ROBUST HEADER COMPRESSION IN 4G NETWORKS WITH QOS SUPPORT

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Abstract— **The 4th Generation of mobile communication networks will use heterogeneous wireless technologies. Voice and low quality video flows will consist of very small IP packets, for which the standard RTP/UDP/IP headers constitute a significant overhead. Considering that the radio resources are scarce, this overhead may be unacceptable and the adoption of header compression mechanisms is desirable.**

This paper presents a solution for including RoHC header compression mechanisms within 4G networks; the solution is combined with the mechanisms required to provide QoS to the real time flows.

Index Terms— **Robust Header Compression, RoHC, Heterogeneous Networks, 4G, QoS, Wireless**

I. INTRODUCTION

THIS RObust Header Compression (RoHC) [6] is a scheme used to compress the headers of IP based protocols, such as RTP, UDP and IP. RoHC is particularly adequate for wireless links, which are characterized by high error ratios, long round-trip times, and scarce resources. The header compression technique is considered profitable when packets have a header/payload size ratio near or above 1. In the 4th generation on mobile communications (4G) there is a tendency to transport audio and video flows as IP packets and provide them with QoS guarantees. RoHC header compression is advantageous in these environments, since the packets transporting voice and low quality video for small devices are under the size ratio mentioned above.

The RoHC solution will be even more appreciated if the bandwidth given to a flow could adapt to the flow compression ratio, which depends on the wireless link conditions.

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This paper describes the AL-RoHC solution, which integrates RoHC into the QoS-Abstraction Layer (QoS-AL) provided by the IST Daidalos Project [1][2]. For that purpose we provide in Sec. II and III an overview of QoS-AL and RoHC, respectively. In Sec. III the requirements defined for the AL-RoHC solution are enumerated and discussed. In Sec. IV the AL-RoHC solution is specified and, in Sec. V, the directions for future work are pointed out. Finally, in Sec. VI, we present the conclusions of the paper.

II. THE QOS ABSTRACTION LAYER

The main purpose of the QoS Abstraction Layer (QoS-AL) is to provide a QoS reservation service over heterogeneous L2 access technologies; it is particularly tailored to wireless technologies, such as 802.11, 802.15.1, 802.16, or 3GPP, though it can also work with wired technologies.

A. Architecture Overview

The L2 Access Network (AN) in the Daidalos project consists of an Access Router (AR) connected to one or more Access Points (APs) and Mobile Terminals (MTs). The QoS-AL is present in all of these elements, and uses a simple L2 based protocol to manage QoS resources across these elements.

The main Service Access Point (SAP) of the QoS-AL is located in the AR. There the QoS Manager, which is an L3 end-to-end QoS module, delegates to the QoS-AL the responsibility of providing the L2 QoS guarantees in the AN, whilst employing other techniques (e.g. RSVP, NSIS, custom protocol) to negotiate end-to-end QoS.

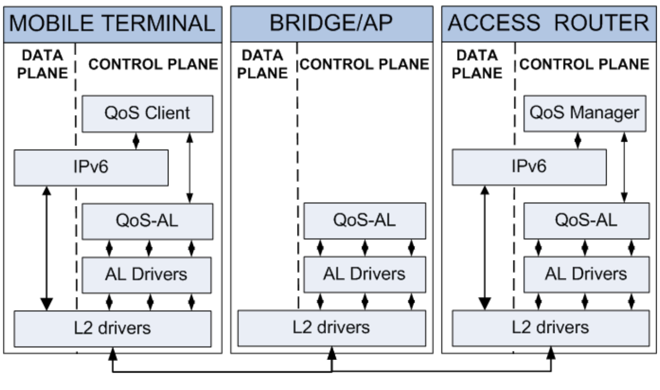

Figure 1 - QoS-AL architecture

From the implementation level point of view, the QoS-AL is split in two components. A generic part which implements the functionality common to all the supported technologies and, beneath, the AL *drivers* which receive abstract primitives from the QoS-AL and implement/adapt the primitives for the particular technology. This modular design eases the addition of new technologies. In the Daidalos project, QoS-AL drivers for 802.11e, 802.15.1, and 802.16 are under development.

B. The Abstract Interface

The SAP to the QoS-AL, used by the QoS Manager and the QoS Client, is named *Abstract Interface* to emphasize the fact that all the primitives in this interface work with abstract QoS parameters, which are later translated, in the driver, to technology-specific parameters. The abstract QoS parameters are based on RSpec/TSpec as defined by IETF [3]. The primitives offered by the Abstract Interface are classified in four groups.

1) QoS reservation

This is the main service offered by the QoS AL, and consists in the creation of *QoS connections*. A QoS connection is a virtual channel between a MT and an AR, provisioned with QoS guarantees such as bandwidth and delay. A *connection identifier* (CnxID), which uniquely identifies a QoS connection in the AN, is returned to the interface user.

The QoS-AL exists only at the control plane, as a signaling protocol. For this reason, no additional header is inserted into a data packet; instead, the IPv6 Flow Label field is reused in the access network, and its value is made equal to the CnxID.

2) Resource Querying

There is a primitive to request a report of the available resources (e.g. bandwidth) in the AN. It requires a single parameter, an L2 address, which identifies the "path" for which resources are to be queried.

3) L2 QoS Notifications

There is one "connection indication" primitive that is issued from the QoS-AL at both AR and MT to indicate that the QoS-AL was forced to modify the QoS for a specific connection due to changing conditions in the wireless medium. The primitive includes the CnxID and the new QoS parameters of the connection. This primitive is important, for it allows link adaptation by applications, and may serve as trigger for higher-level handover decisions.

4) Handover Support

There are a couple of primitives defined to support smooth handover between APs. In the spirit of *make-before-break* handover schemes, such as *Fast Handovers* [4], there is one primitive to prepare QoS resources in an AP to which the terminal will move in the near future. The other primitive notifies the QoS-AL about the handover occurrence, and so the previously prepared resources ought to be activated.

C. The Protocol

The mapping from primitives to Protocol Data Units (PDUs) is straightforward. The QoS-AL PDUs are transmitted as Ethernet frames with a new protocol type. It is based on in-band signaling and soft-state.

By using the MN address as destination address of the signaling frames, several design goals are achieved, namely: 1) path discovery, 2) support of concatenated APs, and 3) support of transparent dynamic reconfiguration of the network topology. This all comes "for free" with IEEE 802.3 Learning Bridges [5], implemented by bridges/APs.

III. RoHC

The RoHC is applied to flows [6], and it uses a *compressor* and a *decompressor*. RoHC is based mainly on the suppression of header fields, since in a flow many of the header fields are static. The variable fields may vary predictably (inferable fields) or unpredictably (dynamic fields). A *context* is maintained by both the *compressor* and the *decompressor* and it consists of a set of static and inferable fields. Each context has a *context ID* (CID), which identifies the *context* of a unidirectional flow. A RoHC packet header consists of a CID, which can be high (2 bytes) or low (1 byte).

Initially, all the header fields are sent uncompressed, in order to build the *context* information. Once the *context* is initialized, the static and inferable fields are no more included in subsequent RoHC packets, which carry out only the dynamic fields. Each set of protocols (e.g. IP/UDP/RTP) is defined as a RoHC profile, which must be used by the communicating parts.

RoHC decompressors can send two types of feedback packets: ACKs to confirm a successful decompression of a RoHC packet, and NACKs to indicate the detection of decompression errors. There are 3 RoHC operation modes: Unidirectional (U-mode), in which ACKs and NACKs are never sent; Bi-directional Optimistic (O-mode), in which only NACKs are sent; Bi-directional Reliable (R-mode), in which both ACKs and NACKs are sent. More information about RoHC can be found in [6],[7],[8],[9].

IV. AL-RoHC Considerations

The integration of RoHC capabilities in the QoS-AL framework poses some challenges.

A. Out-of-band negotiation

The IETF RoHC [6],[9] assumes the existence of an out-of-band negotiation protocol or a predefined channel state. The former can be obtained by extending the QoS-AL protocol to negotiate RoHC channels; the latter is not desired in the QoS-AL framework because there is no prior knowledge of which nodes are going to communicate between themselves.

B. Transport of RoHC packets

There is not, currently, a standard for transporting RoHC packets over IEEE 802 networks. IETF has defined a solution to transmit these packets over PPP [7] but, as mentioned in [8], the overhead and additional complexity discourages its use. There is an ongoing effort to specify RoHC transportation over IEEE 802 networks [8], but it is in an early stage. Some approaches are proposed, but not a final solution.

One of the main problems is how to deal with the Ethernet minimum frame size (64 bytes). In IEEE 802.3 links the padding must be added to frames smaller than 64 bytes. This overhead is not a big penalty on 802.3 links having high bandwidth and low error rates; however, the same approach cannot be adopted in wireless links, where this overhead would negate the use of RoHC. The common use of DIX frames (frame *length* field used as *ethertype*) disables the bridges/APs to remove padding using only L2 information. In order to overcome this problem, these equipments usually inspect the IP *total length* field [8]. However this solution conflicts with RoHC since this field is normally compressed. The problem can be circumvented if the software running on bridges/APs can recognize two new ethertypes (RoHC high CID, RoHC low CID), and a length field is added to L2 payload. Although the addition of new functionally to L2 equipment may pose problems with legacy equipment, most of the solutions developed in the context of 4G networks indicate that these equipments will have to be modified in order to support not only QoS [10],[11], but also micro-mobility [12]. Additionally, the Daidalos QoS-AL already demands some changes to L2 bridges/APs, as shown in Figure 1.

C. Dynamic Adjustment of QoS parameters

The AL-RoHC solution should accommodate a mechanism which enables the dynamic adjustment of the QoS parameters associated to each reservation. This requirement may improve the efficiency of resource utilization, while maintaining the QoS guarantees.

D. QoS-AL requirements

Bridges/AP along the path between the AR and MTs need to access each packet CnxID (IPv6 flow label) for scheduling purposes. Since IPv6 headers are compressed, the addition of the CnxID field just after the L2 header can be a good solution, and paves the way to a new abstract layer 2.5 in 4G heterogeneous networks also in the data plane.

V. AL-RoHC Specification

The AL-RoHC integrates RoHC in the QoS-AL framework, and uses the QoS-AL protocol to negotiate out-of-band the RoHC channels between AR and MTs. The negotiation of a RoHC channel consists of exchanging RoHC parameters between two hosts.

A. AL-RoHC Architecture

The AL-RoHC architecture adds functionality to the QoS-AL (Figure 2). In the data plane, a RoHC Module (RM) was placed between the TCP/IP stack and the L2 drivers, in order to provide the RoHC service. In the control plane, an embedded RoHC Interface Module (RIM) is added to QoS-AL, which negotiates RoHC channels and configures the RM. There are different instantiations of these modules for endpoints (AR, MT) and intermediary nodes (bridges, APs).

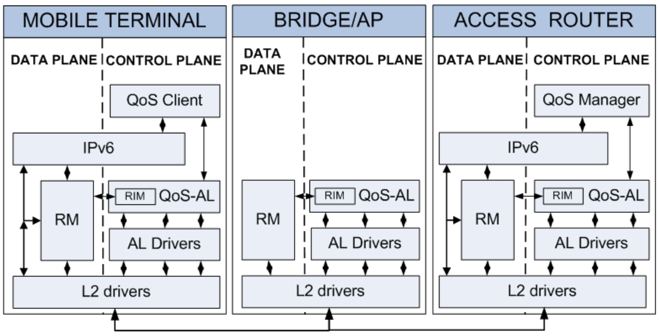

Figure 2 - AL-RoHC architecture

1) RoHC Module

The RM is responsible for compressing/decompressing RoHC packets at the RoHC channel endpoints (AR and MT). In order to identify the packets to compress, this module manages two state tables: a) the *RoHC Channels Table* (RCT), which holds RoHC parameters from other hosts; b) the *Identifiers Map Table* (IMT), which associates the QoS-AL CnxIDs with the RoHC CIDs. The RM at intermediary bridges do not compress or decompress RoHC packets; it just changes the L2 encapsulation.

2) RoHC Interface Module

The RIM is embedded in the QoS-AL module. It negotiates RoHC channels at the endpoints (AR, MTs), and communicates with the RM. At channel endpoints it exchanges information such as (1) identification of RoHC channels negotiated, (2) CnxIDs of reservations set up, and (3) compression statistics.

3) New QoS-AL primitives

The AL-RoHC adds two new primitives to the QoS-AL (*RequestRoHCParameters*, and *RoHCParameters*) for exchanging RoHC parameters between abstraction layer clients. A RoHC channel is said to be set when both endpoints acquire each other RoHC parameters. At the L2 level, RoHC messages are piggybacked on QoS reservation messages. This optimization allows the connection establishment and RoHC Channel negotiation to be made in just one round-trip-time; this is crucial for doing Fast Handovers. A new flag (RF flag) is also added to QoS-AL's reservation primitives, which is used to enable/disable RoHC utilization in a particular connection.

4) RoHC Packets Transportation

In AL-RoHC, RoHC packets are transported directly in L2 frames. In the L2 payload, a CnxID field prefixes the RoHC payload. A *length* field was added after the CnxID field in order to know how much padding was added to the frame, as shown in Figure 3. The RoHC packet itself follows IETF specification [6].

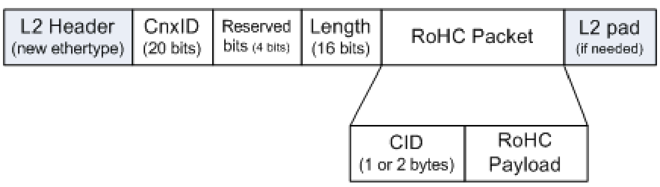

Figure 3 - AL-RoHC frame format

B. AL-RoHC Stages

1) RoHC Channel Negotiation

A RoHC channel establishment is triggered when the QoS Manager receives a request to setup a QoS reservation between the AR and the MT. The RoHC channel negotiation is then set up by sending a *requestRoHCParameters* message piggybacked on the QoS-AL reservation request message (*requestQoSReservation*). After receiving the message, the MT stores the AR's RoHC parameters, checks if RoHC can be used (if there is a common RoHC profile in MT and AR), and prepares a *RoHCParameters* message. In case the QoS reservation is accepted (resources available), a CnxID is generated and included in the response message (with the RF flag), which is returned to the AR, to the QoS Manager, with the *RoHCParameters* message piggybacked.

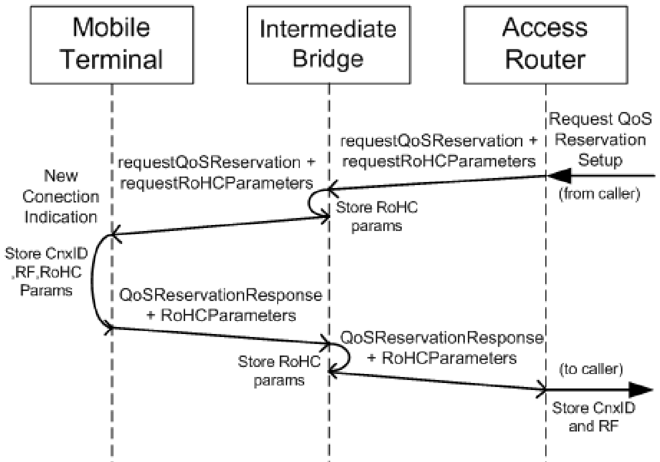

Figure 4 - RoHC Channel Negotiation

2) RoHC Packets Exchange

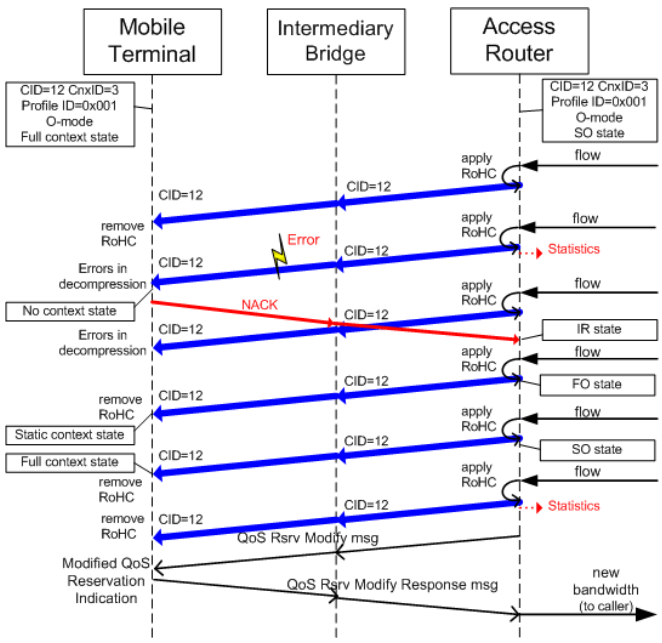

Figure 5 - RoHC Packets Exchange

After a successful RoHC channel establishment and a RoHC-enabled QoS reservation, both AR and MT may send compressed RoHC packets between them. In the RoHC channel endpoints, outgoing IPv6 packets are intercepted and compressed by the RM. In intermediary bridges, the packet is intercepted and the L2 encapsulation is exchanged (padding is added/stripped, if necessary). When a RoHC packet reaches the *decompressor*, it is intercepted by the RM and decompressed based on the CID. A RoHC feedback packet may be returned to the compressor, depending on the operation mode; most likely, real time flows will try to avoid it, by operating most of the time in U-mode or O-mode.

In wireless communications, where link conditions vary, the compression ratio may not be always the best. Periodically, compression statistics are returned by the RM to QoS-AL, which decides if the QoS reservation (bandwidth) needs to be modified. In order to avoid frequent changes, thresholds and a hysteric mechanism may be used.

3) RoHC Channel Termination

The RoHC channel termination can be initiated in both AR and MT, by sending a QoS Reservation Termination message (*QoSReservationTermination*). This action is always successful, so it does not demand an answer. It deactivates the reservation and the associated RoHC mechanisms.

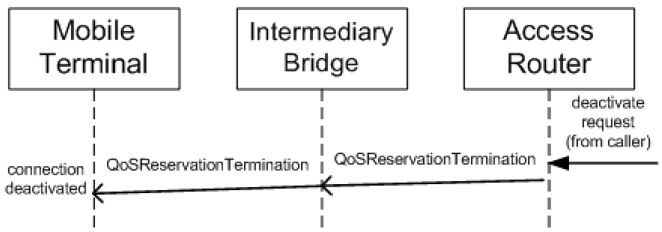

Figure 6 - RoHC Channel Termination

The RoHC channel parameters are kept by each endpoint on its RCT, and need not to be exchanged in the next QoS-AL reservation request. To force periodic refreshes, the RoHC parameters are stored with a timestamp and a TTL.

VI. FURTHER WORK

A proof-of-concept of the AL-RoHC is being developed to prove the feasibility of the solution described in this paper. Some results are expected to be drawn from this implementation, such as compression ratio obtained in different scenarios and the optimization obtained with the dynamic adjustment of QoS parameters. An adjustment algorithm is also under development. This algorithm is the main implementation challenge.

VII. CONCLUSIONS

This paper describes the AL-RoHC solution, aimed to integrate the QoS-AL framework.

The solution solves an open problem - it enables RoHC to be transported over heterogeneous networks, by adding a length field to L2 payload, thus solving the 802.3 padding issue. It also provides a RoHC negotiation mechanism which takes advantage of the QoS-AL framework - the negotiation information is piggybacked on the QoS-AL reservation messages, what reduces the setup period to one round-trip-time and complies with mobility requirements.

The addition of RoHC capabilities to the QoS-AL and the provisioning of compression statistics enable an efficient usage of the radio resources in 4G networks.

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