Reliable Mobile Multicast Transport for Multimedia Content Delivery

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ABSTRACT
Efficient reliable multicast transport reducing the receiver processing overhead and allowing seamless continuation of the multicast service in case of handover is a challenge of today broadband infrastructures including content and mobile networks, The focus of this paper are protocol mechanisms aimed at scalable reliable point-to-multipoint content delivery from access routers to the attached multiple receivers in heterogeneous mobile IPv6 environment. In particular, the access router assistance of reliable content delivery is described, which includes the following tasks:

- Obtaining of data required by mobile multicast receivers based on interaction with the content network;
- Multicasting to mobile nodes using appropriate reliable multicast transport mechanisms;
- Support of the seamless handover of mobile multicast group members.

The design issues and signalling overhead of the proposed scalable reliable multicast transport service including strategies for avoiding implosion and exposure is discussed. Important design concepts of the proposed protocol are:

- Access router assisted error control to mobile receivers using NACK-based retransmission scheme;
- Handover loss repair;
- Optimised receiver processing by using of dedicated channels for processing of retransmissions and handover repair;
- Scalable rate based multicast flow control for reliable transport services with minimum QoS guarantee.

The scalable reliable multicast transport for mobile IPv6 is integrated into mobile IPv6 architecture based on the standard Internet multicast services using multicast listening (MLDv2) and routing (PIM-SM) protocols. The seamless handover is supported by context transfer between access routers, which allows the rapid re-establishment of multicast group membership and reliable transfer operations of the mobile node.

The protocol is developed for the multimedia mobile broadcast Ipv6 environment of EU IST DAIDALOS project [1].

Categories and Subject Descriptors
C.2.2 Network Protocols – applications, protocol architecture

Keywords
Reliable, mobile, multicast, protocol, handover, context transfer, retransmission, heterogeneous mobile networks, rate control, IPv6

1. Introduction
In the past, significant work was aimed at development of reliable multicast protocols providing different QoS guarantees and reliability requirements of applications [38]. Examples are the Restricted Reliable Multicast Protocol [2], Pragmatic General Multicast (PDGM) [3], Versatile File Delivery Protocol [4], FLUTE for scalable multicast file delivery using Forward Error Correction (FEC) [5], Resilient multicast transport [6], T-RMP for reliable multicast with delay guarantees [7].
The idea of flexible reliable multicast transmission dependent on the network and application context was leading to the efforts within the IETF Reliable Multicast Working Group to standardise multicast building blocks, which could be combined to define multicast transport protocols [8], [9].
With the increasing demands for multicast services in large Internet broadband infrastructures, scalable multicast flow control for heterogeneous mobile receivers [12], [36], cooperative caching strategies [13], application-level [29], [30] and router assisted [10], [11] hierarchical retransmission schemes become intensive focus of research in order to optimise network resources required for reliable multicast transport.
The mobile communication introduces new challenges for reliable multicast transport focussing on:

- Efficient interaction of reliable multicast protocols with the Internet mobility protocols for seamless handover and rapid re-establishment of reliable multicast transport in case of handover
- Retransmission schemes aimed to reduce processing and signalling overhead of mobile receivers
- Flow control considering heterogeneous multicast receivers.

The reducing of network and processing overhead for mobile communication depends on the selected protocol mechanisms and on the integration of the multicast protocol into the mobile architecture for multicast group communication.
Reliable multicast transport services within IPv4 regional mobile platform using foreign agents are discussed in [14].
Design of reliable multicast protocols for specific mission critical applications in ad-hoc mobile networks characterised with dynamic topology changes, scare resources, often link failures and network reconfigurations is addressed in [15], [16].
The scalable reliable multicast protocol for mobile IPv6 environment discussed in this paper is aimed to deliver data to mobile receivers tolerating no packet loss.
It is intended to be used for application scenarios of reliable content delivery to mobile users based on carousel services and file downloads, such as software updates and static picture or text distributions.
The protocol defines the interactions between access routers and attached mobile multicast receivers. Access routers obtain the data

from the content network and transfer it to the attached mobile receivers using NACK based techniques for error recovery and signalling mechanisms to repair immediately the handover data loss. Scalability is aimed to support efficiently different number of mobile receivers in heterogeneous mobile networks including wireless (WLAN, WiMAX, and UMTS) and broadcast technologies (DVB-T, DVB-H) with different scope.

The reliable multicast mechanisms are integrated in the heterogeneous mobile IPv6 platform developed in EU project DAIDALOS [1].

The rest of the paper is organised in the following sections.

Related work concerning reliable mobile multicast mechanisms is overviewed in section 2. Section 3 discusses the scenario for reliable multicast based on DAIDALOS IPv6 heterogeneous mobile architecture. Section 4 is aimed to present the design of the integrated multicast transport architecture for reliable content delivery in heterogeneous IPv6 based mobile infrastructure.

The multicast transport mechanisms defined between access routers and mobile receivers to deliver reliably content are described in section 5. Section 6 concludes this paper.

2. Related work

To provide reliable transport to mobile receivers, different mechanisms are required, which could be grouped into:

- Multicast group members mobility support, i.e. support of multicast communication, when the mobile node moves from one access network to another. This includes handling of location changes of multicast group members and multicast routing for moving mobile hosts between different access network;
- Error control and retransmission to assure no packet loss of mobile receivers considering also handover and roaming of the mobile nodes;
- Flow control and resource reservation for mobile nodes in order to support QoS requirements of multicast transport.

The successful integration of the reliable mobile multicast depends on the technology and signalling mechanisms used to support the mobility of the multicast group members.

In [24], different approaches are overviewed to achieve sender and receiver multicast mobility in Internet environment.

The bi-directional tunnelling mechanisms for mobile multicast support using IPv6 Mobility standard, specified in RFC 3775 [22], is based on establishment of a tunnel between Home Agent and mobile node for forwarding of multicast packets. Due to the tunnelling based on unicast transport, this approach is not scalable and could not use not optimal the network resources.

In the remote subscription approach, the mobile node could join the multicast group on the next access network without to wait for the binding of its new care-of address thus reducing the delay for multicast service re-establishment [25]. However, during the handover multicast packets could be lost and in case of frequent handovers there is an increasing overhead at the mobile nodes to re-join multicast groups.

The Fast Multicast Protocol for MIPv6, proposed in [26], is based on extension of MIPv6 for Fast Handovers [23]. It is aimed at establishment of the multicast listening context at the next access router before connecting to the new access network. This is achieved based on extension of the Fast Handovers messages with information, describing the active multicast groups of the mobile node, for which the new access router should establish multicast listening and routing context.

Mobile multicast in the framework of Hierarchical Mobile IPv6 (H-MIPv6) approach is discussed in [27]. The multicast packet forwarding is based on Mobility Anchor Points defined for the H-MIPv6 architectures.

There are also other proposed solutions for mobile multicast considering specific extensions of MIPv6, as for instance the explicit multicast over MIPv6 [28].

The multicast mobility mechanisms usually solve only the problem of multicast group membership and multicast routing for mobile hosts during their movement between access networks.

In addition to this, the reliable mobile multicast requires integration of error and flow control techniques for the delivery of the data to the mobile receivers without packet loss.

The IPv4 based regional mobile platform uses foreign agents to support retransmissions to the mobile receivers in addition to the multicast group addressing and routing [14]. In contrast to this work, the architecture presented in this paper shows mobile reliable multicast solutions based on enhancing of Mobile IPv6 with context transfer is focus of research. The multicast context transfer is aimed to establish the listening and routing context data to multicast groups and optionally specific sources required by the active multicast services of the mobile user. It could be used in case of handover, roaming and failures.

Further mechanisms important for design of reliable mobile multicast transport include multicast retransmission and flow control. Detailed survey of multicast transport techniques in Internet is given [38]. Multicast approaches proposed for fixed mobile Internet could be adapted for mobile networking considering their receiver processing overhead.

The reliable mobile multicast transport discussed in the framework of IPv4 [14] is aimed at usage of foreign agents to support mobility, flow control and retransmissions for mobile group members changing frequently their location. The foreign agents are organised in a hierarchical scheme in order to reduce the overhead for retransmission and group membership processing of mobile nodes. The approach differentiates between immediate and delayed retransmissions dependent on the source of retransmission request (downstream foreign agent or attached mobile node). The goal is to aggregate retransmissions and to save bandwidth resources.

Similar hierarchical scalable multicast is proposed in the framework of router and application-level assisted multicast retransmission schemes, which are overviewed in [11].

The lightweight multicast service, discussed in [10], separates the error control for reliable transport into end-to-end and router assisted forwarding components. Based on the router hierarchy, the scalable reliable multicast routing optimising the network resources is performed.

Further approaches for router assisted retransmission schemes are PGM [3] and active error recovery [31] supporting NACK retransmission states at the routers. Log based reliable multicast [29], and RMTP [30] are examples for application-level reliable multicast, in which designated receivers or loggers at the certain level supply repairs to lower level designated receivers or loggers.

The scheme proposed in this paper for reliable mobile multicast is combining approaches of application-level and router assisted multicast considering the specifics of mobile and content networking.

The reliable mobile multicast transport is separated into:

- Reliable content delivery to the access router from the content network
- Access router assisted reliable transport to mobile receivers.

Figure 1 shows the general approach of the reliable mobile transport scheme discussed in this paper:

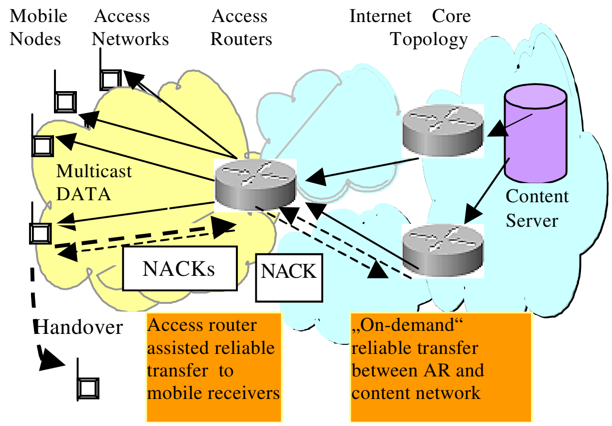

Figure 1: Separated reliable mobile multicast transport scheme supported by the access router

In order to optimise processing at mobile receivers, the state-of-the art based on usage of multiple multicast channels [21] is adapted to the needs of mobile multicast. Key point for adaptation of this scheme to mobile environment is usage of different multicast channels for data, retransmission and handover, which are supported by local multicast groups created at access networks avoiding on this way the significant overhead of IPv6 multicast group services.

Scalable flow control for heterogeneous multicast receivers [12], [32], and layered multicast with retransmissions [36] are considered in the flow control design of the proposed protocol focussing on different service levels with minimum QoS guarantee.

The reliable multicast protocol is incorporated in the IPv6 using context transfer aimed to support receiver based mobility. The scenario and protocol design are discussed in the next sections.

3. Scenario for content delivery to mobile multicast receivers

The scalable reliable multicast protocol is intended to be used in a heterogeneous mobile IPv6 infrastructure including access networks with different wireless technologies (TD-CDMA, WLAN, WIMAX, DVB, GPRS, Bluetooth) and broadcast media (DVB-T, DVB-H).

The reliable content delivery scenario is based on DAIDALOS Mobile IPv6 QoS based infrastructure [1]. DAIDALOS services are designed to support content networks with QoS delivery to mobile receivers. The application suite includes streaming, carousel and reliable file downloads to mobile terminals.

Optimisation based on multicast to mobile receivers is important focus of the architecture. Planning of Internet resources for multicast applications, especially of access networks using distributed QoS brokers for DiffServ and IntServ/RSVP is assumed as well as performance management for resource optimisation and seamless handover in heterogeneous mobile networks.

In DAIDALOS, the receiver and sender multicast mobility is supported by the access routers using the context transfer technology. Context Transfer is used at access networks to transfer states (control data) related to the mobile node's services changing their point of attachment [34]. It is aimed at support of the seamless handover (roaming) based on service continuation using contexts and could be used for transfer of different kind of control data and resources, supporting AAA (Authentication, Authorization and Accounting), security and QoS based services.

The following figure presents a heterogeneous mobile networking scenario for content delivery in DAIDALOS showing different access networks and service provisioning components aimed at content storage, adaptation and distribution, as well as security, accounting and QoS optimisation.

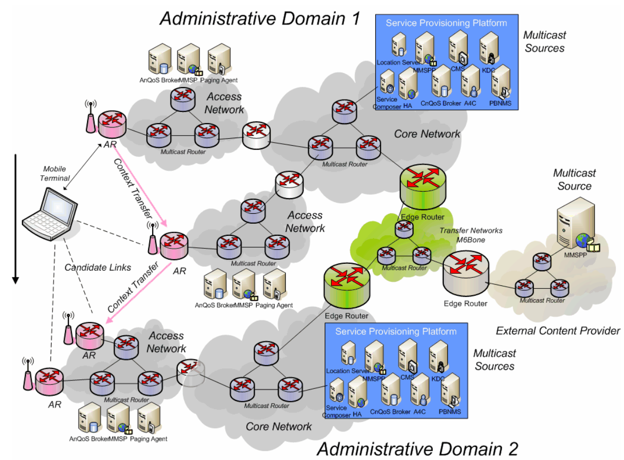

Figure 2: Scenario for content delivery in DAIDALOS heterogeneous IPv6 mobile networking infrastructure

Important components in this scenario are:

- Service provisioning platform supporting the content delivery between the core of the mobile architecture and access routers
- Access router system allowing the mobility in heterogeneous mobile IPv6 environment using the context transfer technology and service provisioning at the access networks.

4. Design of scalable reliable mobile multicast

Considering DAIDALOS architecture, the context transfer is an important issue, which is taken into consideration for the design of QoS based reliable transfer to mobile receivers.

Using context transfer, the access routers in DAIDALOS are able to support seamless communication during handover and to converge the IPv6 multicast protocol suite (MLDv2, PIM-SM) for mobile communication.

The context transfer functions of access router are extended with flow and retransmission states to support reliable transfer of content data to attached mobile multicast receivers.

4.1. Receiver mobility using context transfer

The reliable multicast mechanisms are integrated in the heterogeneous mobile IPv6 platform developed in EU project DAIDALOS [1] supporting dynamic group communication and multicast mobility based on adaptation of services for Multicast Listener Discovery (MLDv2) [17] and Protocol Independent Multicast – Sparse Mode (PIM-SM) [18] for multicast routing to mobile environment.

As result of the context transfer of the mobile node's active multicast listening states, MLDv2 could be rapidly re-established and the routing control data (multicast route tree) could be updated when the mobile node moves from the current to the next access network [33]. The Context Transfer (CT) protocol [19] proposed by Seamoby Working Group is used for transferring control data states (contexts) of MLDv2 protocol between access routers related to the mobile user and its active services before, during and after handover (roaming).

In order to support multiple access network interfaces and optimal access router selection in case of handover, the Candidate Access Router Discovery (CARD) protocol [20] is used.

A scenario for multicast context transfer is described in figure 3.

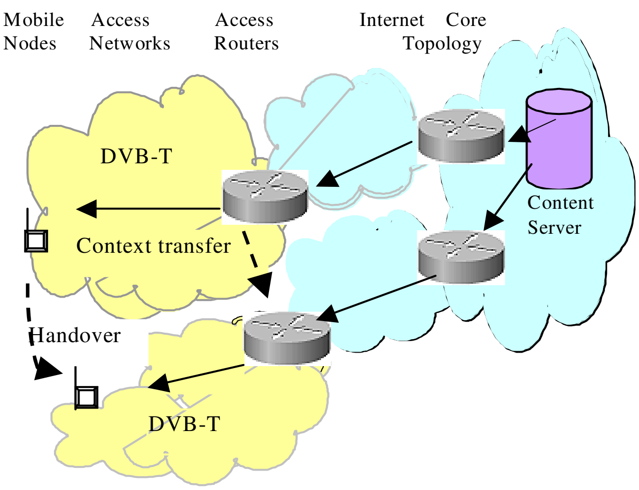

Figure 3: Scenario for multicast context transfer

The mobile node sends a message to the current access router in order to indicate handover to the next access router and to activate the context transfer.

When Fast Handovers [22] for Mobile IPv6 [23] is used, the FBU (Fast Binding Update) message triggers the context transfer between the access routers. The multicast context describing the current MLDv2 states of the mobile node (i.e. active multicast group listening context) is transferred from the current access router to the next access router, when the mobile node moves.

As result, MLDv2 context and multicast routing tables at the next access router could be updated, before the mobile node is finishing the handover. The signalling overhead to provide seamless multicast mobility using context transfer in this case is shown in figure 4:

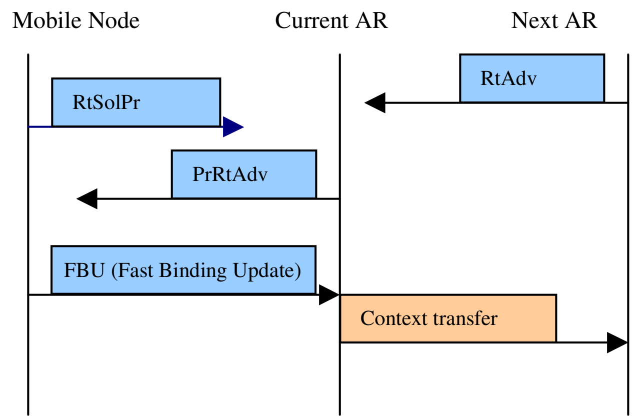

Figure 4: Signaling overhead for multicast context transfer using Fast Handovers

The used messages RtSolPr, RtAdv and PrRtAdv are part of the Fast Handovers [22] protocol. They are included to show the triggering of the multicast context transfer.

More details on multicast context transfer and further signalling techniques are discussed in [33], [35].

In addition to the supporting of the mobility based on multicast listening and routing context updates, the access routers are used to support the scalable reliable transfer to mobile multicast receivers.

4.2 Components of scalable reliable mobile multicast content delivery

DAIDALOS mobile architecture includes service provisioning platform for content storage, adaptation and distribution.

In order to deliver reliably the data from the content network to different number of mobile receivers, the access routers are involved.

The scalable reliable mobile multicast content delivery includes following components:

1. Reliable delivery of content data interacting with the service provisioning platform of the content network;
2. Support of mobility of receiving and sending multicast mobile nodes including mobile node routing and multicast group membership based on context transfer;
3. Access router assisted reliable multicast to mobile receivers. The transport between access routers and mobile nodes includes error, flow and handover control mechanism included in the design of the scalable reliable mobile protocol discussed in this paper.

The integration of the scalable reliable multicast transport into the design of access routers in DAIDALOS is given in figure 5:

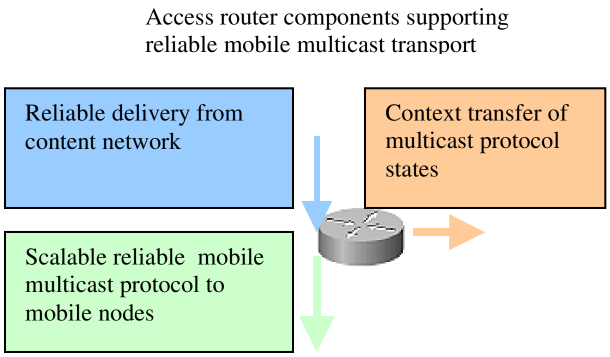

Figure 5: Access router components supporting scalable reliable mobile content delivery

Reliable delivery from content network to the access router is based on application level functions implementing interactions between service provisioning platforms and access routers. For more readings on this topic the documents describing DAIDALOS architecture could be used [1].

Mobility of mobile nodes with multicast services is realised based on the context transfer as described in the previous section.

Focus of this paper is the scalable reliable transport between the access routers and the mobile nodes. The access router is able to support the reliable transport in different ways:

- Usage of selectable error and scalable flow control schemes to heterogeneous mobile receivers;
- Optimising receiver overhead and network bandwidth usage based on flow control aimed to reduce implosion and exposure;
- Integrating minimum QoS guarantee concepts for mobile multicast receivers;
- Automated handover repair, which means rapid re-establishment of the lost data at the mobile node after the handover using context transfer to get the reliable multicast state of the entering mobile node.

5 Access router assisted reliable mobile multicast functions

The functions included in the design of the scalable mobile multicast at access networks are aimed to:

- Optimise the usage of mobile resources
- Reduced protocol processing at mobile receivers considering retransmission of loss packets towards
- Support mobility of multicast group members
- Provide rapid handover repair

5.2 Functions supported at access routers

The following figure shows the main protocol functions integrated in the access routers with their important design considerations for heterogeneous mobile environment:

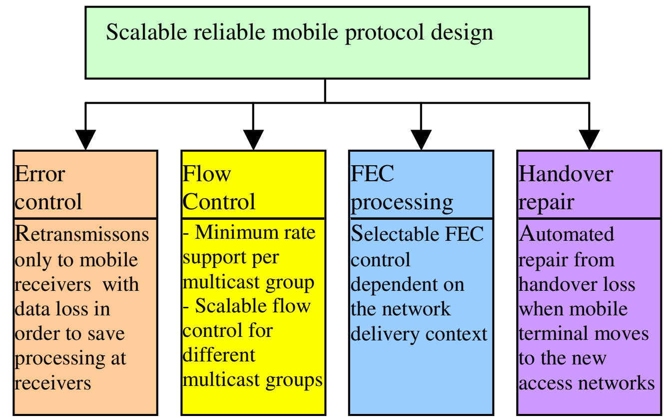

Figure 6: Mechanisms included at access routers for scalable reliable multicast

In heterogeneous mobile networking, rate based flow control considering minimum throughput as multicast flow parameter, is a solution taking into account differences in mobile receiver processing rates.

The approach to partition dynamically multicast receivers in groups based on their processing speed is discussed in [21].

This approach is adapted in the proposed scheme for mobile networking based on the concept of minim QoS guarantee (throughput, delay) for provision of reliable transmission within a multicast group. When the mobile node could not obtain the data in the negotiated minim throughput, it joins a multicast group with lower level of QoS guarantee.

Forward Error Correction (FEC) is used to improve reliability [2], [5], [9] and therefore such mechanisms are important for mobile environment. In mobile heterogeneous networking environment, FEC schemes on transport level could be selected dependent on the mobile network delivery context.

In case that the specific mobile network includes additional FEC and reliable mechanisms, for instance proposed for 802.11 Wireless Networks [6], then FEC on transport level could be skipped in order to save network resources. In this case, the reliability is achieved based on the retransmission and handover repair.

5.3 Error and flow control

There are different strategies for reliable multicast communication, which depend on the applications.
The NACK acknowledgement scheme based on negative acknowledgement sent by mobile receivers when they detect packet loss is studied in the known research. It was shown that NACK behaves in heterogeneous environment more efficiently than the ACK (positive acknowledgment) scheme [21]. Considering mobile networks, there are additional considerations for NACK schemes, especially loss of data during the handover of mobile receivers.
IETF RMT working group proposed a NACK based reliable protocol building block. Currently, the specific of mobile environment is not considered in this proposal, only the possibility for router assistance is mentioned [8].
In this paper, we propose a NACK acknowledgement scheme appropriate for access routers used in heterogeneous mobile IPv6

network infrastructures with varying numbers of multicast receivers, which could be connected to the access network dependent on its specific bandwidth and scope characteristics (WiMAX, WLAN, UMTS, DVB-T).

The error control is based on the adapting of works [21] proposing to restrict retransmissions in multicast protocols to receivers with really lost packets using multiple channels.

We adapt [21] to the heterogeneous mobile networking environment considering:

- Initiation phases with set-up of parameters;
- Dedicated channels for data, retransmission and handover;
- Network layer filtering for the channels based on local multicast addressing at mobile access network.

The specifics of the error control scheme described in figure 7 include:

- Sending of retransmissions to dedicated channels, i.e. "local" multicast group addresses as negotiated at the reliable service setup and context change due to the handover. This allows the filtering of the retransmissions only to the mobile multicast receivers, which are listening to the agreed local multicast addresses for retransmission.
- Minimum transfer rate negotiation during the setup of the reliable multicast and handover binding. The access routers adjust their buffers based on this parameter. At the mobile receivers, the parameter is used to send NACKs, when packet burst is lost. In case that for given threshold interval, no packets are received, the mobile node could send NACK control packets to require retransmission on the dedicated channel
- NACK control packets are sent in unicast mode from the mobile receivers to the access routers. The NACK acknowledgment is filtered at the network interface at the access router in order to drop multiple NACKs containing the same retransmission request.

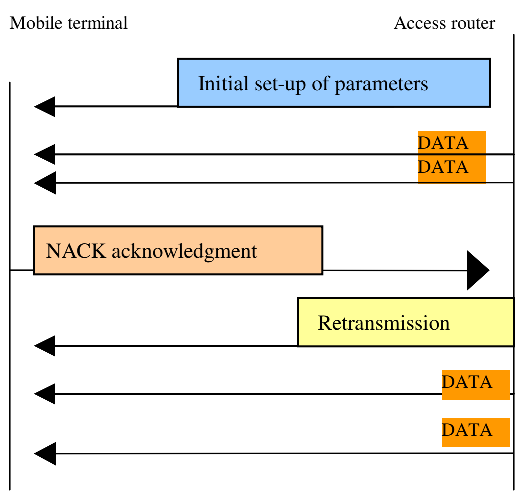

Figure 7: Message sequence diagram for error control

The proposed scheme solves specific multicast transport tasks focussing on following techniques:

Multicast problem	Description	Technique
Implosion	Loss of the packets triggers redundant acknowledgment messages sent from the receivers	Filtering and aggregating of messages at access routers
Exposure	When retransmissions reach receivers that have not experienced losses	Selectable local multicast groups a the mobile networks for retransmission from the access router to the mobile receivers
Multicast QoS support	Minimum throughput to multicast receivers based on rate control	Negotiation at the reliable transfer set-up or after the re-initiation of the transfer due to the handover

5.4 Handover repair

The goal of the handover repair is to replace the lost packets during the handover as soon as possible.

When the mobile node arrives at the next access routers, the retransmission of lost packets during the handover could be started immediately after the attachment of the mobile node to the new access network. For this purpose, the context transfer from the leaving to the new access router supplies the acknowledged data state.

The integration of handover repair based on specific dedicated channel using Fast Handovers [23] and context transfer [20] is shown in figure 8:

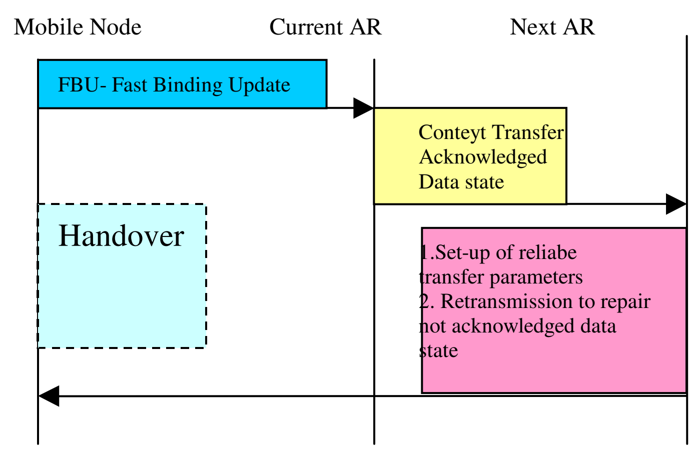

Figure 8: Message sequence diagram for handover repair

6 Conclusions

Protocol mechanisms for efficient reliable multicast transport enhancing the access routers in heterogeneous mobile infrastructure for content delivery were proposed. A main objective of the designed reliable multicast protocol was to reduce the receiver processing overhead considering different number of receivers.

In addition to the reliable transport, support for multiple network interfaces will be integrated to allow optimised selection of access networks for reliable multicast services considering network delivery contexts [37].

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