Influence of the topology on the performance of micromobility protocols

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Abstract—**Micromobility protocols like Cellular IP, Hawaii and Hierarchical Mobile IP (in this paper applied to a single IP domain), are developed to solve problems of handoff latency and control overhead of Mobile IP. Hereby, a tree access network topology is assumed. For reasons of robustness against link failures and load balancing, extra uplinks and mesh links in the topology are desired. This paper makes a classification of several topology types and investigates the influence of these structures on the performance of the protocols. While Cellular IP and Hierarchical Mobile IP do not take advantage of extra links, Hawaii uses the presence of meshes to reduce handoff latency and packet loss. However, this results in the use of suboptimal routes after several handovers.**

Keywords— **micromobility, access network topology, protocol performance**

I. Introduction

Today, wireless networks evolve towards all-IP based infrastructures. Unfortunately, the IP address of a terminal is not only used to identify the end point of a connection, it also indicates the location of the terminal, i.e. the point of attachment to the network. However, as a result of mobility, this point of attachement can frequently change and IP-routing based on the hierarchical addressing structure of an IP address will fail to deliver the packets to the mobile host.

Mobile IP (IPv4 [8], IPv6 [7]) is the most popular routing protocol that supports host mobility. Every time a host moves to another access router, a new (care-of) IP address is required, which results in a handoff latency and control overhead in the core network. Therefore, routing protocols like Cellular IP, Hawaii and Hierarchical Mobile IP are developed. These micromobility protocols support the local movements of a host within one IP domain. As long as the mobile terminal resides in the same domain, the same (care-of) IP address can be used and other mechanisms will realize the change of access router. In this case, Mobile IP is still used to support macromobility, i.e. the movements from one IP domain to another (see also Fig. 1).

Although all those micromobility protocols are designed to work correctly irrespective of the topology of the IP domains, this topology has an important influence on the performance of those routing protocols, which is studied in this paper.

This paper is organized as follows. The following section gives a short overview of Cellular IP, Hawaii and Hierarchical Mobile IP and aims to indicate the differences between these protocols. The next section makes a classification of the possible topologies of an IP domain. The influence of the topology on the performance of the micromobility protocols is subsequently studied: simulation results are presented and explained and conclusions are made.

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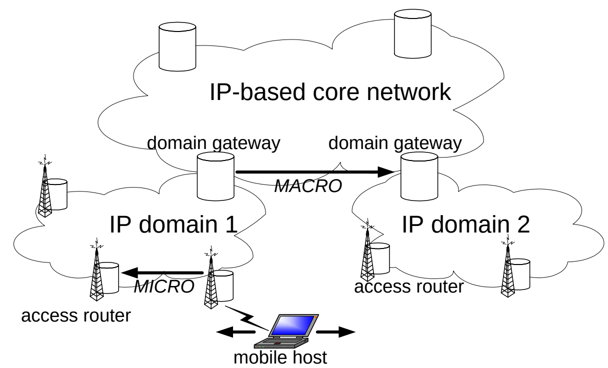

Fig. 1. General topology of an IP-based network.

II. Micromobility routing protocols

This section aims to give a short overview of the three micromobility routing protocols studied, namely Cellular IP [1] [2], Hawaii [9] [10] and Hierarchical Mobile IP [6]. It is not our intention to explain the detailed working, but to emphasize the differences between these protocols, concerning the domain gateway, the encapsulation of data packets in the access network, the way of routing, the mobile host and the handover process.

A. Cellular IP

Gateway The domain gateway functions as foreign agent. When a mobile host resides in a foreign IP domain, it uses an IP address of the gateway as care-of address. As a result, the home agent of the mobile host intercepts the packets destined to the mobile host and tunnels this data traffic to the gateway. This gateway then decapsulates the received packets.

Encapsulation The domain gateway does not reencapsulate the packets. The use of host routes in the IP domain, based on the mobile hosts home address, supports the delivery of the packets.

Routing The nodes of the access network run Cellular IP instead of standard IP routing.

Mobile host The mobile host is also Cellular IP enabled.
Handover During handoff, the cross-over node is defined as the node closest to the new access router, that is part of the path between the gateway and the old access router and the path between the gateway and the new access router. Page updates and route updates are directed towards the gateway via the new access router, updating the routing table of every node on this path. As soon as these updates reach the cross-over node, the host routes in the access network are updated. For the simulations of section IV, hard handoff is used.

B. Hawaii

Gateway The domain gateway is called the domain root router. A mobile host that moves to a foreign IP domain, uses a co-located care-of address, i.e. a local IP address, obtained from the domain through some external means (e.g. DHCP [5]). Packets for the mobile host have to pass the domain gateway, which forms the connection between the foreign domain and the core network. However, this gateway will only forward the packets based on their care-of address and will not decapsulate or reencapsulate any packets.
Encapsulation The care-of address is used by the home agent to tunnel the packets directly to the mobile host. The decapsulation of the packets is executed by the mobile terminal itself.
Routing The nodes of an IP domain run Hawaii in addition to standard IP routing.
Mobile host The use of Hawaii is transparent to the mobile terminal. The mobile host uses Mobile IP, a macromobility routing protocol.
Handover In case of Hawaii (for the simulations in section IV, the Multiple Stream Forwarding mechanism is used), the cross-over node is the node closest to the new access router that lies at the intersection of the path between the gateway and the old access router, and the shortest path between the new and old access router. In contrast to Cellular IP, Hawaii path setup messages are sent via the new access router to the old one. And then from the old base station back to the new one, updating the forwarding table of every node on this path. As soon as the path setup message reaches the cross-over node on its way to the old access router, new data packets will be sent correctly to the mobile terminal. Note that for the same topology, Cellular IP and Hawaii can have different cross-over nodes.

C. Hierarchical Mobile IP

Gateway The domain gateway is called the gateway foreign agent (GFA). When entering a new foreign domain, the mobile terminal has to perform a home registration: a publicly routable address of the domain gateway is registered at the home agent as the care-of address of the mobile host. So, the home agent tunnels the packets for the mobile host to the gateway. The domain gateway keeps a visistor list of all the mobile nodes currently registered with it.
Encapsulation The proposed regional registration protocol (see [6]) supports one level of hierarchy. Beneath a GFA, there are one or more regional foreign agents (RFA), located at the access routers. The domain gateway will decapsulate, reencapsulate and reroute the packets to the correct access router, based on a local care-of address (the address of the current access router). This access router, in its turn, decapsulates and delivers the packets to the mobile host.
Routing In an IP domain, the routers that have not the function of a GFA or a RFA, run standard IP routing.
Mobile host The mobile node is aware of the possibility of regional registration. The node must be able to make a distinction between home registrations and regional registrations.
Handover When moving within the same IP domain, the change of RFA must be noticed to the GFA. In this case, there is no real cross-over node for handovers: regional registration requests are sent via the new access router towards the gateway and have to reach the GFA in order to realize an effective change of routes.

III. Classification of wired access network topologies

In order to evaluate the influence of the wired access topology, it is necessary to make a classification of possible topologies. To this end, every node of the access network is characterized by a number d, indicating the minimum number of hops needed to reach the domain gateway. Then, an uplink of a node with a d-number with value k is defined as a link from this node to another one with d-value $(k - 1)$. A downlink of a node with a d-number with value k ends in a node with d-value $(k + 1)$. Finally, links between nodes with the same d-value are called mesh links with mesh-level d. An example is given in Fig. 2.

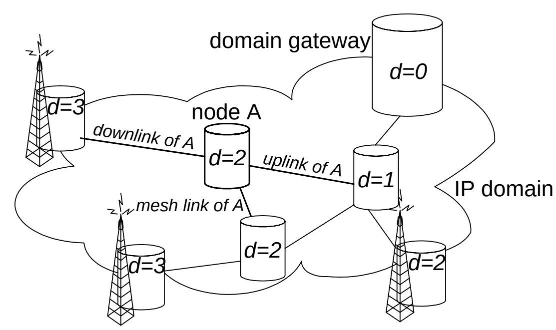

Fig. 2. Illustration of the different link types of node A in an IP domain.

These definitions allow the following classification of possible topologies:
Tree The tree topology is considered as the basic type, because most micromobility protocols assume that the nodes and links of an IP domain form a tree topology, connected to the core network by a single gateway. Every node of the tree has exact one uplink and some downlinks. This topology has no mesh links.
Mesh A mesh topology is defined as a pure tree topology with additional mesh links.

Random The term random topology is used to indicate a mesh topology with additional uplinks. This means that one or more nodes of the topology have more than one uplink, while the other nodes have exact one uplink.

The following table gives a summary of the different topology structures and the corresponding per node values for the different link types.

topology	uplinks	downlinks	mesh links
tree	1	$\geqslant 0$	0
mesh	1	$\geqslant 0$	$\geqslant 0$
random	$\geqslant 1$	$\geqslant 0$	$\geqslant 0$

IV. Simulations

The simulations are performed with the network simulator ns-2 [11] and for the implementation of the mentioned micromobility protocols, the Columbia IP Micromobility Software which contains micromobility extensions for ns-2 version 2.1b6, is utilized [4]. The following parameters are used for the simulations:

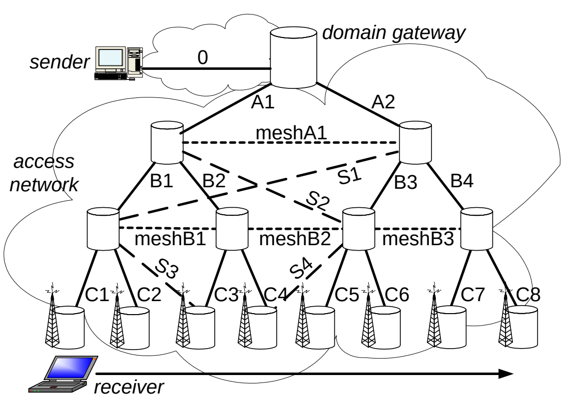

Fig. 3. The tree, mesh and random topologies that are used in the simulations.

Topology Simulations are performed for an IP domain with a single gateway and a tree, mesh or random topology (Fig. 3). The mesh topology consists of the tree stucture with the indicated additional mesh links, while the random topology is formed by the mesh one with extra uplinks for some nodes in the IP domain. Only for the simulations of subsection IV-B, more simple topologies are used.

Links The wired links of the access network have a fixed delay of 2 ms and a capacity of 10 Mbit/s. Except for the results presented in subsection IV-A, where this delay is the variable parameter for the simulations.

Access Routers The distance between two adjacent access routers is 200 m, with a cell overlap of 30 m. All the base stations are placed on a straight line.

Traffic A CBR data traffic pattern is used, with a packet inter arrival time of 10 ms and a packet size of 210 byte. This results in 0.168 Mbit/s. Therefore, the routing of the traffic is not limited by the capacity of the links. Between the sender, a fixed host in the core network directly connected to the gateway, and the receiver, the mobile terminal, an UDP connection is set up.

Scenario During one simulation, the receiver travels from the most left access router of Fig. 3 to the most right one, with a speed of 20 m/s. During such a simulation, it has to perform 7 handovers.

A. Comparison of the different protocols

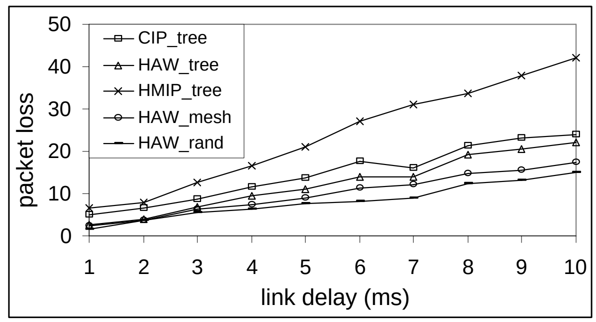

Fig. 4. Average number of packet loss during 1 simulation (7 handovers) as a function of the link delay.

In Fig. 4, the results, which are average values calculated for a set of 500 independent simulations, for CIP-mesh and CIP-rand coincide with these for CIP-tree and are therefore not shown. The same applies for the results of HMIP-mesh, HMIP-rand and HMIP-tree.

Cellular IP does not use the meshes or extra uplinks of the topology, due to the fact that the route updates are routed to the gateway via the links of the tree structure in the three situations. So the packet loss during handoff and the used paths are the same for the three topologies.

In Hierarchical Mobile IP, the presence of extra uplinks may result in multiple routes with the same hop count between the new access router and the domain gateway. This means that the time needed by a regional registration request to reach the gateway, is independent of the chosen path and results in the same packet loss during handoff. In this case, the protocol will pick arbitrarily one of these paths. The mesh links are not used by HMIP. The packet loss is also much higher for HMIP compared to CIP and Hawaii, because the routes are only updated when the regional registration requests reach the gateway. In case of CIP or Hawaii, the distance to the cross-over node instead of the distance to the gateway determines the amount of packet loss.

In contrast to the other protocols, Hawaii sends path setup messages from the new access router to the old one and not towards the gateway. This protocol will use the extra meshes and uplinks if those links help to realize a shorter path between the new and old base station.

As the link delay increases, the differences between the packet losses of the three protocols become more important. The mechanisms of Cellular IP and especially Hawaii result in a much lower packet loss compared to Hierarchical Mobile IP. Simulations that measure the handoff delay as a function of the link delay, give analogous results.

B. Cross-over distance and meshes

Cellular IP, Hawaii and Hierarchical Mobile IP behave differently in terms of distance to the cross-over node and the presence of meshes, as illustrated in Fig. 5 for some very simple topologies. The IP domain has only two access routers and during one simulation, the mobile host travels from the left to the right one, performing one handover. The figures show the average packet losses during one handover, calculated for a set of 200 simulations.

The cross-over distance is defined as the number of hops between the new access router and the cross-over node. For the definition of the cross-over node, see subsection II-A and II-B. Remark that the definition is different for CIP and Hawaii. In what follows, the term route update is used to indicate the route updates of CIP, the path setup messages of Hawaii and the regional registration messages of HMIP.

In diagram *a*, the route updates of all the three protocols have to reach the domain gateway to update the routes after an handoff, so the packet loss increases with the distance to the gateway.

However, when the cross-over node for CIP and Hawaii is not longer the gateway node, the cross-over distance becomes the determining factor for the packet loss, in contrast to the gateway distance for HMIP, shown in diagram *b*.

That the cross-over nodes can be different for CIP and Hawaii is indicated in figure *c*: Hawaii uses meshes to find a shorter route to the old base station, while CIP still uses the gateway as cross-over node.

These results show that the packet loss for CIP and Hawaii can be much lower than for HMIP, due to the fact that the gateway distance is often much higher than the cross-over distance. Hawaii is the only protocol that takes advantage of the mesh links to reduce the packet loss drastically.

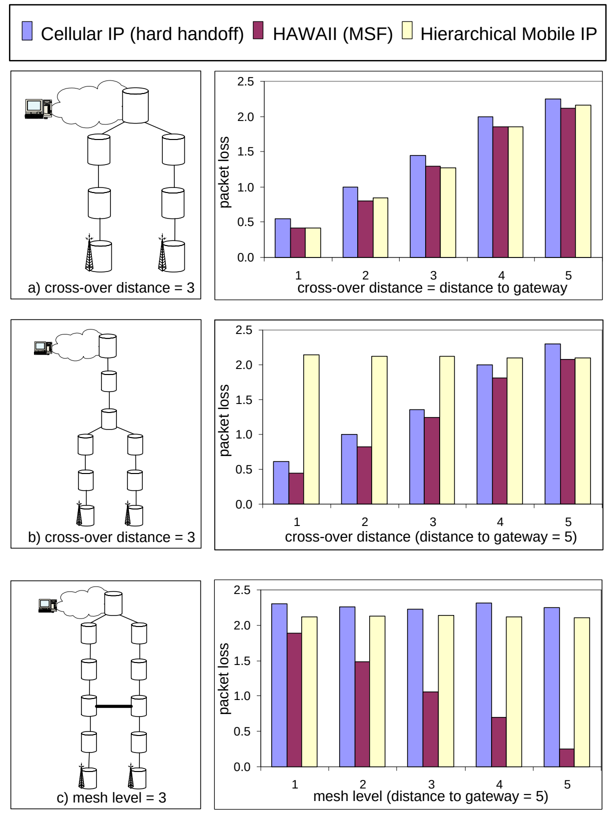

Fig. 5. Influence of the cross-over distance and the presence of mesh links on the average number of lost packets of 1 handover.

C. Load balancing

The simulation results shown in Fig. 6 and Fig. 7 are obtained for a random topology, consisting of a tree topology with 4 mesh links and 4 additional uplinks. For the exact topology and the significance of the used link names, we refer to Fig. 3. The results are average values, calculated for a set of 100 simulations. The figures represent the average number of control and data packets that pass on the different links during 1 simulation. For example, *B2down* monitors the number of packets routed from the node with *d*-value 1 to the node with *d*-value 2, while *B2up* counts the packets routed in the opposite direction. The same explanation is valid for *S2down* and *S2up*. For a mesh link like *meshA1*, *meshA1r* monitors packets travelling from the left to the right router with *d*-value 1 and *meshA1l* is used for packets routed from the right to the left router.

Fig. 6 gives the results for the control load. Cellular IP uses only the uplinks of the tree structure for its control traffic: page updates and route updates that are sent by the mobile terminal, are directed towards the domain gateway. There are much more control packets on the links than the number of handovers, due to the use of a registration interval of 0.5 s to update the soft-state routes. The registration requests by Hierarchical Mobile IP are also directed to the gateway, but every request is answered by a registration reply, resulting in the same amount of traffic on the uplinks and corresponding downlinks. Hawaii sends path setup messages from the new to the old access router and a reply is sent from the old to the new access router. This protocol also uses the presence of mesh links to find a shorter route between these access routers, resulting in control traffic on the mesh links and the links closest to the access routers. Hawaii uses hard-state routes, so no periodical route updates are needed and the amount of control traffic on the links is much lower in comparison to the two other protocols.

As a connection is set up between a fixed host in the core network and the mobile host which is the receiver, all data packets have to be routed from the core network, via the domain gateway and the access network, towards the mobile terminal.

Fig. 7 shows that Cellular IP only uses the downlinks of the tree structure. In addition, links at the same distance of the domain gateway are equally loaded, resulting in a good load balancing for the links of the tree. The link load increases with decreasing distance to the gateway. Hawaii shows completely different results: the number of data packets monitored on *A1down* equals the number of

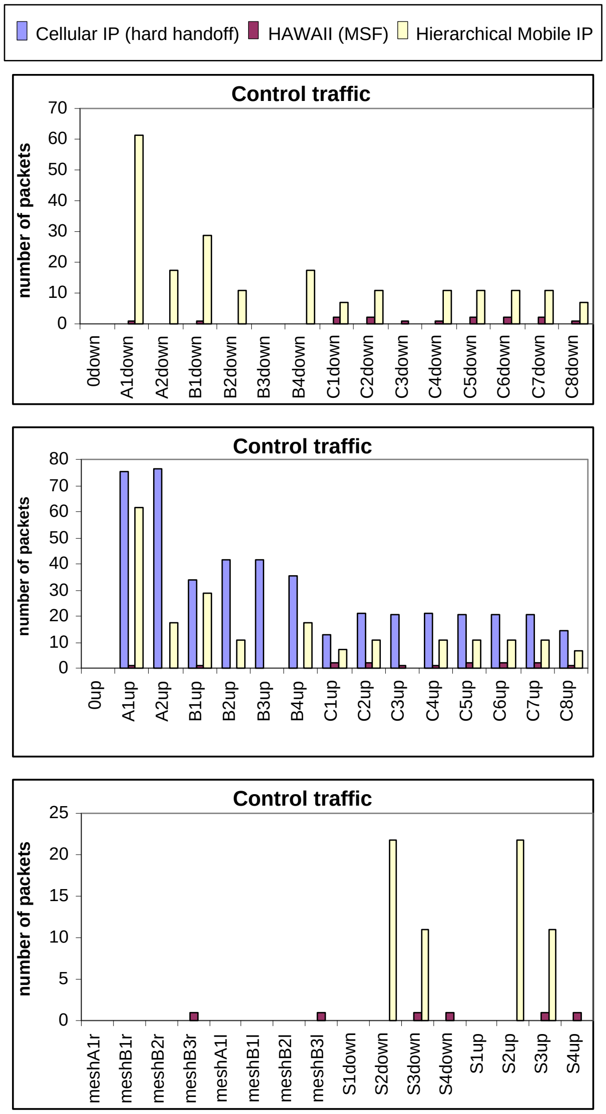

Fig. 6. Average number of control packets on the links of the access network during 1 simulation.

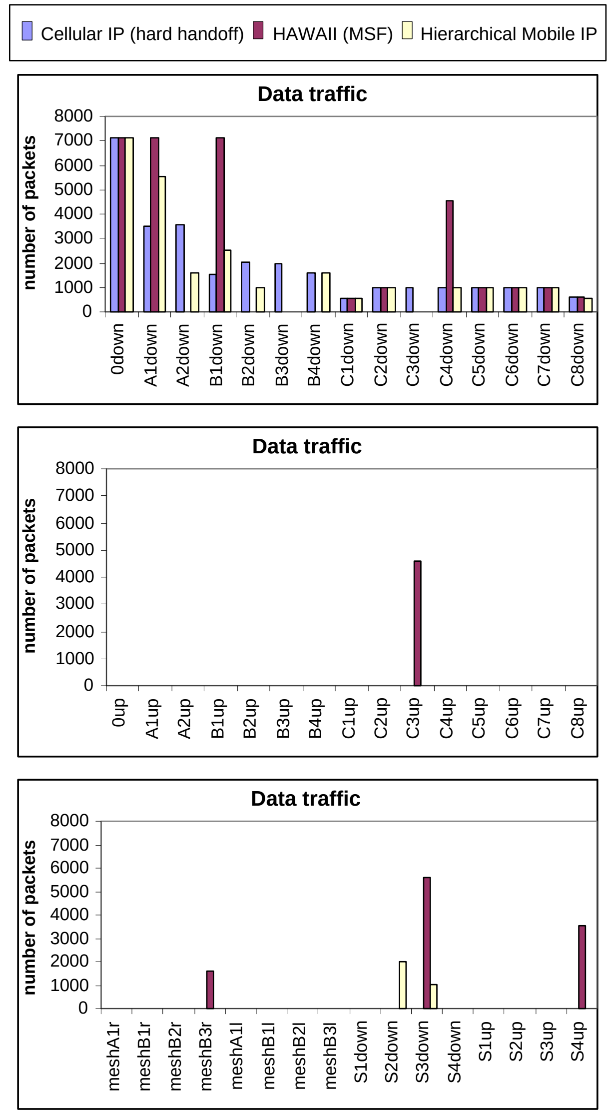

Fig. 7. Average number of data packets on the links of the access network during 1 simulation.

packets on *0down*, while *A2down* is not used during the entire simulation. This results in a bad load balancing for Hawaii. Also other links than the downlinks of the tree topology are used, namely *S3down*, *C3up*, *S4up* and *meshB3r*. The results for Hierarchical Mobile IP are similar to those of Cellular IP. The additional links *S2* and *S3* are used to route the data traffic, resulting in a less good load balancing for the tree links. The mesh links are not used.

The different results for the three protocols can be explained by the differences between the handover mechanisms. These differences have important implications for the routing within the access network. The handover mechanism in Hawaii will result in the use of suboptimal routes after several handovers. When the mobile host, initiating its connection while being in the area of the most left access router, arrives in the area of the most right access router, the data packets are routed via the links *A1-B1-S3-C3-C4-S4-meshB3-C8*. This path counts 8 hops, while the shortest path between an access router and the domain gateway has only 3 hops. In addition, the paths depend on the moving pattern of the mobile host and the location of the previous visited access points, which is an undesirable characteristic.

V. Conclusion

This paper presented several topology types for the access network and investigated the influence of this classification on the performance of micromobility protocols. The studied protocols are Cellular IP, Hawaii and Hierarchical Mobile IP. Hereby, the cross-over distance is a very important parameter during handoff for Cellular IP and Hawaii, while the distance to the gateway is important for the amount of handover packet loss by Hierarchical Mobile IP. In contrast to Cellular IP and Hierarchical Mobile IP, Hawaii takes advantage of extra meshes and links to reduce the handoff latency and packet loss. The use of Hawaii sounds thus very promising, but has also some serious disadvantages. The routing mechanism of Hawaii results in the use of suboptimal routes after several handovers, which gives a bad load balancing in the access network. In addition, the used paths depend on the mobility pattern of the mobile host and the location of the access router where the connection was set up. This is expected to cause important problems in case of multiple mobile terminals and traffic patterns.

VI. Acknowledgments

Part of this research is funded by the Federal Office for Scientific, Technical and Cultural Affairs (OSTC, Belgium) through the IUAP (phase V) Contract No. P5, and by the Flemish IWT through the GBOU Contract 20152 "End-to-end QoS in an IP Based Mobile Network".

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