Mechanisms for QoS Signaling in a Mobile Internet Environment

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***Abstract* -- End-to-end signaling of Quality of Service (QoS) requests provides an interface for end systems to specify certain performance characteristics for transmitting data flows across communication networks. If routing and packet forwarding is enhanced by capabilities to support mobile end systems, this imposes new challenges for intermediate nodes to handle end-to-end signaling. In this paper, we investigate these challenges and identify a crucial set of abstract functions to augment certain nodes along the data path, in order to deliver an end-to-end signaling service for mobile end systems. Opposite to previous approaches, we do not incorporate such enhancements into basic building blocks of the system, but instead we present the design of two additional independent components to carry out the new functionality. One component is given by an extension to QoS signaling, which allows to handle service requests in advance. The second component, the Third-Party Signaling Protocol (TPSP), provides a generic set of primitives to request enhanced signaling functionality at intermediate nodes.**

I. Introduction

The current service model of the Internet is to deliver best-effort connectivity to stationary end systems. This service model is currently being enhanced in two directions. One extension is given by approaches to offer predictable and stable transmission performance, termed *Quality of Service* (QoS). The second enhancement is to enable seamless end-to-end transmission to and from mobile end systems. In this paper, we investigate the relationship between both enhancements and identify the crucial basic mechanisms that need to be added, in order to accommodate QoS requests from mobile end systems.

A *mobile node* is characterized by the fact that it changes its topological network access point over time and consequently, the routing path to other so called *correspondent nodes*. There are four fundamental mechanisms to enable connectivity in this case. One mechanism is termed *triangle routing* and describes the fact that a *home agent* intercepts packets sent to a mobile node's regular network address. These packets are then forwarded to the mobile node by using its temporary, topologically currently valid network address. The other mechanism is called *route optimization* or *binding update* and denotes the ability of a correspondent node to cope with the change of a mobile node's network address by directly forwarding application-generated packets to the temporary network address. Therefore, no home agent is needed for data delivery. Similar alternatives, i.e. direct versus indirect delivery, exists for the reverse direction of delivering packets from a mobile node to a correspondent node, as well. As part of the IETF standardization activities, extensions for mobile connectivity are defined for IPv4 in [1], [2] and for IPv6 in [3], respectively. These proposals employ the aforementioned mechanisms. In case of IPv4, an additional, dedicated entity is defined to support and control a mobile node in a foreign access network. This entity is called *foreign agent*. In this case, two additional orthogonal mechanisms can be distinguished: the mobile node obtains the topological correct subnet address from a foreign agent, which is called *care-of address*; or it obtains a *co-located care-of address* by using services like DHCP [4], DHCPv6 [5], or neighborhood discovery [6] with address autoconfiguration [7].

The proposals to enable QoS in the Internet can be distinguished by whether the QoS model relies on adequate capacity provisioning in combination with rather static *service level agreements*, e.g. based on *Differentiated Services* [8]. Alternative proposals include the explicit signaling of QoS requirements along the end-to-end data path, e.g. the *Integrated Services* architecture [9] in combination with the *Resource reSerVation Protocol* (RSVP) [10]. Relying on coarse-grained mechanisms and capacity provisioning might conflict with the objective of efficient resource utilization in certain scenarios [11], [12] and [13], depending on the level of service that is going to be provided. Basic uncertainties about the actual usage and traffic patterns give rise to this conflict, which becomes even more apparent, when taking into account the mobility of end systems. We therefore focus on signaling-based QoS provisioning in this work.

Particularly, we investigate the issue of providing continuous signaling-based QoS to mobile end systems. While others have proposed ad-hoc extensions to existing mechanisms (see Section V for details), we approach the problem in a more fundamental fashion. First, we formulate a simple model to describe mobility. Based on this model, we identify two basic mechanisms, which are required to enable continuous QoS-based transmission to and from a mobile end system. Such a model is both useful and necessary to avoid confusion about which functionality should be implemented as basic *mechanism* and which is part of a *strategy*. Thereby, we can show that all other proposals are encompassed by this model. We then specify and discuss the respective technology to implement these mechanisms. In particular, this technology is given by extending RSVP to accommodate advance service requests and a new protocol, called *Third-Party Signaling Protocol*

(TPSP). A mobile node will regularly encounter a situation, in which it is unable to signal its future service requests, because it is topologically not at the right location to do so. TPSP allows to signal such indirect requests to *third party agents*, which then carry out the actual signaling on behalf of a mobile node. We envision that a dedicated protocol can be used for other purposes, as well, for example as described in [14].

The remainder of the paper is organized as follows. In Section II, we present our general model, which is the basis of TPSP. In Section III, the realization of the QoS mechanisms are described. An example how to use these mechanisms is given in Section IV. The related work is discussed in Section V. The paper is wrapped up by a summary and an outlook to future work in Section VI.

II. General Mobile QoS Model

In this section, we introduce our general mobile QoS model, which is the basis of our approach to offer end-to-end QoS signaling to a mobile end system.

Strategy	
Connectivity mechanisms IP and • triangle routing • binding update • care-of • co-located	*QoS mechanisms* RSVP and • in advance • third party

FIGURE 1 Mechanisms and Strategy Fields

As shown Figure 1, the basic *mechanisms* to provide connectivity and QoS to a mobile end system have to be complemented by appropriate *strategies*, which give the rules how to apply them and compose continuous service invocations out of them. For example, even in a traditional, i.e. "non-QoS", connectivity scenario, it has to be decided under what circumstances the mechanism of binding update is used in favor of triangle routing. When considering QoS as an additional domain, the range of possible strategy decisions becomes even larger. In order to describe the full gamut of such strategies, we first formulate a simple mobility model and then continue by refining the model in terms of a strategy.

A. Simple Mobility Model

The movement of a mobile end system can be described as a relation of triples specifying the time period when a mobile end system is connected to an access node:

> Let m denote a mobile end system, M be the movement of a mobile end system, t_0 its starting time, and t_e its end time. Further, let a_i be the access node at time t_i and d_i the duration the mobile end system is connected to a_i. The movement of the mobile end system can then be formalized as the relation of the triples:
> $M(m) = \{(t_0, d_0, a_0), (t_1, d_1, a_1), \ldots, (t_i, d_i, a_i), (t_{i+1}, d_{i+1}, a_{i+1}), \ldots, (t_{e-1}, d_{e-1}, a_{e-1})\}$
> for $e \in \aleph_0$ (1)
> and it applies $d_i = t_{i+1} - t_i$ for all $i \in [0, e-1]$ (2)

In reality, such a precise relation can usually only be established a posteriori, however an assumption about the movement might exist a priori. Therefore, an extension to relation (1) is given, to describe an assumption of the movement:

> Let A_i represent a set of assumed access nodes at the point of time t_i, which is guaranteed to contain the actual access node a_i. The *movement closure* $\tilde{M}$ of the mobile end system can then be formalized as the relation:
> $\tilde{M}(m) = \{(t_0, d_0, A_0), \ldots, (t_{e-1}, d_{e-1}, A_{e-1})\}$ for $e \in \aleph_0$ (3)
> and it applies $d_i = t_{i+1} - t_i$ for all $i \in [0, e-1]$ (4)

Note that this relation (3) can be transferred into a representation similar to (1) by relaxing (4). For relation (3), the following statement applies:

> The relation (3) can be found for every mobile end system and movement. (5)

This is true, because obviously for every mobile end system and every movement, the following relation exists:

> $\tilde{M}(m) = \{(t_0, d_0, A_0)\}$ for $d_0 = \infty$ and A_0 contains all the access nodes of the Internet. (6)

In other words, relation (1) can be considered as the optimal case for a movement assumption of a mobile end system and the relation (6) as the worst case. The relation might be derived from movement measurement by GPS, or prediction profiles given by the end-user or other mechanisms. How to obtain this relation and how to give an optimal prediction is beyond of the scope of this paper. For further details, see [15] and [16] and references contained therein. In this paper, we investigate the case, that it is possible to generate a realistic and tractable relation (3), which (6) is not.

B. Mobile Signaling Strategy

According to statement (5), the relation (3) can be assumed to be known and the following strategy to offer QoS to a mobile end system can be derived:

> QoS can be offered to every mobile end system by establishing a reservation in advance according to the relation (3), that means to all of the access nodes of the set A_i at the given time t_i for the duration d_i. (7)

In the following section, we show, that this strategy can be fully utilized for the given connectivity mechanisms binding update, triangle routing and foreign agent by the two QoS mechanisms reservation in advance and third party signaling. Thereby, a correlation between the connectivity and the QoS mechanisms domains is established.

C. Mobile Signaling Mechanisms

According to the connectivity mechanisms, four cases can be distinguished, as shown in the matrix of Figure 2.

	co-located care-of address	care-of address
Binding Update	I	II
Triangle Routing	III	IV

FIGURE 2 Matrix of the connectivity mechanisms

First we consider the binding update mechanism. As already shown in (7), reservation in advance can be used to keep the communication service alive. But obviously, a mobile node can only be the endpoint of a reservation, when it has access to the network. Therefore, a *third party entity* is needed, which takes care of the reservation when the mobile does not access the network.

In case **I**, any host, which has access to the foreign network can offer these *third party services* to the mobile node. This host has to obtain a co-located care-of address for establishing the reservation with the correspondent node. The mobile node takes over the address and reservation after accessing the network.

In case **II**, the foreign agent offers its own interface address to the visited network as a care-of address to the mobile node. Therefore, the foreign agent has to establish the reservation. But, because of the binding of the care-of address to an interface of the foreign agent and the mismatched topology of the home address, the mobile node can not be addressed directly. That means, the mobile node cannot take over the reservation when it arrives at the network. The foreign agent remains as the reservation endpoint. In this case, an additional reservation between foreign agent and mobile node has to be established.

In cases **I** and **II**, third party signaling functionality has also to be added to the correspondent node. The mobile node requests to establish a reservation to a certain network address and it does not take over the reservation while connection time.

By introducing triangle routing mechanisms, the end-to-end transmission path is split into multiple network connections. The reservation path between a mobile node to its correspondent node has to be separated at least into two network reservations: the reservation between the correspondent node and the home agent and the reservation between home and foreign agent respectively the third party entity. According to the concepts of RSVP, a *data flow* is a sequence of data packets following the same path through a network from the same source host and port to the same destination address and port using the same protocol ID. A *reservation session* is identified by the destination address, destination port and the protocol ID of the data flow. Consequently, the mobile node and the correspondent node are still the two end points of a reservation. But, on the network layer, the home agent has to use the home IP address of the mobile node as an identifier for the reservation session. Therefore, a new role as a third party entity has to be provided for the home agent and a *mapping rule* from the application layer to the network layer has to be defined (see Section D).

Case **III** and **IV** differ only with respect to the details of MAC layer reservations applied to the last hop. This is beyond the scope of this paper. Further information can be found on the web page of the IETF working group Integrated Services over Specific Link Layers (issll) [17].

D. Mapping Rules

Additionally to relation (3), mapping rules have to be given, to define the roles of certain entities. Therefore, a so called *logical layer* is introduced. In the basic RSVP model, the logical layer end-to-end flow is mapped to one network layer flow, which is depicted in Figure 3(a). Due to the independency of routing decision and path reservation, there is no possibility to specify the network layer endpoints of the reservation, nor whether some intermediate router should fulfill third party functionality like it is shown in the example of Figure 3(b).

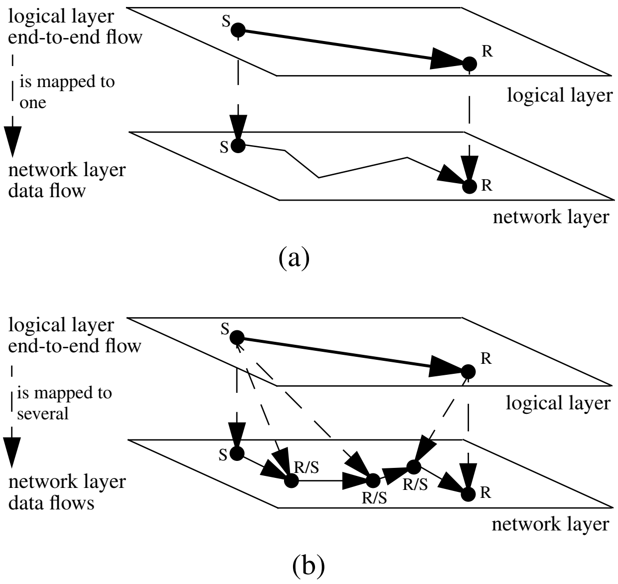

FIGURE 3 Logical Layer Mapping

But, as discussed above, the network layer flow is split and therefore, mapping rules are needed for the following cases:

1. The *mapping of the reservation endpoints* from the logical layer to the network layer.
2. The *mapping of the reservation path* from the logical layer to the network layer.
3. The *mapping of the reservation starting time and the duration* from the logical layer to the network layer.

The information, which is needed to do this mapping can be achieved by combining relation (3) with the matrix drawn in Figure 2. Obviously, the mobile node has the ability to collect and combine the needed information for formulating the mapping. Therefore, it is called the *initiator* of the third party signaling. The initiator assigns the roles to the concerned network entities, which are called *third party agents*. According to Section II.C two roles have to be assigned:

1. Whether the third party agent is the *sender* or the *receiver* of a reservation session.
2. Whether the third party agent is using its own IP address for signaling, this role is called *proxy*. Or whether the agent uses another IP address (e.g. the home IP address or the co-located care-of address of a mobile node). This role is called *commissary*.

Now, the mapping can be done initiating a *tp_agent_configuration* from the initiator to the third party agent with the following parameters:

- sender (s) or receiver (r) role
- proxy (p) or commissary (c) role
- correspondent reservation endpoint (cre)
- starting time (t_s)
- duration (d)
- parameter set (e.g. TSPEC) (ps)

See Figure 4 as an example: This mapping is initiated between the mobile node as a sender and the correspondent node as a receiver. While a mobile node has no access to its home network, the home agent has to take care of the IP packets, which are directed to the mobile node. Therefore, as a third party agent it has to fulfill the role as a *sender commissary.*

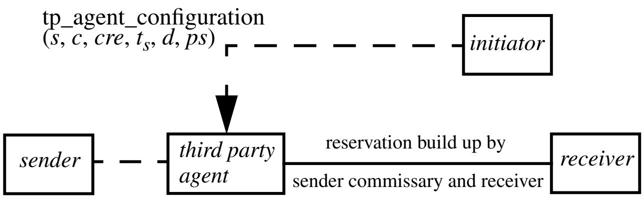

FIGURE 4 Example of the Mapping

III. Realization of the QoS Mechanisms

Resource reservation in advance and its realization, particularly as an extension to RSVP, has been extensively discussed, for example in [18], [19] or [20] and references therein. We propose to realize the third party signaling mechanism as an own protocol - the Third Party Signaling Protocol (TPSP).

TPSP, as described by the general model in Section II.D, introduces four entities *sender*, *receiver*, *third party agent* and the *initiator*. The sender entity is the sender of a data flow now or in the future. The receiver entity is the receiver of a data flow now or in the future. The direction of the data flow is always form sender to receiver. Sender and receiver entities are the endpoints of the logical layer reservation initialized by an application. For establishing the corresponding network reservation, the initiator is able to perform third party agent configuration. Therefore, parameters are transmitted to the third party agent, which define the roles, described in Section II.D, and the characteristics of the reservation.

According to these entity definitions, protocol functions for the initiator and the third party agent have to provided. The initiator has to derive the needed information for the network reservation from the given relation (3), the strategy (7) and the knowledge of the used connectivity mechanisms described in Section II.C. Thereafter, third party configuration has to be initiated to the correspondent agents and nodes. The tp_agent_configuration primitive with its parameters, described in Section II.D, is sent and the agent, which strikes the assigned role. The requested reservation is signaled by the third party agents using RSVP due to the given parameters. The result of the RSVP signaling procedure is replied to the initiator by a tp_agent_response. The initiator collects the agents responses and forwards the result as shown in Figure 1 to the entity, which is responsible for the strategy. Now this entity has to decide whether the results of the third party signaling process are suitable or not. This approach guarantees the separation of the mechanisms and strategy, which is claimed in Section II. In the following, an example is given, to show how this third party mechanism can be used.

IV. Example

Consider Figure 5 as a mobility scenario example. A mobile node is moving through different cells 2 to 4 depicted by the dotted arrow. In this example, we assume that the routing is supported by Mobile IPv4, including the option for route optimization, so that both connectivity mechanisms, triangle routing and binding update, are possible. Cell 1 is the home network of the mobile node with the home agent (H), whereas cells 2 - 4 are foreign networks.

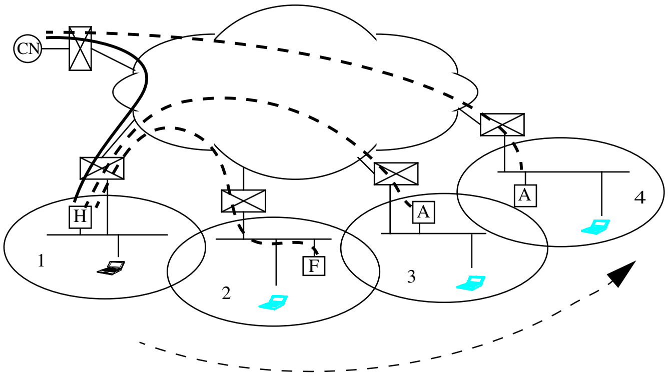

FIGURE 5 Example of a Mobility Scenario

A. Movement Prediction

The relation (3) developed in Section II.A is given as follows (with d_i in minutes and t_i as *hhmm*).

$$\tilde{M}(m) = \{(0800, 60, II), (0900, 30, (II, III)), (0930, 30, III)(1000, 30, (III, IV))\}$$

B. Strategy

Therefore, according to Section II.B, the strategy can be formulated by deriving the needed reservations in advance (*rera*):

1. rera(II): at 8 am for 90 minutes.
2. rera(III): at 9 am for 90 minutes.
3. rera(IV): at 10 am for 30 minutes

C. Connectivity Mechanisms

In cell 2, the mobile node receives a care-of address from the foreign agent (F), while in cell 3 and 4 it has to obtain a colocated care-of address by an agent (A). So, the cases I, III and IV distinguished in Section II.C are covered by the example.

D. QoS Mechanisms

The mobile node requests an end-to-end QoS guarantee to a correspondent node (CN). As defined in Section II.D the logical layer end-to-end flow can be given from the sender correspondent node to the receiver mobile node. Mapping rules have to be defined and the agents have to be configured according to Section II.D.

1) Configuration of the foreign agent in cell 2

In cell 2, a foreign agent (F) offers a care-of address to the mobile node, which is its own interface to the subnet. Therefore, the foreign agent can do the signaling as a proxy and takes care of the reservation until the mobile node arrives in the subnet.

F: tp_agent_configuration (r, p, MN(1), 0800, 90, *ps*)

2) Configuration of the agent in cell 3

Within cells 3 and 4, no foreign agent offers network access. However, other agents (A) offer third party signaling services and network access. The agents receive IP addresses on behalf of the mobile node. When the mobile node enters the cell, it takes over the IP address as wall as the reservation. Therefore, the agents are commissaries. Within cell 3, triangle routing is used. Therefore the correspondent reservation endpoint is the home IP address of the mobile node.

A(3): tp_agent_configuration (r, c, MN(1), 0900, 90, *ps*)

3) Configuration of the agent in cell 4

Because, within cell 4 route optimization is used, the correspondent reservation endpoint is the correspondent node.

A(4): tp_agent_configuration (r, c, CN, 1000, 30, *ps*)

4) Configuration of the correspondent node

On the other side, the correspondent node is requested to establish the reservation in advance to the IP address of the mobile node in cell 4.

CN: tp_agent_configuration (s, p, MN(4), 1000, 30, *ps*)

5) Configuration of the home agent

The home agent has to take care of the reservation to the correspondent node, while triangle routing is used and to the respective agent within the actual visited cell. The reservation to the correspondent node can be held on, while the mobile node moves within cell 2 and 3.

H: tp_agent_configuration (r, c, CN, 0800, 150, *ps*)

H: tp_agent_configuration (s, c, F, 0800, 90, *ps*)

H: tp_agent_configuration (s, c, MN(3), 0900, 90, *ps*)

V. Related Work

[21] concentrate on problems that arise by mobile end systems and their unpredictable movement. To support rapidly moving users with a small staying time in each cell, the basic concept of *groups* is introduced. For every cell c_i, which is visited by a mobile end system at time t_i, a surrounding collection of cells g_i can be given, the so called *shared region*. Any data destined for c_i are then multicasted to all the cells in g_i and buffered for the mobile node. This method is called *predictive buffering*. It can be optimized by taking into account additional information, e.g. about walls between cells or the movement direction of a mobile user. This model can be mapped to our general model. Since in our model no geographical information about the cells are needed, it is even more general.

In [16], mobility independent service guarantees are obtained in an Integrated Services Network by establishing advance resource reservations towards all locations a mobile end system may visit during the lifetime of a connection. Since RSVP is not directly adequate to make such reservations, a new reservation protocol MRSVP is proposed. This protocol offers the functionality to establish advance reservations for a given *specification* of a locations set. A mobile node makes an *active* reservation from its current location, whereas *passive* reservation are established by so called *proxy agents* in the locations given by the specification. Although both basic mechanisms, advanced reservation and third party signaling, are included in this protocol, they are tightly integrated and focused on mobile communications. Such an approach does not allow the re-use of these mechanisms for different application scenarios.

The proposal [22] is also based on the concepts of active and passive reservations and shared regions. Additionally, an architecture based on a hierarchical connectivity structure is introduced, which is aimed to keep the balance between *local routing updates* for faster handoffs and Mobile IP for long range mobility. Two management domains are defined. Within a *QoS-domain* passive reservations for the shared region of a mobile node are established by extending the path of the original reservation. All passive reservations outside the QoS-domain are done by partial re-routing. Therefore, in a single *routing-domain* route changes are done with the help of routing table updates. Inter-domain routing is carried out through Mobile IP. Similar to other work, this approach contains the basic mechanisms identified in our work, but in an implicit and integrated fashion. Furthermore, it requires to extend the functionality of all IP routers within the routing domain.

[[FHNS98]] identifies the challenge of RSVP supporting Mobile IPv6 as the *change of route* and the *flow-mismatch*, which both have impact on the operation of RSVP. While Mobile IP provides transport layer transparency, there is no possibility to interoperate seamlessly with QoS signaling protocols, like RSVP. To enable the correct routing of RSVP messages between a correspondent and a mobile node, changes to either RSVP or Mobile IP are required. In the first case, all RSVP-capable routers learn the mapping between the mobile node's home address and current (co-located) care-of address. In the second case, which is preferred in the proposal, the Mobile IP modules need to become RSVP aware, by providing an interface for looking up the home address to obtain correct routing information. Additionally, to avoid an extra delay between the mobile node's binding update, the respective message must trigger an immediate transmission of the next PATH message from the correspondent node. This work identifies the basic problems, such as the mismatch between the end-to-end logical layer and the actual transmission path, which are addressed by our work.

In [23], a simple QoS signaling protocol for mobile end systems is proposed. In contrast to the work described above, it is not assumed that the movement of mobile nodes can be predicted in advance. The potential for signalling guaranteed services is traded off against achieving a low control overhead. The approach is based on RSVP tunnels, established between the home agent and the foreign agent, which are triggered by the end-to-end RSVP messages exchanged between the mobile and the correspondent node. For the original end-to-end RSVP session, the tunnel appears as a single (logical) link along the path between the source(s) and the destination(s). This work focuses on the technical details of implementing a certain scenario for mobile services. The concept of third party signaling is implicitly encompassed in this approach, although not in a very structured fashion.

[15] took an approach of an extended RSVP protocol, which is also based on active respectively passive reservation and the group concept. The protocol is proposed to enable a higher degree of flexibility for mobile nodes, which might not be able to adhere to a pre-defined mobility specification. Three different kinds of reservations are distinguished, best effort, guaranteed service and active handover. Therefore, *priorities* are defined with diminishing values and a so called *dynamic resource-sharing* algorithm is proposed to make use of these priorities. The *progressive resource reservation* is offered to a mobile node by a foreign agent and distributes RSVP messages to the neighboring cells for installing a path state in the correspondent node. The prioritization ensures, that the reserved resources for the mobile node are available as soon it enters the cell, but it also enables other mobile nodes to consume reserved but still unused (passive) resources.

The approaches in [24] as well as [23] use tunnels, which are triggered by the end-to-end RSVP messages between the mobile node and the correspondent node. But in contrast to the first proposal, the routing is based on Cellular Mobile IP, which is basically an adaptation of Mobile IP to an architecture of base stations. Compared to our work, these proposals implicitly identify and approach similar problems, but fail to clearly structure the problem space. Instead, the proposed solutions are integrated and targeted to specific scenarios.

VI. Summary and Future Work

In this paper, we have investigated the challenge to enable signaling-based QoS in a mobile environment. We have developed a simple mobility model in order to theoretically comprehend and express the fundamental issues related to this work. Based on this model, it can be concluded that two basic mechanisms, advance reservation and third-party signaling, are necessary in order to accommodate QoS signaling for mobile end systems. In fact, it turns out that almost all previous work produced similar or a subset of these results. However, previous work has failed to clearly structure and decouple these mechanisms from the rest of the overall system architecture. By doing so, we identified that in case of advance reservations, existing approaches can be reused. Unfortunately, for third-party signaling no suitable previous approaches exist, such that we decided to propose a new protocol.

Future work must be directed to a variety of work items. A complete theoretical mobility model is needed to formally prove that indeed all technical proposals for achieving mobile connectivity can be expressed by the four basic mechanisms, described in Section II.C. Much algorithmic and optimization work can be carried out, aimed at finding and processing a tractable movement closure. Last but not least, we are currently in the process of designing and realizing an experimental implementation of TPSP and integrating it that in a QoS-enabled system architecture, based on an existing version of RSVP [25], in order to demonstrable the practicability of our approach.

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