Impact of Link State Changes and Inaccurate Link State Information on Mobility Support and Resource Reservations

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Abstract. The increasing use of wireless networks and the popularity of multimedia applications, leads to the need of QoS (Quality of Service) support in a mobile IP-based environment. This paper presents the framework, needed to support both micromobility and resource reservations. We present an admission control mechanism in which a mobile host can trigger reservations without performing handoff, taking advantage of link state changes caused by the handoff of other mobile hosts. We also investigate the impact of inaccurate link state information and the occurrence of simultaneous handoffs on the performance of the handoff and reservation mechanism. This impact is higher when only a small part of the mobile hosts can receive QoS service at the same time. For the simulations, we use Q-MEHROM [10]. Herein, QOSPF [11] gathers the link state information and calculates the QoS tables. However, the ideas and results presented in this paper are not restricted to these protocols.

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 (access networks), each connected to the core network via a domain gateway. Mobile IP [1,2], which is standardized by the IETF, is the best known routing protocol that supports host mobility. Mobile IP is used to support macromobility, while, examples of micromobility protocols are per-host forwarding schemes like Cellular IP [3], Hawaii [4], and tunnel-based schemes like MIPv4-RR [5]. 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.

Most research in the area of micromobility assumes that the access network has a tree or hierarchical structure. However, for reasons of robustness against

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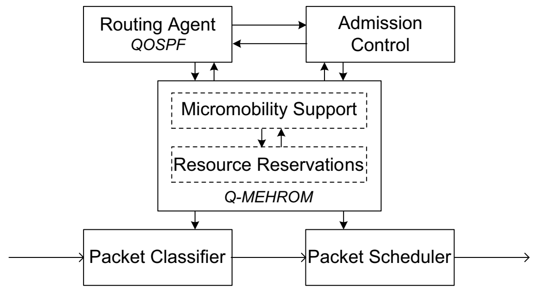

Fig. 1. Framework for micromobility and QoS support in an IP-based access network

link failures and load balancing, a much more meshed topology is required. In our previous work, we developed MEHROM (Micromobility support with Efficient Handoff and Route Optimization Mechanisms). It shows a good performance, irrespective of the topology, for frequent handoffs within an IP domain. For a detailed description of MEHROM and a comparison with Cellular IP, Hawaii and MIPv4-RR, we refer to [6].

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 (Resource Reservation Protocol) under macro- and micromobility are proposed in [7]. However, the rerouting of the RSVP branch path at the cross-over node under micromobility again assumes a tree topology and introduces some delay. Current work within the IETF NSIS (Next Steps in Signalling) working group includes the analysis of some existing QoS signalling protocols for an IP network [8] and the listing of Mobile IP specific requirements of a QoS solution [9]. In [10], we presented Q-MEHROM, which is the close coupling of MEHROM and resource reservations. By defining the resource reservation mechanism as an extension of the micromobility protocol, resources can be re-allocated at the same time that the routing tables are updated.

In this paper, we investigate how the admission control of a mobile host can take advantage of link state changes due to the handoff of other mobile hosts. We also study the impact of inaccurate link state information and simultaneous handoffs on the handoff and reservation mechanism. The rest of this paper is structured as follows. Section 2 presents the framework used. Section 3 describes a way to enhance the admission control mechanism. In Sect. 4, the impact of inaccurate link state information and simultaneous handoffs on the handoff and reservation mechanism is explained. Simulation results are presented in Sect. 5. The final Sect. 6 contains our concluding remarks.

2 Framework

Figure 1 presents the framework, used to support micromobility routing and resource reservations. A micromobility protocol updates the routing tables in the access network to support data traffic towards mobile hosts (MHs). In this paper, we consider the resource reservations for data flows towards MHs.

Micromobility Support and Resource Reservations The central block of Fig. 1 is responsible for the propagation of mobility information and the reservation of requested resources through the access network.

For the simulations, Q-MEHROM [10], based upon the micromobility protocol MEHROM [6], is used. MEHROM is a per-host forwarding scheme. At the time of handoff, the necessary signalling to update the routing 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. These characteristics make the MEHROM handoff scheme very suitable to be closely coupled with a resource reservation mechanism for traffic towards the MHs. During handoff, Q-MEHROM propagates the necessary QoS information as fast as possible to limit the degradation of the delivered QoS. Hereby, the signalling is restricted to the part of the new path that does not overlap with the old path and reserved resources along the unused part of the old path are explicitly released.

Topology and Link State Information A micromobility protocol needs information about the access network topology, e.g. to find the next hop to the domain gateway (GW). A resource reservation mechanism requests information about the link states, e.g. to find a path with enough available bandwidth. The routing agent, presented by the upper left block of Fig. 1, gathers this information and computes paths in the access network that satisfy given QoS requirements. The micromobility and resource reservation mechanism, in its turn, informs the routing agent every time resources are reserved or released on a link.

For the simulations, we use QOSPF, as described in [11]. QOSPF advertises link metrics, like available bandwidth and delay, across the access network by link state advertisements. As a result, all routers have an updated link-state database. To provide useful information to the micromobility and resource reservation mechanism, QOSPF calculates, in each router, several QoS routing tables from the database. Q-MEHROM uses information from the following QoS tables:

- 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. The next hop to that AR is then put in the Delay table.
- A Bandwidth table is used to reserve resources for a new traffic flow or to switch from best-effort to QoS service. Here, the available bandwidth on the links of the access network as well as the hop count are taken into account. As we consider traffic towards the MHs, a router calculates a Bandwidth table with the GW as source and itself as destination. For a certain value of the hop count, the path with at most this amount of hops and with maximum bandwidth is calculated. The Bandwidth table gives the last node on the path before reaching the router.
- A Reuse-Bandwidth table is used for the handoff mechanism of flows with QoS service. After handoff, it is possible that the new path partly overlaps with the old path. Resources along this common part should be reused and not allocated twice. Therefore, QOSPF must consider the resources, reserved for the MH before handoff, also as available resources. Using this additional information, the Reuse-Bandwidth table is calculated.

Admission Control The upper right block of Fig. 1 represents the admission control policy. We have chosen for a simple admission control priority mechanism: priority is given to handoff requests above new requests. When a new request for resources is made by a MH, its AR decides whether the access network has enough resources to deliver the required QoS. If not, the request is rejected. If, at the time of handoff, the required resources for an existing connection can not be delivered via the new AR, the handoff request is not rejected, but the delivered service is reduced to best-effort. At the time of a next handoff, the availability of resources is checked again and reservations can be made.

When the micromobility and resource reservation mechanism of an AR must decide how to treat a new request or handoff request, the admission control mechanism gives the routing agent information about the resources that were reserved by the MH before handoff. The routing agent in its turn provides information about paths with sufficient resources in the access network. The admission control then informs the micromobility and resource reservation mechanism about the availability of resources.

3 Impact of Link State Changes on Admission Control

The simple admission control mechanism, explained in Sect. 2 and used in [10], has an important drawback: as long as a MH, receiving best-effort service, does not perform handoff, its service remains best-effort. Even if enough resources became available due to the handoff of other MHs.

In order to overcome this important drawback, we propose to extend the admission control policy. In this extended admission control mechanism, the AR must check whether enough resources became available for one of the MHs in its routing cache that still receive best-effort service. This check can be triggered periodically or after the receipt of a link state advertisement, indicating that the available resources on a link are increased. However, both of these trigger mechanisms can not avoid that the AR starts the resource reservation mechanism while the MH performs handoff to another AR, possibly leading to router inconsistency in the access network. Therefore, we propose a solution in which the MH itself triggers the link state check by the AR, by sending a new Mobile IP Registration Request. The MH sends this trigger when it receives a new beacon, i.e. a Mobile IP Agent Advertisement, from its current AR, if it receives best-effort service and is not performing handoff soon. To make an estimation about the next time of handoff, it can be very useful to use link layer (L2) information, e.g. the signal strength of the beacons. If the AR detects that enough resources became available, the AR starts the resource reservation mechanism, and the delivered service is switched back from best-effort to QoS. We will call the reservation of resources without performing handoff, the switch mechanism.

4 Use of Inaccurate Link State Information

As the state of the access network changes constantly, e.g. as a result of handoffs, the QoS tables need to be recalculated as time passes by. Several approaches for these recalculations can be used. A QoS table can be recalculated either:

– Periodically at given time intervals P, irrespective of the number of link state changes;
– After an amount of N_{ads} received link state advertisements or interface changes, proportional to the number of link state changes;
– On demand, depending on the number of times information is requested from the QoS table.

For an increasing value of P and N_{ads}, the number of calculations in the routers of the access network decreases at the cost of possible inaccurate information in the QoS tables. If the information is calculated on demand, the most accurate link state information, available by the router, is used to calculate the QoS tables.

While the routers in the access network use the QoS tables to find the next hop towards the old AR or towards the GW, the ARs use the information also during admission control. Even though an AR decided that enough resources, e.g. bandwidth, are available to make reservations for a MH, still the following can occur during the handoff or switch mechanism:

– When a router requests information from a QoS table, no longer a next hop on a path with enough available bandwidth may be found;
– When a router wants to make reservations on a link, the available bandwidth on the link may no longer be sufficient.

When such an error is detected, the delivered service is switched to best-effort. These errors can occur when the QoS tables of the AR are not up to date. This is the case when the AR has not the most recent link state information, due to the fact that the propagation of link state information through the network requires some time. Even when the correct link state information is already available, the AR may not have recalculated the QoS tables yet, due to the fact that these tables are calculated periodically or after a number of link state changes.

Moreover, even when the QoS tables are up to date at the moment of handoff, errors can occur as several MHs can perform handoff more or less at the same time. Especially in the case of mobility, the latter reason causes the major part of the errors. If ARs broadcast beacons to trigger handoff at the MHs, the sending of beacons influences the occurrence of errors:

– MHs newly arriving in the same cell, send a handoff request when a beacon from that AR is received, resulting in simultaneous handoffs;
– MHs in different cells, performing handoff more or less at the same time, can cause errors on the links of the access network.

5 Evaluation

The statements in Sects. 3 and 4 are supported by the evaluation results in this section. The network simulator ns-2 [12] is used, with Q-MEHROM as micromobility and reservation mechanism and QOSPF as routing agent [13]. However, the conclusions are not restricted to these protocols. In what follows, the results are average values of a set of 200 independent simulations of each 1800 s, i.e. there is no correlation between the sending of beacons by the ARs, the movements of the MHs and the arrival of data packets in the ARs.

The following parameter values are chosen: *1)* The wired links of the access network have a delay of 2 ms and a capacity of 2.5 Mb/s. For the wireless link,

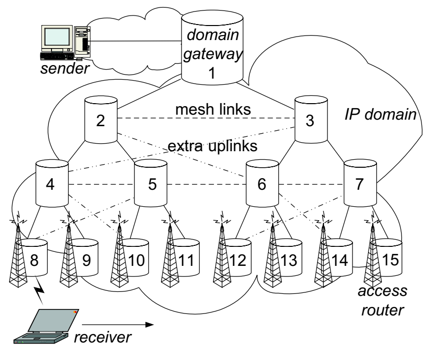

Fig. 2. Simulated access network topologies. The mesh topology consists of the tree structure (full lines) with the indicated additional mesh links (dashed lines). The random topology is formed by adding extra uplinks (dotted lines) to the mesh topology.

IEEE 802.11 is used with a physical bitrate of 11 Mb/s. *2)* Every AR broadcasts beacons at fixed time intervals of 1.0 s. These beacons are Mobile IP Agent Advertisements. The distance between two adjacent ARs is 200 m, with a cell overlap d_{o} of 30 m. All ARs are placed on a straight line. Eight MHs, labeled 1 to 8 in Fig. 3, move at a speed v_{MH} and travel from one AR to another, maximizing the overlap time to $d_{\mathrm{o}}/v_{\mathrm{MH}}$. *3)* CBR (constant bit rate) data traffic patterns are used, with a bitrate of 0.5 Mb/s and a packet size of 1500 bytes. For each MH, one UDP connection is set up between the sender (a fixed host in the core network) and the receiver (the MH). The requested resource is thus an amount of bandwidth of 0.5 Mb/s. *4)* Tree, mesh and random topologies are investigated. The simulated topologies are given in Fig. 2.

Using these values, the access network is highly loaded and the accuracy of the information in the QoS tables becomes important. As the wired links have a capacity of 2.5 Mb/s and a small part of this bandwidth is reserved for control traffic, only 4 reservations of 0.5 Mb/s can be made on a link. In the tree topology, the link capacities closest to the GW form the bottleneck for the number of MHs that can make a reservation. In the meshed and random topology, Q-MEHROM is able to take advantage of the extra links to offer QoS service to more MHs. The capacity of the links closest to the ARs becomes then more important.

5.1 Extended Admission Control Mechanism

To investigate the performance of the extended admission control mechanism, proposed in Sect. 3, the fraction of time that a MH receives QoS service is measured. At the end of each handoff or switch mechanism, the current AR sends a Mobile IP Registration Reply to the MH. This message is extended with a flag r, indicating whether the requested resources were successfully reserved ($r = 0$ means best-effort service, $r = 1$ means QoS service).

We define $T_{\mathrm{r=1}}$ as the fraction of the total simulation time that a MH receives QoS service. $T_{\mathrm{r=1}}$ is then given by formula (1). At moment t_i, the MH receives the flag r_i of the i^{th} handoff, with H the total number of handoffs. At t_0 the MH

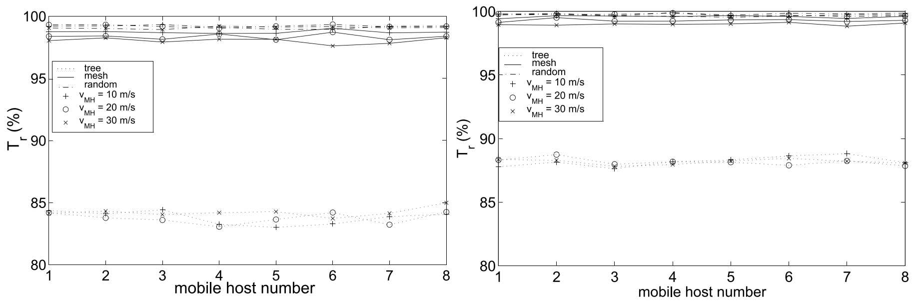

Fig. 3. Fraction of time that resources are reserved for each MH. In the left figure, only the handoff mechanism is used. In the right figure, the extended admission control is used.

performs power up and at t_{end} the simulation ends. Although the effects during the handoff and switch mechanisms are neglected, this metric gives a good idea of the fraction of time that QoS service is obtained.

$$\mathrm{T}_{\mathrm{r}=1}(\%) = \frac{(\mathrm{t}_1 - \mathrm{t}_0)\mathrm{r}_0 + \sum_{i=1}^{\mathrm{H}-1}(\mathrm{t}_{i+1} - \mathrm{t}_i)\mathrm{r}_i + (\mathrm{t}_{\mathrm{end}} - \mathrm{t}_{\mathrm{H}})\mathrm{r}_{\mathrm{H}}}{(\mathrm{t}_{\mathrm{end}} - \mathrm{t}_0)} \quad . \tag{1}$$

The use of only the handoff mechanism (left figure of Fig. 3) is compared with the use of the extended admission control mechanism, i.e. both the handoff and switch mechanism (right figure). The extended admission control mechanism clearly results in a better performance. The improvement is most significant for the tree topology, as only a few MHs can receive QoS service at the same time. Therefore, there is an important chance that at the time of handoff, not enough resources are available and the MHs highly benefit from the switch mechanism to make reservations when other MHs perform handoff and release their resources. For the mesh and random topologies, more MHs can receive QoS service at the same time. Even then, the MHs benefit from the use of the switch mechanism.

5.2 Use of Inaccurate QOSPF Information

Calculation of the QoS Tables. The information in the QoS tables should be as accurate as possible. The Delay table needs no frequent recalculation, as the link delays are not expected to change frequently. The available bandwidth on the links changes frequently, due to the bandwidth reservations and releases by Q-MEHROM. As QOSPF needs additional input information about the old path of a specific MH, the Reuse-Bandwidth table can only be calculated on demand at the time of handoff. However, the different recalculation mechanisms, explained in Sect. 4, can be applied to the Bandwidth table.

The left figure of Fig. 4 gives the average number of Bandwidth table calculations during one simulation. When N_{ads} or P increases, the number of calculations decreases, as expected. For a given value of N_{ads}, the amount of calculations depends upon the MH's velocity: for higher velocities, the number of handoffs increases which results in more bandwidth reservations and releases, thus more

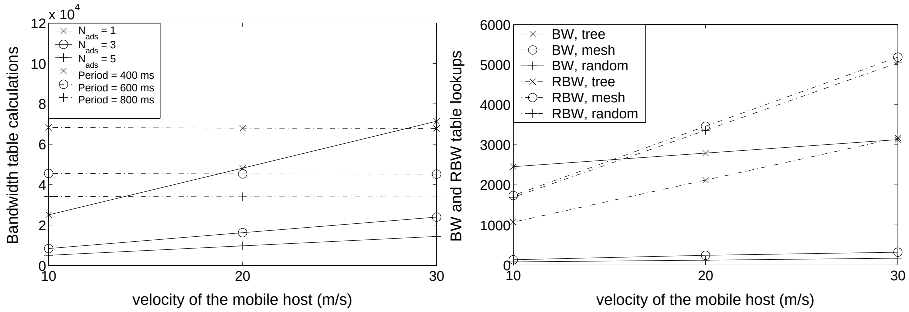

Fig. 4. Average number of Bandwidth table calculations (left figure) for the tree topology. The results for the mesh and random topology are very similar. Average number of lookups for the Bandwidth (BW) and Reuse-Bandwidth (RBW) table (right figure).

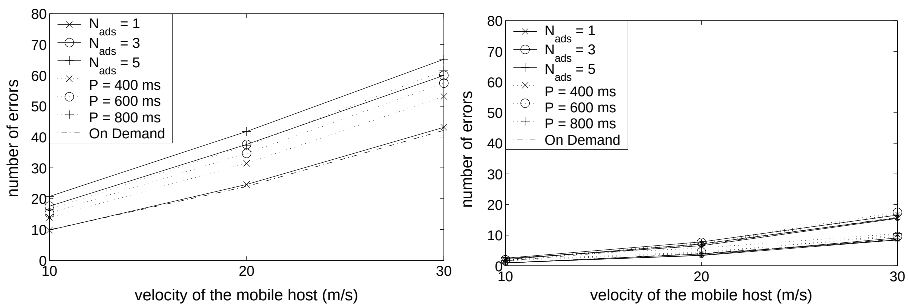

Fig. 5. The left figure gives the average number of errors for the tree topology. The right figure gives the results for the mesh and random topology, the upper bundle of curves applies to the mesh topology, the lower bundle to the random topology.

link state changes. The right figure gives the average number of Bandwidth and Reuse-Bandwidth table lookups, which equals the number of on demand calculations. The Bandwidth table is used when no previously reserved resources must be taken into account. This includes the path setup at power up and the switching from best-effort services to QoS or vice versa. Only for the tree topology, the Bandwidth table is frequently used, as only a few MHs can make reservations at the same time and thus a MH's service switches more often from best-effort to QoS and back.

Inaccurate Information. Figure 5 shows the average number of errors during one simulation for the different recalculation mechanisms of the Bandwidth table. As explained in Sect. 4, an error occurs when a router fails to find a next hop or fails to make a reservation. The cause of such an error stems from the fact that the QOSPF information, used by the AR to perform admission control, was not up to date or became incorrect shortly afterwards due to the handoff of other MHs. When an error is detected, Q-MEHROM switches to best-effort service.

For the tree topology (left figure of Fig. 5), the parameters N_{ads} and P have an important impact. For higher values of N_{ads} and P, the probability that an AR uses inaccurate information and that an error occurs during the path setup,

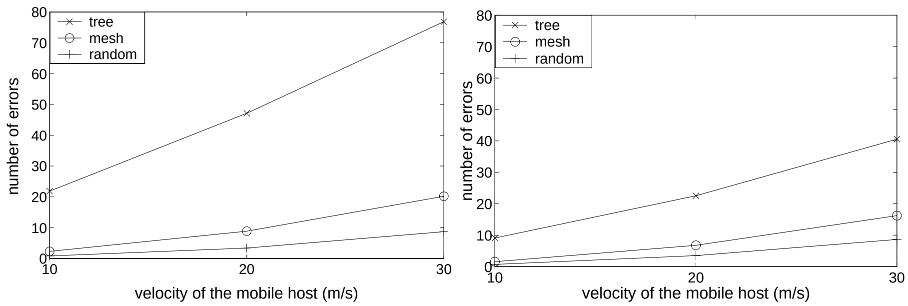

Fig. 6. The average number of errors per simulation. For the left figure, all access routers start to send beacons at 0.5 s. For the right figure, the start times for access router 1;. . . ; 8 are given by (0.125 s; 0.75 s; 0.375 s; 0.0 s; 0.5 s; 0.875 s; 0.25 s; 0.625 s).

increases. The number of errors also increases for higher velocities as this results in more frequent admission control decisions by the ARs. Although Fig. 4 showed that for a velocity of 20 m/s, the number of calculations for $N_{\text{ads}} = 1$ equals the number for $P = 600$ ms, the number of errors is significantly higher in the latter case. The reason is that not only the amount of table recalculations but also the moment of recalculation influences the accuracy of the information at the time of admission control. In the case of a mesh and random topology (right figure), the calculation mechanism has a insignificant influence on the occurrence of errors, as Q-MEHROM does not use the Bandwidth table often. In addition, the results show much lower values, as more MHs can make a reservation at the same time, which makes the admission control decision less critical.

Simultaneous handoffs. Even if the most accurate information ($N_{\text{ads}} = 1$ or on demand) is used by the ARs, errors can occur when multiple MHs perform handoff at the same time. Therefore, the moments that the handoff mechanisms are triggered, i.e. when the MHs receive a beacon and decide to perform handoff, influence the occurrence of errors. To study the impact of simultaneous handoffs, two situations are considered. The left figure of Fig. 6 presents the results for the situation in which all ARs send beacons at the same times. As a result, all handoffs, also handoffs in different cells, start more or less simultaneously. For the right figure, simultaneous handoffs are avoided by choosing different start times for each AR. In both cases, the Bandwidth table is calculated on demand. The figures show that ARs should not be synchronized, as this implies that more admission control decisions are made at the same time, and the chance that an error occurs during the handoff or switch mechanism is much higher.

6 Conclusions

In this paper we presented an extended admission control mechanism, in which the MH can trigger the reservation mechanism without performing handoff, taking advantage of resources, released by the handoff of other MHs. We also studied the impact inaccurate link state information and simultaneous handoffs on the occurrence of errors during the handoff or switch mechanism.

Simulation results showed that the use of the extended admission control mechanism increases the fraction of time that the MHs receive QoS service. Mechanisms to calculate the Bandwidth table periodically or after a number of link state changes, reduce the accuracy of the information and increase the occurrence of errors. However, even if the Bandwidth table is calculated on demand, errors can be caused by simultaneous handoffs. Therefore, if the handoff is triggered after the reception of a beacon from a new AR, the ARs should not be synchronized. The impact of the extended admission control mechanism and the use of inaccurate information is higher for situations where only a small part of the MHs can receive QoS service at the same time.

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