck links and the majority of users accessing the network are mobile routers.

Key-Words: - Wireless Networks, High Altitude Platforms, Mobility Management, Mobile Routers, Mobile IP

1 Introduction

High Altitude Platform (HAP) networks are wireless telecommunication alternative to terrestrial and satellite communications. They can take different forms, from balloons to airships or aircraft located in the stratosphere. HAPs have many advantages. An HAP network has larger coverage than the terrestrial wireless systems, low cost of deployment, rapid on-demand expansion and is environmentally friendly. In comparison with satellite networks the problem of large propagation delay does not exist. HeliNet [1] and Capanina [2] are examples of HAP related research projects funded by the European Community. This paper presents some results of a research within the CAPANINA project that are related to mobility support in HAP networks.

Route optimization in HAP networks is of high importance because not only the last segment is wireless. An environment where mobile nodes access the network through mobile routers has an adverse influence on the effectiveness of routing. Here the Mobile IP (MIP) protocol [3, 4] is assumed as a macro-mobility protocol. Route optimization is supported by MIP, however, roaming network poses additional challenges. Several proposals for route optimization in multi-level MIP exist; one of them is by Network Mobility Working Group [5, 6]. It is based on Hierarchical MIP technology (HMIP) [7, 8]. Due to its inability to do path optimization within hierarchical domain in presence of mobile routers, it does not map well on HAP architecture.

Proxy Home Agents adopt an idea of distributing routing information in selected parts of the network in order to speed up route convergence to its optimal path. Similar principles can be used to enable route optimization within HMIP. The rest of the paper is structured as follows. Section 2 gives a short introduction on HAP network architecture. In Section 3 routing in two-level MIP is discussed. Inefficiency as regards backhaul link utilization is identified due to MIP inability to bypass the mobile router's home agent. Proxy Home Agent (PHA) functionality for platform nodes is proposed in Section 4. In Section 5 the proposed mechanism is evaluated in terms of backhaul link utilization and flow performance.

2 HAP Networks

Various architectures have been proposed for HAP networks. Here, the most general topology for an access network is assumed and the one considered is depicted in Fig. 1.

![Fig. 1. HAP network topology](image-url)
HAPs operate in the stratosphere at altitudes of 17-22 km. The coverage area is determined by line-of-sight propagation and the minimum elevation angle at the ground terminal. The area is estimated at 60 km in diameter [1]. Cellular architecture is employed to allow for channel reuse schemes. The size, number, and shape of these cells are subject to the design of the antennas on the HAP. When the scheme with 121 cells is used, the ground size of a cell is approximately 5 km diameter.

Only platforms with onboard switching payload are considered. The processing power suffices for packet based switching and routing. IP packet switching is assumed as the underlying network technology. The inter-HAP links connect adjacent platforms without the need for any ground network elements. The links are based on optical technology with large bandwidth. Network elements on the ground provide HAPs with connection to the high-speed Internet through a set of backhaul links. User and backhaul radio communications with HAP take place on mm wave bands.

Only mobile users are considered in this paper. It is assumed that the prevailing type of mobile user would be a vehicle; i.e. bus, train, ship or automobile. The passengers access the network through a local wireless or wireline network. Efficient mobility support in the HAP network should handle mobility of the vehicles as well as that of the passengers. The limited radio spectrum should be used as efficiently as possible as the wireless link will often be the bottleneck. Unnecessary use of backhaul links must be avoided. Note that user data does not necessary pass through the ground core network – only user-to-HAP and HAP-to-HAP links may be involved.

The main difference between the end-user mobile terminal and the terminal on the vehicle is that the latter is expected to function as a mobile router. A mobile router allows an entire network to roam. Often, the passengers will require global mobility, in which case they will have to use their own MIP, in addition to the MIP performed by the mobile router. So-called two-level mobility management will take place.

3 Routing Efficiency of Two-level Mobile IP

Mobility management for end-nodes is well defined in current RFCs and Internet Drafts [3, 4]. However, mobility management for mobile routers is an active field of research [5, 6, 9, 10]. Although the same principles of mobility apply, the roaming network poses additional challenges, path optimization being one of them. There is a Home Agent (HA) that intercepts all packets for an entire network domain and forwards them to the mobile router. The nodes served by the mobile router register with their own home network when they require global mobility. The resulting two-level MIP architecture is illustrated in Fig. 2. The inner architecture is required because of the mobility of the router on the vehicle, while the outer architecture guarantees global mobility of the passenger's mobile terminal. If a path is not optimized, a data packet from the correspondent node to the mobile node is first routed to the mobile node's home network. The mobile's HA tunnels the packet to the mobile's care-of-address (COA), which is in the name space of the mobile router's home domain. Therefore, the tunnel from the mobile's HA to the node itself passes through the mobile router's HA, where it is further encapsulated due to a tunnel that connects the mobile router's HA with the mobile router. Note that routing of IP packets from the mobile node to the correspondent node is based on the correspondent node's address and therefore can take the optimal path.

Fig. 2. Two-level MIPv6 architecture
Triangular routing, as seen in Fig. 2, is inefficient as regards backhaul link utilization. Without route optimization, HAP-to-HAP and even intra-HAP communications use the backhaul link. While MIPv6 can bypass the mobile node's HA, it cannot skip the mobile router's HA. In Fig. 3 packet flow is illustrated after first-level route optimization takes place. All packets between mobile nodes still traverse backhaul links in both directions, even when both nodes are within the same HAP network coverage. This holds even for nodes that do not require global mobility.

One of the latest proposals by the Network Mobility Working Group (NEMO) [5, 6] for route optimization in multi-level MIP is based on hierarchical MIP technology (HMIP) [7, 8]. HMIP targets primarily time-critical situations that emerge when binding updates take place. Binding updates inform recipients, i.e. the HA and the correspondent nodes, about the current COA. A large round trip time may prevent fast handoffs, so a hierarchy of binding updates is defined. A new node, called the Mobility Anchor Point (MAP) can be located at any level in a hierarchical network of routers. It can be viewed as a local HA. The mobile node obtains On-link Care-of Address (LCOA) and Regional Care-of Address (RCOA). The RCOA is an address of the mobile node in the MAP domain. Before registering the RCOA with the HA and correspondent nodes, the mobile node registers with the MAP in order to establish a binding between the RCOA and LCOA. Because only local binding updates are required within the MAP area, the number of messages sent to all correspondent nodes and the HA is reduced. On the other hand, all traffic to the mobile node is routed through MAP and encapsulated.

A mechanism has been proposed to shortcut HAs of mobile routers in multi-level hierarchy [5]. The mobile node registers binding information with the MAP, which can then send packets to the mobile node via an IPinIP tunnel, without relaying them through the mobile router's HA. This is possible because the MR registers its own binding information with the MAP. The MAP binds the information from both the MN's and the MR's registration in order to properly tunnel packets to the MN. Note that, for the segment between the MAP and the mobile router, an IPinIPinIP encapsulation is needed.

The MAP functionality should be located on each platform in order to exclude the backhaul links from the HAP-to-HAP communications. However, the advantages of hierarchical mobility management are lost by placing the MAP on the very edge of macro-mobility area. It is more likely that MAP functionality would be placed on the ground, which does not solve the problem of excessive load on backhaul links. Packet flow after HMIP based route optimization in the HAP network with the MAP on the ground is shown in Fig. 4.

4 Proxy Home Agents for Mobile Routers

A solution is proposed to cope with two-level route optimization in HAP networks. We introduce a Proxy Home Agent (PHA) functionality in HAP nodes. The PHAs perform similar tasks as home agents in home networks. The PHAs are used only by mobile routers that roam in the HAP network and are interconnected in a group.

The operation of Proxy Home Agent is the following. A mechanism allows a mobile router to discover the nearest PHA on a visited link. This may be achieved in a similar way as mobile nodes discover MAP node in HMIP, where a new option is introduced in router advertisements. In addition to
sending a registration request to its HA, mobile router would register, i.e. send a binding update, with nearest PHA, which would in turn multicast the registration request to the PHA group.

Suppose that both a CN and a MN access the network through the mobile routers that are roaming in an HAP network. The first few packets from the CN to the MN are routed through the MN's HA. After the first-level route optimization, the CN is notified about the MN's COA, which is within the MR's home domain. Further packets from the CN to the MN are destined to the MR's home address and, therefore, intercepted by the PHA on the access HAP and tunneled to the MR's COA. Backhaul links and the MR's HA are excluded from the packet flow between these two nodes. The exchanged packets take optimal path because they are intercepted at the very border of the network. Existing IP routing mechanism forwards the packets to the MR's current location based on the knowledge of the network topology, which includes the knowledge of the alternative routes. Packet flow after first-level route optimization in HAP network with PHA support is shown in Fig. 5.

Each PHA maintains a binding cache. Upon receiving of the binding update, PHA creates a new entry for the mobile router or updates its existing entry, if such an entry already exists. The entry binds the MR's home network prefix with its COA. The entry is not removed from the binding cache until the expiration of the lifetime period or until a cancellation is received.

An HAP intercepts all packets that are addressed to the mobile router's network while it is serving as the PHA for the MR. Like the HA, the PHA establishes a tunnel to the MR and forwards intercepted packets.

The MR continues to notify, i.e. sends binding updates to the advertised PHA, until it stays within the HAP coverage. As soon as the MR leaves the HAP network it de-registers with the last known PHA and withdraws any further notifications. The cancellation is, like other messages to the PHA, multicast to the PHA group.

Fig. 4. HMIP based route optimization

Fig. 5. PHA based route optimization
The PHAs perform route optimization in HAP network. On the other hand, HMIP based route optimization is capable of global optimization. It would be beneficial to HAP networks that both mechanisms coexist. In that case HMIP could be extended with a proxy MAP functionality, which could be based on the same principles as described above. This is an open area for future work.

5 Performance Analysis

Proposed mechanism was evaluated in terms of backhaul link utilization and flow performance. HAP-to-HAP communications were considered as only they benefit from the PHA mechanism. TCP and UDP traffic has been examined by means of the ns-2 simulator. Series of simulation experiments were performed in probing different communication scenarios. Simulations were performed for the environment with no second-level optimization, for the HMIP based optimization with MAP placed on the ground, and for the PHA based optimization.

The PHA based optimization requires from the MR to send additional binding updates to the nearest PHA on every change of IP address, which are then broadcast to other HAPs. This event is not frequent. The coverage area of a single HAP is expected to be at least 60 km in diameter, therefore PHA updates are still manageable. For example, a train at a speed of 250 km/h stays within the HAP coverage area for at least 14 minutes. The total number of binding updates sent for a single location update equals the number of HAP platforms.

The network topology considered in the ns-2 simulation runs is shown in Fig. 6. This topology depicts a simplistic version of an HAP network topology.

![Fig. 6. Simulation network topology](image)

There are two access links from the MR to the HAP and from the MR to the HAP, an optical link between the ground stations GR and GR. The ground link represents the path within global network through the MR's HA. 50ms link delay was selected for the link on the ground as opposed to 2.5ms delay for other links. We believe that the topology is a good starting point for the first evaluation; however, a more complex topology and scenarios needs to be constructed for future simulation experiments.

A TCP and an UDP agent are attached to the MR, where the CN is assumed to be located. The MN is positioned in the MR,'s network with a TCP sink and a "null" agent for UDP packets. For the TCP connection, a persistent FTP file transfer was set up, while CBR (Constant Bit Rate) source is used to feed the UDP connection. The maximum size of a packet that the TCP agent can generate is 1Kbyte.

We define $\text{RTTi}$ as the round trip time (RTT) of the path from the CN to the MN that traverse the ground link and $\text{RTTi}'$ as the RTT of the path that does not involve ground nodes. In a best case the delay between the start of the communication and the creation of a new binding entry in the CN's cache can be approximated at $\Delta_{opt} = 1.5 \times \text{RTTi} + \text{RTTi}'/2$. $\text{RTTi}'/2$ is needed for the first packet to reach the MN, while the rest of the time is needed for the return routability procedure that precedes the Binding Update message. Note that the MN starts using the optimal path $\text{RTTi}'/2$ later, when the Binding Acknowledgement message reaches the MN.

The backhaul link utilization analysis is straightforward. When only first-level optimization is performed and in case of HMIP based optimization all packets pass backhaul links in both directions. PHAs manage to relieve a load on backhaul links. Only if the CN establishes the first connection with the MN, some packets are sent down and up the backhaul links during $\Delta_{opt}$ time period. The slow start congestion avoidance algorithm limits the amount of data being injected into the network by a TCP sender during $\Delta_{opt}$ interval. Only a few packets are routed through the ground path, as can be seen in Fig. 7. In our simulation 2040 bytes was sent from the HAP to the GR and 120 bytes in the opposite direction before connection was rerouted. UDP flows put larger load on backhaul links as they are not acknowledged. The amount of data sent through the ground path is 2 CBR $\Delta_{opt}$.

TCP performance suffers on the longer RTT connections as can be seen in Fig. 7. This is due to the TCP window-based transmission algorithm that, being triggered by acknowledgement arrivals, depends on network delays. Long RTTs, reducing the congestion window growth rate, result in throughput degradation. In comparison with the flow that takes optimal path from the beginning, the time...
needed by the optimization causes a shift of the TCP performance line in time for approximately 
\[ \frac{2 \Delta_{\text{opt}}}{\text{RTT}_L} \left( \frac{\text{RTT}_L - \text{RTT}_S}{2} \right) \]. The HMIP optimized flow and the unoptimized flow take paths with larger RTT for the lifetime of the connection, which can be observed as a lower slope of the performance lines. The tunneling overhead was ignored in the simulations.

\[0 \leq t \leq 1000\]
\[0, 1, 0, 2, 0, 3, 0, 4, 0, 5, 0, 6, 0, 7\]
\[0 100 200 300 400 500 600 700 800 900 1000\]

Fig. 7. Performance of different TCP flows

6 Conclusion
Proxy Home Agent, the Mobile IP enhancement in HAP networks proposed in this paper, represents a path optimization solution for the network architectures for which the efficiency of route optimization in presence of mobile routers is of high importance. The mechanism is completely transparent to mobile and correspondent nodes. Analytical results show that, in case of HAP networks, the load on backhaul links can be reduced. TCP performance improvement due to shorter RTTs was confirmed and evaluated numerically. Finally, it should be noted that the PHA principles can be extended to support the intra-domain HMIP route optimization.

References: