Q-MEHROM: Mobility Support and Resource Reservations for Mobile Hosts in IP Access Networks

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Abstract. The increasing use of wireless networks and the popularity of multimedia applications, leads to the need of Quality of Service support in a mobile IP-based environment. This paper presents Q-MEHROM, which is the close coupling between the micromobility protocol MEHROM and a resource reservation mechanism. In case of handoff, Q-MEHROM updates the routing information and allocates the resources for receiving mobile hosts simultaneously. Invalid routing information and reservations along the old path are explicitly deleted. Resource reservations along the part of the old path that overlaps with the new path are reused. Q-MEHROM uses information calculated by QOSPF. Simulation results show that the control load is limited, mainly QOSPF traffic and influenced by the handoff rate in the network. Q-MEHROM uses mesh links and extra uplinks, present to increase the link failure robustness, to reduce handoff packet loss and improve the performance for highly asymmetric network loads.

1 Introduction

Today, wireless networks evolve towards IP-based infrastructures to allow a seamless integration between wired and wireless technologies. Most routing protocols that support IP mobility, assume that the network consists of an IP-based core network and several IP domains (also referred to as access networks), each connected to the core network via a domain gateway. This is illustrated in Fig. 1.

In contrast to wired networks, the user's point of attachment to the network changes frequently due to mobility. Since an IP address indicates the location of the user in the network as well as the end point of its connections, user mobility leads to several challenges. Mobile IP (IPv4 [1], IPv6 [2]), which is standardized by the IETF, is the best known routing protocol that supports host mobility.

While Mobile IP is used to support macromobility, i.e. the movements from one IP domain to another, much research is done to support the local movements

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Fig. 1. General structure of an all IP-based network.

within one IP domain, called micromobility. Examples of micromobility protocols are per-host forwarding schemes like Cellular IP [3] and Hawaii [4], and tunnel-based schemes like MIPv4 Regional Registration [5] and Hierarchical MIPv6 [6], proposed within the IETF, and the BCMP protocol [7], developed within the IST BRAIN Project. These protocols try to solve the weaknesses of Mobile IP by aiming to reduce the handoff latency, the handoff packet loss and the load of control messages in the core network. Low Latency Handoff protocols, like Low Latency MIPv4 [8] and Fast MIPv6 [9], were developed by the IETF to reduce the amount of configuration time in a new subnet by using link layer triggers in order to anticipate on the movement of the mobile host.

Most research in the area of micromobility assumes that the links of the access network form a tree topology or hierarchical structure. However, for reasons of robustness against link failures and load balancing, a much more meshed topology is required. Although the above mentioned micromobility protocols work correctly in the presence of mesh links, the topology has an important influence on their performance. E.g. Cellular IP and MIPv4-RR do not use the mesh links, while Hawaii takes advantage of the mesh links to reduce the handoff latency and packet loss. However, the use of Hawaii in a meshed topology results in suboptimal routes and high end-to-end delays after several handoffs. In our previous work, MEHROM (Micromobility support with Efficient Handoff and Route Optimization Mechanisms) was developed, resulting in a good performance, irrespective of the topology, for frequent handoffs within an IP domain. This handoff scheme consists of two phases. During the first phase, a fast handoff is made in order to limit the handoff latency and packet loss. If necessary, the second phase is executed, which guarantees the set up of an optimal new path between the domain gateway and the current access router. For a detailed description of MEHROM and a comparison with Cellular IP, Hawaii and MIPv4-RR, we refer to [10] and [11].

In a mobile IP-based environment, users want to receive real-time applications with the same QoS (Quality of Service) as in a fixed environment. Several extensions to RSVP under macro- and micromobility are proposed in [12] and [13]. However, the rerouting of the RSVP branch path at the cross-over node

under micromobility again assumes an access network with tree topology. Moreover, for mobile receivers, the cross-over node triggers a PATH message after a route update message was received, introducing some delay. Current work within the IETF NSIS (Next Steps in Signaling) working group includes the analysis of some of the existing QoS signaling protocols for an IP network [14] and the listing of Mobile IP specific requirements of a QoS solution [15].

In this paper, we present Q-MEHROM, which is the close coupling between MEHROM and a resource reservation mechanism. Hereby, the updating of routing information and the allocation of resources for mobile receivers is performed at the same time, irrespective of the topology. Information gathered by QOSPF (Open Shortest Path First protocol with QoS extensions [16], [17]) is used. In what follows, we assume that the requested resource is a certain amount of bandwidth.

The rest of this paper is structured as follows. Section 2 presents the framework used. Section 3 describes which information, obtained by the QOSPF protocol, is used by Q-MEHROM. In section 4, the operation of Q-MEHROM is explained. Simulation results are presented in section 5. The final section 6 contains our concluding remarks.

2 Micromobility and Resource Reservations

In Fig. 2, the framework, used for a close interaction between micromobility routing and resource reservations, is presented. A micromobility protocol updates the routing tables to support data traffic towards mobile hosts. In this paper, we consider the resource reservations for data flows towards mobile hosts.

The central building block is responsible for the propagation of mobility and requested resources information through the access network. Frequent handoffs within one IP domain are supported by MEHROM [11]. This is a per-host scheme and every router along the path between the domain gateway and the current access router has an entry in its routing table indicating the next hop to the mobile host. At the time of handoff, the necessary signaling to update the routing

Fig. 2. Framework for micromobility routing and QoS support in an IP access network. The grey building blocks are the focus of this paper.

tables is kept locally as much as possible. New entries are added and obsolete entries are explicitly deleted, resulting in a single installed path for each MH (mobile host). This micromobility scheme is very suitable to be closely coupled with a resource reservation mechanism for traffic towards the mobile hosts. When a mobile host performs a handoff, we want to propagate the necessary QoS information as fast as possible to limit the degradation of the delivered QoS. Hereby, we want to restrict the signaling to the part of the new path that does not overlap with the old path and explicitly release reserved resources along the unused part of the old path. By defining the resource reservation mechanism as an extension of MEHROM, resources can be re-allocated at the same time that the routing tables are updated after handoff. The combination of MEHROM and its resource reservation extensions is referred to as Q-MEHROM.

In order to obtain information about the topology of the access network and the state of the links, we use QOSPF, as described in [17]. This is presented by the upper left building block of the framework.

The interaction between both grey building blocks is as follows. QOSPF computes paths in the access network that satisfy given QoS requirements and provides this information to Q-MEHROM. Every time Q-MEHROM reserves or releases resources on a link, QOSPF is informed so that updated link state advertisements can be spread throughout the access network.

The upper right block represents the admission control policy. Although a variety of mechanisms is possible, we have chosen for a simple admission control priority mechanism: when a new request for resources is made by a mobile host, the access router decides whether the access network has sufficient resources to deliver the required QoS. If not, the request is rejected. At the time of handoff, priority is given to handoff requests above new requests. When the required resources for an existing connection can not be delivered via the new access router at the time of handoff, the handoff request is not rejected, but the delivered service is reduced to best-effort. For simplicity, only at the time of a next handoff, the availability of resources is checked and reservations can be made again. The admission control mechanism gives QOSPF information about the resources that were reserved by the mobile host before handoff (these resources can be reused). QOSPF in its turn provides information about paths with sufficient resources in the access network.

Finally, the lower building blocks are the packet classifier and scheduler. When Q-MEHROM updates the routing tables, these routes are installed in the packet classifier so that data packets are mapped towards the correct outgoing link. As scheduler, a variant of CBQ (Class Based Queueing) is used [18]. When resources are reserved for a mobile host, Q-MEHROM inserts a class for that mobile host. When these resources are released after an handoff, the class is removed again. One class that is never removed is the class for all control traffic. To reduce complexity, we assume that the routing decision is only based on the mobile host's care-of address, irrespective of the amount of flows. For simplicity, we consider one class for all flows to a specific mobile host.

3 Information Calculated by QOSPF

QOSPF advertises link metrics, like link available bandwidth and link delay, across the access network by Link State Advertisements (LSAs). As a result, the domain gateway, all routers and all access routers have an updated link-state database that reflects the access network state and topology. To provide useful information to Q-MEHROM, QOSPF calculates, in each node of the access network, several QoS routing tables from the database, see also Table 1.

Delay Table. The Delay table is used during the first phase of the Q-MEHROM handoff algorithm, when the new access router sends a route update message towards the old access router as fast as possible. The Delay table of a router has this router as source and an entry for every access router (AR) as destination. Therefore, the router calculates the path with smallest delay to a specific AR, using a single objective path optimization. The next hop to that AR is then put in the Delay table. As the delay characteristics are not expected to change frequently, the Delay table needs no frequent recalculation.

Bandwidth Table. A Bandwidth table is used when resources are reserved for a new traffic flow. Hereby, the available bandwidth on the links of the access network is taken into account. As we consider traffic towards the mobile hosts, a router calculates a Bandwidth table with the domain gateway as source and itself as destination. The Bandwidth table gives the last node on the path before reaching the router. A double objective path optimization is used, taking also the hop count into account. For a certain value of the hop count, the path with at most this amount of hops and with maximum bandwidth (BW) is calculated. When the amount of available bandwidth in the access network changes, the Bandwidth tables should be recalculated.

Reuse-Bandwidth Table. A Reuse-Bandwidth table is used for handoff reservations. When a mobile host performs handoff, a new path must be set up. It is

Table 1. Delay, Bandwidth and Reuse-Bandwidth table for router R2 of Fig. 3.1.

Delay table		Bandwidth table (for new traffic flow)		
destination next hop		max. hops	last hop	max. bandwidth
oAR	R1	1	-	-
nAR	nAR	2	R3	2 Mbit/s
		3	R3	2 Mbit/s

Reuse-Bandwidth table (if MH performs handoff)		
max. hops	last hop	max. bandwidth
1	-	-
2	R3	5 Mbit/s
3	R3	5 Mbit/s

possible that the new path partly overlaps with the old path. Resources along this common part should be reused and not be allocated twice. Therefore, QOSPF must consider the resources, reserved for the mobile host before handoff, also as available resources and calculate another bandwidth table, called the Reuse-Bandwidth table. This table can only be calculated at the time of handoff and needs as input the old path and the amount of reserved bandwidth for a specific mobile host. This table has the same structure as the Bandwidth table.

4 Q-MEHROM Mechanism

The basic operation of Q-MEHROM is explained using the example in Fig. 3. There are three successive situations:

Bandwidth Reservations. When a MH powers up in the access network, only basic MEHROM is used to set up a (best-effort) path for the MH in the access network. This path is a path with minimum hop count between the domain gateway (GW) and the current access router.

When a traffic flow is set up towards a MH, this MH requests an amount of bandwidth (information obtained from the application layer) for that flow at its current access router. After a positive admission control, the access router starts the resource reservation mechanism, using its Bandwidth table. If the MH is the receiver of multiple flows, the requested bandwidth is the sum of the individually amounts of bandwidth requested by the applications.

Handoff Phase 1 – Fast Handoff. After the receipt of a Mobile IP registration request, the new access router (nAR) (we describe the case of a positive admission control) adds a new entry for the MH in its routing cache and sends a route update message towards the old access router (oAR) in a hop-by-hop way. Like basic MEHROM, Q-MEHROM is capable to detect if the new path will be optimal, using an *optimal_path* parameter in the route update messages.

When R2 processes the route update message, it checks the *optimal_path* parameter in this message. This parameter has value 1, i.e. the node is part of the optimal path between the GW and the nAR. Therefore, the necessary resources are reserved on the link between R2 and the nAR. As a next step, it looks up the next hop on the path with smallest delay towards the oAR in the Delay table (i.e. R1). Furthermore, it retrieves in the Reuse-Bandwidth table the last node before reaching R2 on the optimal path between the GW and R2 (i.e. R3). As both nodes are different, the *optimal_path* parameter is set to 0, indicating the path will be suboptimal. Once this parameter contains the value 0, it remains 0 and only the Delay table must be consulted. The route update message is forwarded using the next hop from the Delay table.

R1 has an old entry for the MH. Therefore R1 is considered as the cross-over node (CN), and the route update message is not forwarded further. The CN sends a suboptimal handoff acknowledgment (ACK) back to the nAR. The CN also deletes the reservation on the link from R1 to oAR and sends a route delete message to the oAR, to delete the invalid entry in its routing cache.

Fig. 3. Example of bandwidth reservation for a mobile host. 1) the MH requests resources for its traffic flows, 2) the MH performs handoff which consists of phase 1 and 3) phase 2. The arrows indicate entries for the mobile host and point to the next hop in the path. A dashed arrow indicates an entry without resource reservations on the next link. $[x, y] = [\text{link delay (ms), available bandwidth (Mbit/s)}]$; $[z] = [\text{requested bandwidth (Mbit/s)}]$.

The nAR is informed through a suboptimal handoff ACK that a suboptimal path is found during phase 1. As data packets can reach the MH via this suboptimal path, the nAR sends first a Mobile IP registration reply to the MH. Next, the nAR starts the route optimization phase.

Handoff Phase 2 – Route Optimization. The nAR sends a new route update message towards the GW, also in a hop-by-hop way, to establish an optimal path. During phase 2, the optimal path parameter is set to value 2, indicating that the route update message must be forwarded towards the node

retrieved in the Reuse-Bandwidth table (the Delay table is not consulted). As R2 has already a new entry in its routing table, the entry is refreshed and the message is simply forwarded. This route update message finds a new CN, R3. R3 updates its routing cache, allocates resources on the link from R3 to R2 and deletes the reservation on the link from R3 to R1. At that time, an optimal path is set up: an optimal handoff ACK is sent back to the nAR and a route delete message is sent to R1.

5 Evaluation

In order to evaluate the performance of Q-MEHROM, the protocol is implemented in the network simulator ns-2 [19]. QOSPF is simulated by extensions, for the calculation of the QoS routing tables, to the implementation of [20]. Unless otherwise mentioned, the following parameter values are chosen:

Wired and Wireless Links. The wired links of the access network have a delay of 2 ms and a capacity of 2.5 Mbit/s. For the wireless link, IEEE 802.11 is used with a physical bitrate of 11 Mbit/s.

Access Routers and Mobile Hosts. Every access router broadcasts beacons at fixed time intervals T_b of 1.0 s. The distance between two adjacent access routers is 200 m, with a cell overlap d_o of 30 m. All access routers are placed on a straight line. Mobile hosts move at a speed v_{MH} of 20 m/s and travel from one access router to another, maximizing the overlap time. They reside thus in an overlap region during 1.5 s.

Traffic. CBR (constant bit rate) data traffic patterns are used, with a bitrate of 0.5 Mbit/s. For every mobile host, one UDP connection is set up between the sender (a fixed host in the core network directly connected to the domain gateway) and the receiver (the mobile terminal).

Access Network Topology. Tree, mesh and random topologies are investigated. The topologies that are used for the simulations, are given in Fig. 4.

5.1 Load of Control Traffic in the Access Network

For the different topologies of Fig. 4, the average amount of control traffic on a wired link of the access network is investigated. The leftmost figure of Fig. 5 gives the results for an increasing number of mobile hosts, while the rightmost figure shows the influence of the speed of a single mobile host. The mobile hosts move randomly from one access router to another during 300 s, requesting 0.5 Mbit/s. Randomly means that a mobile node moves towards a randomly chosen access router. When arriving, the mobile host stays there for maximum 1 second before a new access router is chosen as destination. The Q-MEHROM control load consists of Route Update, Route Delete, Acknowledgment and Power Up messages.

Fig. 4. Tree, mesh and random topology of the access network, used during the simulations. The mesh topology consists of the tree structure (full lines) with the indicated additional mesh links (dashed lines), while the random topology is formed by adding extra uplinks (dotted lines) to the mesh topology.

Fig. 5. Average amount of control traffic on a wired link of the access network as a function of the number of mobile hosts (left figure) and the speed of a single mobile host (right figure).

The QOSPF control traffic consists of two parts. The first part is formed by the QOSPF messages at the start of the simulation, advertising the initial link state information through the network. The second part consists of QOSPF traffic caused by resource reservations and resource releases during the simulation as they change the available bandwidth of some links.

The load of control messages specific to Q-MEHROM is very low compared to the load of QOSPF traffic. The QOSPF traffic in the absence of mobile hosts contains only the first part, with messages to spread the initial link state information. This part depends purely on the topology and the number of links. The second part of the QOSPF load, with messages triggered by resource reservations and releases, is also determined by the number of handoffs and their location in the topology.

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The required amount of bandwidth for QOSPF control traffic increases for higher handoff rates, i.e. the number of handoffs in the network per time unit. This handoff rate grows for higher number of mobile hosts, illustrated in the leftmost figure of Fig. 5 and for higher speeds as shown in the rightmost figure. Note that this is the worst case, as every change in available bandwidth triggers QOSPF LSAs. Periodically triggering of LSAs or triggering only after a significant change in available bandwidth can reduce the control load, at the cost of the accuracy of link state information. The required amount of bandwidth for control traffic remains low compared to the link capacities ($\pm 0.05\%$ for 8 mobile hosts with a speed of 20 m/s). In what follows, we reserved 1% of the given link capacity for the control traffic class of CBQ. This is sufficient to support more than 100 mobile hosts with a speed of 20 m/s.

5.2 Handoff Performance

To investigate the handoff performance, the following scenario is considered: during 1 simulation, a single mobile host moves from the leftmost to the rightmost access router of Fig. 4, performing 7 handoffs. The results in Fig. 6 are average values of a set of 200 independent simulations, i.e. there is no correlation between the sending of beacons by the access routers, the movements of the mobile host and the arrival of data packets in the access routers.

The leftmost figure of Fig. 6 shows the loss of data packets as a function of the speed of the mobile host. The data flow has a packet size of 500 bytes and a rate of 1 Mbit/s. Results are given for beacons sent at time intervals $T_b = 1.0$ s, 0.75 s and 0.50 s. The packet loss is independent of the velocity, as long as the mobile host resides long enough in the overlap region to receive at least one beacon from a new access router while still connected to its previous access router. Otherwise, packet loss increases rapidly. In the considered situation, where the mobile host moves on a straight line through the center of the overlap regions, this requirement is fulfilled when

$$v_{MH} \leq d_o / T_b . \quad (1)$$

In this case, Q-MEHROM takes advantage of mesh links and extra uplinks to reduce the packet loss compared to the tree topology.

The rightmost figure of Fig. 6 gives the results for the data packet loss as a function of the data rate. The mobile host moves at a speed of 20 m/s and the access routers send beacons at time intervals of 1.0 s. The used packet sizes are 500 bytes, 1000 bytes and 1500 bytes. For a given packet size, the packet loss increases for higher data rates and is higher for the tree topology compared to the other topologies. The use of IEEE 802.11 and collisions on the wireless link limit the achievable throughput. For a wireless bitrate of 11 Mbit/s, the use of the RTS/CTS mechanism and a data packet size of x bytes, the TMT (Theoretical Maximum Throughput) is given by [21]:

$$TMT(x) = \frac{8x}{ax + b} \cdot 10^6 \text{ bps} \quad \text{with } a = 0.72727 \text{ and } b = 1566.73 . \quad (2)$$

Fig. 6. Average packet loss as a function of the mobile host's speed for several beacon time intervals (left figure) and as a function of the data rate for several packet sizes (right figure).

Fig. 7. Received bandwidth by the mobile hosts in highly loaded networks for the tree topology.

This explains the rapid increase of packet loss for a packet size of 500 bytes and data rates higher than 1.85 Mbit/s.

5.3 Highly Loaded Access Networks

In order to investigate how well Q-MEHROM can handle the mismatch between traffic load and network capacity, we consider the following scenario: at the start of the simulation, the network is symmetrically loaded by a single mobile host in each of the eight cells of Fig. 4. During one simulation, those mobile hosts move randomly from one access router to another during 300 s. Each mobile host is the receiver of a CBR data flow with a packet size of 1500 bytes and a bitrate of 0.5 Mbit/s. These values are chosen so that the wireless channel is not a bottleneck for the received bandwidth ($TMT = 4.515$ Mbit/s), even if all mobile hosts move into the same cell. Figure 7 gives the average bandwidth received by each mobile host during the last 3.0 seconds as a function of time for the tree topology, Fig. 8 for the random topology.

For the tree topology, only one possible path between the domain gateway and a specific access router exists. So both in case of best-effort (left figure) as in

Fig. 8. Received bandwidth by the mobile hosts in highly loaded networks for the random topology.

case of Q-MEHROM (right figure) the data packets for mobile hosts residing in the same cell are routed via the same path. The capacity of the links closest to the domain gateway limits the amount of bandwidth that can be allocated for mobile hosts residing in the underlying cells. As a small part of the total link bandwidth, 2.5 Mbit/s, is reserved for control traffic, only four reservations of 0.5 Mbit/s can be made on a single link. For best-effort, the available bandwidth is shared between all mobile hosts using the same link. In case of Q-MEHROM, mobile hosts that made a reservation, receive their requested bandwidth irrespective of newly arriving mobile hosts. As a result, more mobile hosts receive 0.5 Mbit/s compared to best-effort.

For the random topology, the difference between best-effort (left figure) and the use of Q-MEHROM (right figure) is much more significant. Due to the presence of extra uplinks, more than one path with minimum hop count may be found between the domain gateway and a specific access router. In case of best-effort, one of these possible paths is chosen without taken into account the available bandwidth. Only for mobile hosts in cell 15, ns-2 uses the path via the right link closest to the domain gateway. Q-MEHROM chooses a path with enough resources, if available. Due to mesh links and extra uplinks, the capacity of the links closest to the domain gateway forms no longer a bottleneck. Q-MEHROM uses the presence of these extra links, to support asymmetric network loads and to spread the data load over the network.

6 Conclusions

In this paper we presented Q-MEHROM, which is the close coupling between the micromobility protocol MEHROM and a resource reservation mechanism. In case of handoff, the updating of routing information and resource reservations for traffic flows towards the mobile host are performed at the same time. Hereby, invalid routing information and reservations along the old path are explicitly deleted. Resource reservations along the part of the old path that overlaps with the new path are reused. Q-MEHROM uses information gathered and calculated by QOSPF.

Simulation results showed that the amount of control overhead caused by Q-MEHROM and QOSPF is mainly QOSPF traffic. The control load increases for higher handoff rates in the network, which is influenced by the number of mobile hosts and their velocity. For the studied topologies and scenarios, this load remains very low compared to the link capacities. The first phase of Q-MEHROM takes advantage of extra links, present to increase the robustness against link failures, to reduce the handoff packet loss compared to a pure tree topology. This handoff packet loss is independent of the speed of the mobile hosts and increases with the data rate. For high network loads, simulations indicated that by the use of Q-MEHROM, mobile hosts can make reservations and protect their received bandwidth against newly arriving mobile hosts. Furthermore, Q-MEHROM takes the available bandwidth into account by choosing a path and is able to use mesh links and extra uplinks to improve the balancing of data load in the access network.

The study of resource reservations for traffic flows sent by mobile hosts and the study of different classes per mobile host are subject of future work. Also the influence of inaccurate link state information on the Q-MEHROM performance is an important issue that will be investigated.

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Abstract: The increasing use of wireless networks and the popularity of multimedia applications, leads to the need of Quality of Service support in a mobile IP-based environment. This paper presents Q-MEHROM, which is the close coupling between the micromobility protocol MEHROM and a resource reservation mechanism. In case of handoff, Q-MEHROM updates the routing information and allocates the resources for receiving mobile hosts simultaneously. Invalid routing information and reservations along the old path are explicitly deleted. Resource reservations along the part of the old path that overlaps with the new path are reused. Q-MEHROM uses information calculated by QOSPF. Simulation results show that the control load is limited, mainly QOSPF traffic and influenced by the handoff rate in the network. Q-MEHROM uses mesh links and extra uplinks, present to increase the link failure robustness, to reduce handoff packet loss and improve the performance for highly asymmetric network loads.

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