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Publish-Subscribe-Based Control Mechanism for Scheduling Integration in Mobile IPv6

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***Abstract*—Currently discussed handover protocols do not provide the means to allow holistic flow handover scheduling. However, flow scheduling leads to a performance boost resulting from efficient parallel network use and a match of network characteristics to application requirements. Mobile IPv6 with flow binding extension and route optimization fulfills most requirements. However, control data is redundantly transmitted to every communication partner. This forbids coordination of parallel data flows and, therefore, scheduling.**

We introduce a new publish-subscribe-based control data routing which makes Mobile IPv6 compatible with centralized flow scheduling and furthermore reduces overhead via the wireless channels. The result offloads computationally intensive tasks of scheduling to servers in the Internet and moves handover control to the same. The resulting handover protocol is an enabler for client-centric scheduling and paves the way towards this promising topic.

I. Introduction

Heterogeneous networks integrate different technologies with individual communication characteristics, usually operated by independent providers. Applications, moreover, have individual communication requirements. Hence, particular networks are more suited to transfer data of certain applications than others. Network choice can be matched to individual application requirements using scheduled flow bindings.

To allow matching of application data requirements to network characteristics, application flows must be individually controllable. Conventional handover schemes either do not allow to control individual flows at all or create a control traffic storm via the air interface on changes in network access.

However, handover mechanisms alone can only act as a tool for a control algorithm. It is the control that makes the difference between good and bad perceived quality in mobility handling. Features of handover and its control have to be developed hand in hand with a scheduling concept.

We therefore present a network-controlled and client-triggered handover approach based on Mobile IPv6 (MIPv6). It offers a novel publish-subscribe-based structure to control handovers for individual application flows. Finally, it integrates scheduling on external servers and is, therefore, independent from network providers. This allows for client-centric optimization of application data transmission using heterogeneous multiple-provider networks in parallel.

In section II and III we discuss important handover-related features and give an overview of an automotive scenario applied to choose evaluation boundary conditions. In section IV, we explain what features of MIPv6 are reused for our protocol. Subsequently, our publish-subscribe-based control data routing concept is explained and evaluated in section V and VI.

II. Related Work

Most performance parameters of handover protocols are only influenced by few design decisions. We extract important protocol design decisions and show how they influence the resulting characteristics.

A. Direct versus Proxy Schemes

Direct handover schemes set up a straight communication between a mobile node and its communication partner. Control traffic is exchanged directly. They are usually characterized by high throughput and low latency [2][6]. However, direct handover schemes force servers to adapt their communication stack. This is realizable only for a subset of servers in the Internet. Mobility feature use therefore is very restricted. Prominent examples for this category of direct handover schemes are Multipath TCP (MPTCP) and Host Identity Protocol (HIP).

Proxy schemes in comparison use a relay node to hide protocol stack changes from legacy servers. They provide transparent communication which results in full compatibility. In comparison to direct handover schemes, their communication performance is worse. The relay node introduces an additional mandatory hop and therefore latency. The relay node also has to process each network packet which flows through it. This requires high performance hardware to prevent throughput degradation as a result of overload.

Finally, there exist handover schemes providing transparent communication for legacy servers as well as for mobile nodes. In this case, access routers act like a second relay node. This leads to completely network-managed handovers and guarantees full compatibility. Since clients are not involved in handovers at all, this is especially beneficial for low-performance and low-power mobile nodes [4]. Prominent protocols following this concept are Proxy MIPv6 and LISP.

B. Layer of Mobility

Transport layer covers flow control. This has high impact on link performance because changes in network access through handover imply instant changes of QoS parameters. As a result, flow control has to adapt as well. Consequently, handover protocols should be tightly coupled with flow control in order to use networks efficiently. Hence, transport layer is well suited for handover mechanisms. Famous candidates for transport layer mobility protocols are Stream Control Transmission Protocol and MPTCP. The latter supports reliable transfer only. If MPTCP is used, additional logic is required to support handovers for unreliable data transport.

Applying handover mechanisms at Network Layer solves problems of multiple protocol dependent mechanisms since it is used for all Internet traffic. Consequently, a mechanism in this layer covers all communication. Prominent examples are MIPv6 and HIP. Nevertheless, applying handover at network layer separates handover from flow control.

C. Separation of Data and Control

Handover control traffic can be inserted into data packets using protocol options or additional headers. This implies minimal overhead and ideal synchronization of data and control traffic. However, changes in default protocol stack often lead to packet drop at middle boxes. Examples are MPTCP and HIP. For full compatibility, changes at data packets must be transparent for the network. Control traffic must then be sent in dedicated packets. This is used in most MIPv6 derivatives.

III. Prerequisites

Instead of focusing on the handover alone, we couple it with flow scheduling. Accordingly, we consider the handover mechanism as a tool for execution of elaborated schedules. Without scheduling mechanisms, only trivial scenarios can reach good performance; and even those use routing rules that can be seen as a basic kind of scheduler. Moreover, scheduling triggers handovers and should, therefore, be located nearby handover control to reduce control traffic. Hence, our goal is the tight integration of a generic scheduling component into the handover concept.

A. Automotive Evaluation Scenario

The automotive scenario is characterized by networks of different providers including small cells and clients moving with high speed. This leads to potentially *frequent handovers* [5]. Consequently, potential handover latency and control overhead problems are amplified in this scenario.

Furthermore, clients must be able to use networks of different network providers in parallel. Thus, mechanisms must work independently from network operators.

IV. Protocol Design and Reusable Features

To develop the design of our protocol, we derive required features and choose Mobile IPv6 as base protocol.

A. Requirement-Based Design Implications

Compatibility is a principal requirement of our concept. This firstly refers to legacy servers as communication partners. Servers which do not integrate our protocol should still be reachable and profit from the mobility protocol. In contrast, vehicle Internet connectivity is still not introduced to the mass market and mandatory changes in their communication stack are possible. Moreover, transparency for the client is not desired because we want to influence routing according to individual client requirements. We decided to use a *single proxy server* which provides transparency to legacy servers only. To stay independent from network providers, the proxy server is located in the Internet.

Yet, proxy nodes add an additional mandatory hop into routes. This delays packet delivery and produces load at the proxy. Extensive use may exhaust the proxy's Internet connection or its computational resources which consequently leads to reduced performance. As a competitive advantage, service providers might be interested in high-performance transmission to mobile nodes. An adaption of their communication stack to support our protocol enables direct communication with the mobile node. We, therefore, integrate *route optimization* as an elementary but optional part which reduces latency of data transmission significantly and increases throughput.

The handover protocol serves as a tool for scheduling of application traffic. The system benefits most from scheduling if it handles all application traffic. Consequently, the handover protocol must act below transport layer to cover all Internet connections. To prevent packet drop at middle boxes, packets must be transparent. This forbids to use additional headers. We firstly decided to use *IP layer* and tunneling to enable handover and secondly to separate handover control traffic from data traffic.

The handover protocol which matches the requirements best is MIPv6 with selected extensions explained in the following.

B. Reused Mobile IPv6 features

1) Multi-homing with Flow Binding: We use Multiple Care-of Address Registration (RFC 5648), which basically enables multi-homing. It defines a table of assigned IP addresses and attaches a Binding Identifier to each entry. We furthermore use Flow Bindings (RFC 6089) which enable identification and control of individual flows. It allows to use networks of multiple independent providers in parallel. This is a basic requirement for flow scheduling.

2) Route Optimization Extension: Direct routing between mobile node and its communication partner is more efficient than routing via a proxy. If the communication partner is capable of MIPv6, a direct connection can be established using route optimization (RFC4866). The mobile node (MN) requests route optimization at the communication partner, called correspondent node (CN) in the following.

MIPv6 with the selected features experiences problems, especially in the automotive scenario with scheduled and frequent handovers.

C. Weaknesses of default Mobile IPv6 Route Optimization

When default MIPv6 route optimization is applied, the mobile node exchanges control information directly with each correspondent node, as shown in figure 1b.

The Home Agent (HA) proxy node is not aware of these additional flows. However, this is an essential input for future scheduling.

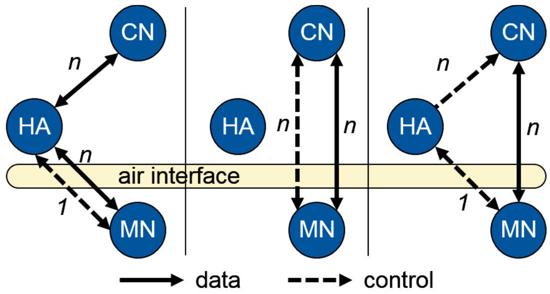

Fig. 1. a) MIPv6 default routing (left) b) MIPv6 default route optimization (center) c) proposed route optimization (right)

Furthermore, when connections to multiple CNs exist, redundant control information is transmitted to each of these servers separately. This behavior strains resources from the wireless channel. Yet, parallel connections to multiple CNs using default routing optimization results in large overhead, especially in the vehicle scenario with frequent handovers. Moreover, the resulting knowledge distribution allows scheduling only at the performance restricted MN.

Hence, we propose another control scheme for route optimization in order to move knowledge to the HA and to reduce overhead linearly by the number of connections.

V. Contributions

A. Novel Control Scheme During Route Optimization

To solve these problems, we propose to use the HA as a publish-subscribe broker for control information. MIPv6 Control messages are sent only once directly between HA and MN. CNs subscribe at the HA for updates from the MN, like shown in Fig. 1c. Consequently, the overhead of control traffic over the wireless channels gets independent from the number of CNs. Each control message has to be transmitted via the air only once: to the HA. This reduces control traffic via the wireless channel significantly.

Moreover, all control data passes the HA and centralizes control. This is a critical enabler for scheduling in future systems. Scheduling and mobility management can cooperate at the HA without creating further control traffic.

However, this publish-subscribe based management introduces an additional mandatory hop into control traffic routes and causes additional latency. In order to make handover latency neglactable, scheduling is supposed to trigger handovers proactively. The HA controls the routing of client traffic and executes strategic and proactive handovers according to calculated schedules.

B. Protocol detail

Initialization of the publish subscribe system requires new messages. We use the sequence diagram of Fig. 2 to explain the steps of our protocol extension and refer to the specific messages using numbers in brackets.

The MN registers with a request for a Home Address (HoA) at a selected HA (1). After receiving a client-specific HoA (2), MN and HA regularly exchange Binding Updates (BU) containing new IP addresses and Flow Binding Updates (FBU) containing routing rules (3). The initialization is finished according to existing MIPv6 specifications.

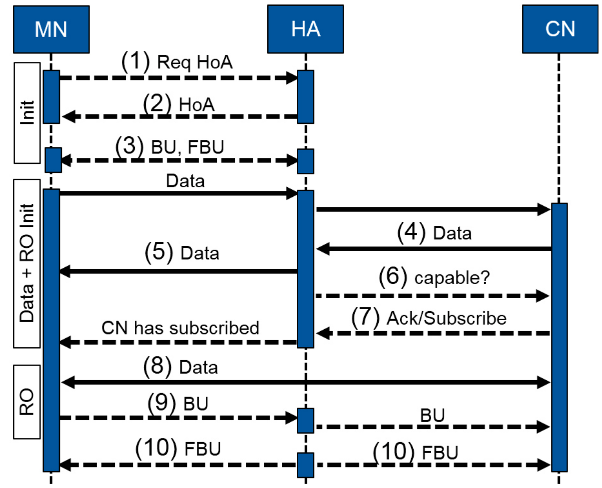

Fig. 2. Sequence diagram of proposed route optimization

As soon as the HA receives first data from the CN (4), the HA requests the CN for route optimization (6). This new request contains the required information to establish route optimization. If the CN is not capable to do route optimization, it will ignore the request and use default MIPv6.

If the CN is capable, it acknowledges the request. This acknowledgment contains a subscription (7) to relevant BUs and FBUs and initiates route optimization. The HA informs the MN about the successful route optimization initialization with the CN.

In the following, the route is optimized according to our concept. Data takes the direct route between MN and CN (8). BUs from the MN are published at the HA (9) which forwards them to subscribers. The HA uses scheduling results to create routing rules in form of FBUs and forwards them to the subscribers (10) including the MN.

This results in a mixed system using both of the two scenarios of Fig. 2a without route optimization and 2c with route optimization.

C. Scheduling and Home Agent Role

Scheduling is a computationally intensive task and requires environmental data like future network availability. Gathering of such data causes additional traffic which strains throughput. To release wireless resources, we place scheduling on the HA. The HA can use its cable link to access this information.

Furthermore, computational power is a restricted resource at mobile nodes. This relates to additional energy consumption as well as hardware limits. Consequently, both requirements for scheduling integration – throughput and computational power – are satisfied more easily by Internet servers.

To combine HA functions and scheduling, we move both functions to an independent server in the Internet. This fusion eliminates further control traffic for coordination of HA functions and scheduling and offloads computationally intensive tasks to powerful servers.

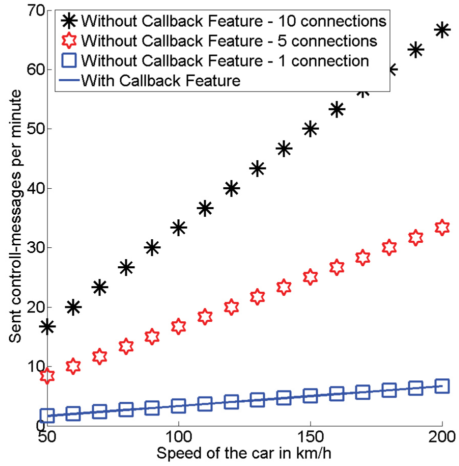

Fig. 3. Callback-Feature scenario with variation in speed of the driving car/mobile node. Range of the road side units for all cases: 1000 m

VI. Evaluation

To show the advantages of our protocol, we analyze savings of control messages via the air interface. The most important aim, the integration of scheduling, is achieved by design.

The HA acts as a publish-subscribe broker for control information during route optimization. Control information from the MN has to be sent only to the HA which distributes information to subscribers. This callback to subscribed CNs reduces the control overhead via the air interface in comparison to default route optimization with multiple connections.

We denote the number of control messages via the wireless channels by χ. The initialization overhead in both approaches is two messages, a request and an acknowledgment, and is denoted by χ_{init}. The signaling overhead for a single connection handover χ_{ho} is equal for both approaches and measures two messages. We moreover introduce the variables n for the number of parallel connections and f_{ho} for the handover frequency.

The overhead over the air interface of default MIPv6 route optimization is defined in Equation 1. For our publish-subscribe based route optimization, it is defined in Equation 2. Both consist of initialization messages χ_{init} per connection n and control messages for handover χ_{ho} over the complete connection duration t in a certain frequency f_{ho} which depends on the scenario; especially on the mobility model and used cell sizes. To calculate the gain G independent from the connection duration t, we derive the terms and calculate the quotient in Equation 3. In comparison to default MIPv6 route optimization, the overhead for handovers of our mechanism is lower by the number of open connections n.

$$\chi_{mip}(t) = n(\chi_{init} + f_{ho}\ \chi_{ho}\ t) \tag{1}$$

$$\chi_{ps}(t) = n\ \chi_{init} + f_{ho}\ \chi_{ho}\ t \tag{2}$$

$$G = \frac{\dot{\chi}_{mip}(t)}{\dot{\chi}_{ps}(t)} = \frac{n\ f_{ho}\ \chi_{ho}}{f_{ho}\ \chi_{ho}} = n \tag{3}$$

We apply our route optimization and default MIPv6 route optimization in the automotive scenario and compare control overhead per vehicle. For vehicular 802.11p networks, ranges in urban environment vary between 100 and 1000 m [3]. For our analysis we assume the worst case range of 1000 m and a distance of 2000 m along a straight road. We furthermore vary vehicle speed from 50 km/h to 200 km/h to calculate the handover frequency f_{ho}.

We vary the number of parallel connections n from one to ten. In a real scenario, the number will be tentatively higher because mobile applications prefer to keep connections open for higher responsiveness [1].

Additionally, we normalize values to messages per minute to give a better overview on the number of regular control messages. With a speed of about 150 km/h, five control messages must be sent for each connection. For default route optimization, this results in 50 overhead messages per minute for ten ($n = 10$) connections. With our route optimization only five messages must be sent. This is the same for any number of open connections. Neglecting initialization, the publish-subscribe callback feature reduces the overhead by factor n.

VII. Conclusion

To use parallel connections in heterogeneous multi-provider networks efficiently, independent flows must be controlled in an intelligent way. We therefore develop a protocol based on Mobile IPv6 with flow binding and route optimization to integrate a generic scheduling component at the home agent.

Hence, we redefine Home Agent as a publish-subscribe broker for control messages during route optimization. This firstly fuses handover control with scheduling at the Home Agent and secondly reduces overhead for connection management significantly. The resulting protocol integrates scheduling at the Home Agent and allows for further investigation of scheduling algorithms for more efficient parallel use of heterogeneous networks.

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