# Multicast Retransmission Strategies for content delivery in heterogeneous mobile IP environment

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ABSTRACT

For efficient deployment of new reliable multicast applications in heterogeneous mobile Internet environment, appropriate multicast retransmission strategies are discussed.

The focus of the proposed multicast retransmission schemes is the minimisation of the protocol overhead for reliable transport taking into account behaviour in mobile networks and application requirements (such as carousel file transfer, one-to-many download and media streaming combined with recording.

The application-specific retransmission strategies are designed for localized multicast error control supported by access routers. Considering IETF RMT standardisation work, they can be used for flexible configuration of tree-based reliable multicast protocols in converged wired and wireless Internet environment.

The implementation is based on Linux IPv6 environment. Simulations in ns2 focussing on the benefits of the proposed multicast retransmission schemes for particular application scenarios are presented.

## I. INTRODUCTION

Reliable multicast transport is expected to increase on importance with the deployment of new scalable multicast applications aimed at entertainment (on-demand music, on-line gaming, IPTV), one-to-many software downloads and infotainment (remote teaching, on-demand advertising, news distribution) in converged fixed and mobile IPv6 environments.

To support efficiently different reliability requirements for multicast transport based on optimization of the protocol data and control overhead, retransmission strategies are proposed considering the specific characteristics of new applications and mobile networks.

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The reliable multicast transport strategies are discussed based on the service framework of the QoS based architecture for heterogeneous mobile IPv6 environment developed in the European Community (EU) IST project DAIDALOS [1].

For flexible protocol configuration according different multicast applications and network requirements, the IETF RMT group has designed a reliable multicast framework based on building blocks [2], [3]. An example is the IETF NORM protocol [4] configured of such components for multicast error and flow control in order to provide efficient and scalable reliable bulk data transfer across heterogeneous networks.

In this paper, application-specific retransmission schemes are discussed, which are aimed to reduce the retransmission overhead considering new multicast application services with different reliability requirements for mobile Internet.

In particular, retransmission strategies are designed to support business scenarios based on repeated file transmissions (carousel), one-to-many reliable software downloads and streaming multicast combined with reliable storage. Important focus of the retransmission strategies is to provide efficient solution for multicast in heterogeneous mobile networking environment, where longer packet losses are possible due to disturbance, handoffs and “ping-pong” effects.

The proposed application-specific retransmission strategies, which provide local error recovery based on access router support, can be integrated as local schemes in tree-based reliable multicast protocols. The access routers receive the data reliably from the multicast source, cache it and transfer it to the attached mobile and fixed nodes belonging to the multicast group using the proposed retransmission schemes.

The paper is organised in the following sections. Section 2 discusses the IETF Reliable Multicast Transport (RMT) standardisation efforts and current research on retransmission schemes for scalable reliable multicast focussing on mobile environments. Reliable multicast protocol architecture for heterogeneous mobile Internet environment is addressed in section 3.

New application scenarios for mobile and fixed environment using reliable multicast transport together with appropriate application-specific retransmission strategies are presented in section 4. Simulations aimed to show the benefit of the proposed retransmission strategies for reducing of retransmission overhead for specific application scenarios are discussed in section 5.

## II. RELIABLE MULTICAST - STATE-OF-THE-ART

### A. *IETF standardisation of reliable multicast*

Reliable multicast protocols for fixed Internet are specified by IETF RMT (Reliable Multicast Transport Working Group) based on building blocks and protocol instantiations.

As it is defined in RFC 3048 [5], RFC 3269[6], a building block performs some specific functionality including particular algorithms and procedures with well-defined interfaces (application programming interface) to other building blocks and protocol instantiations.

Building blocks are designed to support specific tasks aimed to provide data reliability, congestion control, security, group membership and session management. Building blocks can be combined to build protocols with different complexity based on well-defined and standardised components.

Example for building blocks, which could be combined to configure reliable multicast protocol instances are:

- TCP-friendly multicast congestion control (TFMCC) [7],
- Multicast negative-acknowledgment (NACK)- oriented retransmission scheme [2] and [3];
- Forward Error Correction (FEC) building block defined in RFC 3452 [8];
- Signalling mechanisms for generic router assist [9].

Using building blocks, reliable multicast protocols could be flexibly configured [4], [10], [15]. The configured protocols can consist besides of the building blocks (i.e. standardised components) also of additional application functionality.

The Asynchronous Layered Coding (ALC) protocol [10] includes the layered coding transport, the multiple rate congestion control and FEC building blocks to provide congestion controlled reliable asynchronous delivery of content to unlimited number of concurrent receivers from a single sender.

The negative-acknowledgment (NACK)-oriented Reliable Multicast (NORM) protocol RFC 3940 [4], [11], is defined based on NACK-building block [2], [3].

For more complex reliable multicast protocols considering localised retransmissions and network topology to reduce the overhead, the Tree Based Acknowledgment protocol (TRACK) can be used, which support automatic tree building, retransmission and session management [12].

Currently, the proposed RMT building blocks do not consider the specific retransmission requirements for reliable multicast in wireless and broadcast Internet environments, as well as requirements for multicast mobility management in heterogeneous Internet infrastructures [13].

In this paper, in order to support new application scenarios for converged fixed and mobile environment, application-specific retransmission schemes considering mobile networks are proposed.

### B. *Reliable multicast retransmission schemes*

To argue appropriate schemes for new content delivery applications in converged mobile and fixed environment, related research activities are summarized. Survey of reliable multicast transport techniques in Internet is given in [14].

Dependent on the network infrastructure, the reliable multicast protocols are differentiated as:

- <u>Localised</u> reliable multicast protocols, which could take into account specific characteristics of the network (satellite, DVB-T, wireless network). For instance protocol for reliable content delivery over satellites focussing on unidirectional links techniques is proposed in [16];
- <u>Tree based (hierarchical)</u> reliable multicast protocols using localised retransmission schemes, which group the nodes in recovery regions and hierarchical topologies based on criteria such as administrative domains, geographical proximity or distance from the sender (for example, see [17]).
- <u>Reliable on-demand multicast</u> based on asynchronous requests of multiple users to the same content with integration of caching techniques to synchronise the transmission to the different users [18].

Selective Negative Acknowledgment (NACK)-oriented loss recovery is a scalable retransmission technique for multicast networks, which do not include hierarchical topologies [19]. In NORM protocol [4], multicast NACKs (to all members of the multicast group) are used based on a timer based back-off mechanism to suppress NACKs and avoid NACK-implosion at the sender. The retransmissions are performed at the sender awaiting some interval for NACK-aggregation. The NACK-implosion problem arises, when the number of receivers in the mobile network subscribed to the multicast service is high.

In heterogeneous networking environment, appropriate reliable multicast retransmission schemes can consider the characteristics of particular network. For instance, unicast NACK-based retransmission schemes are found to be useful technique for unidirectional networks, such as DVB-T or satellites. In [16], NACK-based schemes are proposed for reliable transport in Hybrid HAP-satellite architectures, where the satellite transmitter acknowledges the NACK receptions.

For design of reliable multicast retransmission schemes in mobile networking environment, there are different goals, which are aimed at efficient resource utilisation and reduced overhead. Such are:

- Optimisation of retransmission and control overhead adapting the retransmission scheme to the specific application requirements;
- Avoiding of duplicated retransmissions using delayed retransmissions and aggregation of retransmission requests;
- Algorithms adapted to specific access network delivery context (wireless networks with multicast facility, networks based on unidirectional links);
- Reducing the processing overhead at mobile multicast receivers to handle retransmissions by usage of unicast retransmissions and NACKs;
- Retransmission control at the sender to avoid additional processing at mobile receivers;
- Congestion and rate control to avoid packet loss due to resource lack;
- Tree based strategies for reliable multicast with local schemes dependent on the in specific network.

In order to reduce multicast receiver's overhead in mobile environment, retransmissions requested by NACK-oriented techniques can be sent on dedicated retransmission channels [30], to which only the receivers having losses are subscribed. A general framework for reliable multicast transport based on usage of separate channels for retransmission is discussed in [29].

Aim of reliable multicast in mobile networks is reducing the processing overhead of the receivers and avoiding of duplicated retransmissions. For this purpose, hybrid retransmission techniques based on switching between unicast and multicast retransmissions have been proposed [23].

Reliable multicast for the data link level of wireless networks is aimed to consider power and memory limitation of the mobile nodes [27]. Positive acknowledgments (ACKs) are collected at the back stations and sent to the source. In [28], a three-tired reliable retransmission scheme for wireless networks is proposed, based on "supervisory" hosts collecting ACKs and forwarding them to the source.

Log based reliable multicast [20], and Reliable Multicast Transport Protocols (RMTP) [21] are examples for tree-based reliable multicast, in which designated receivers or loggers at the certain level supply repairs to lower level designated receivers. In randomized tree based protocols, all of the members of the local region can perform retransmissions (see for instance Scalable Reliable Protocol [34]).

Router and application-level assisted hierarchical tree retransmission schemes for reliable multicast are overviewed in [26]. Router assisted schemes are included in the Pragmatic General Multicast (PGM) protocol [24] and in the active error recovery multicast [25] based on NACK retransmission states at the routers.

Tree based multicast combined with NACK-retransmissions is proposed in the framework of mobile IPv4 [22]. Foreign agents are used to support mobility, flow control and retransmissions for mobile group members frequently changing their location. The foreign agents are organized in a hierarchical scheme in order to reduce the overhead for retransmission and group membership processing of mobile nodes. It is differentiated between immediate and delayed NACK based retransmissions dependent on the source of retransmission request (downstream foreign agent or attached mobile node).

The Reliable Mobile Multicast Protocol (RMMP) is based on remote subscription [31]. The mobile node moving to a new access network reports its state to the mobile agent, who forwards the retransmissions.

Reliable multicast architecture based on a Multicast Subnet Agent (MSA) and Multicast Region Agent (MRA), acting as recovery nodes using the Reliable Range Based Multicast Protocol (RRBMoM) in a tree based hierarchical infrastructure, is described in [32].

In complex and large scale networking environment, deterministic tree based protocols consisting of localised network retransmission schemes could be used. In such schemes, repair groups are formed and arranged in tree-like hierarchies [39]. Each repair group has a repair head, which caches data packets and acknowledgments for retransmissions. The repair head may be re-selected based on changing network topologies.

The deterministic tree based protocols could be adapted for mobile environment considering access router as repairing head for the local region of a specific access network. Such scheme for mobile IP infrastructures is proposed in the next section.

## III. RELIABLE MULTICAST TRANSPORT ACHITECTURE

In DAIDALOS architecture [1], [33], wireless networks (WiFi, WiMAX, TD-CDMA, and Bluetooth) and broadcast media (DVB-T, DVB-H) are connected via access routers to the Internet (IPv6) infrastructures.

The infrastructures includes fixed core and mobile access network substructures, based on which tree based reliable multicast protocol can be flexibly configured considering the characteristics of each network component.

The design of reliable multicast architecture in DAIDALOS, discussed in [30], [33], is separated into localised reliable multicast delivery parts including:

(1) Reliable transfer schemes from the server(s) at core networks to access router(s);

(2) The caching of data at access routers and the reliable multicast transfer to attached mobile nodes, particularly considering the specific characteristics of the access networks.

The reliable multicast transport architecture is shown in figure 1:

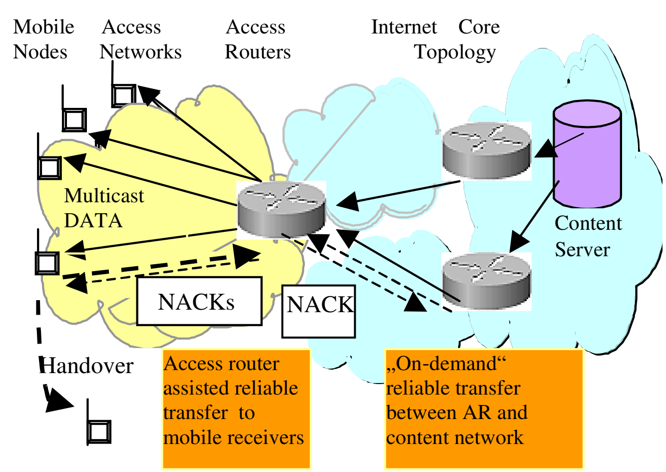


Fig. 1: General architecture for reliable multicast transport

Access routers are used to support mobility, context transfer of mobile node's services, resource reservation and retransmission [33]. The design involves access router assistance not only for mobility reasons, but also for intermediate caching of transmitted packets and their retransmissions to mobile or fixed receivers.

In the reliable multicast approach [30], it is proposed that access router communicate using context transfer to allow recover of lost packets due to handover of mobile nodes.

The end-to-end reliable multicast transport protocol can be based on appropriate application and network specific local schemes providing the reliable transport from the server to the access router (the core network segment) and from access router to the mobile or fixed receivers (the access network segment).

The core network topology connecting the server to the access router could be of different complexity. In case of global multicast to very large receiver groups, satellites could be used as cost efficient solution.

The localised retransmission schemes allow reducing the overhead in the mobile networks based on distributed processing of the retransmissions in fixed and mobile network infrastructures. Further efficiency arises from the usage of local retransmission strategies, which are optimised for the particular network (satellite, wireless LAN, broadcast media).

## IV. APPLICATION-SPECIFIC RETRANSMISSION STRATEGIES

This section describes scenarios for on-demand content delivery with asynchronous receiver requests based on different applications in heterogeneous fixed and mobile environment.

For each of the discussed scenario, cost efficient retransmission scheme is proposed aimed to reduce the network overhead for the multicast session.

The retransmission scheme can be used at the access network, where the router is the sender and the mobile nodes are multicast receivers.

### A. *Reliable carousel multicast*

File contents, such as news advertisement and information services, could be distributed periodically to multiple mobile and fixed receivers in carousel mode. The file contents could be updated based on actual information changes (i.e. flight plans or tourist information).

The carousel services can use different media (picture, graphics, text, audio, video) and be location and context aware. For example: When a user enters an area, where tourist information is distributed in carousel mode (location aware), the user's preferences will be retrieved (context aware) and dependent on the user's subscriptions the received content will be displayed. Another scenario could be the display of advertisements in a car when driving past a shop.

Multicast receivers may join asynchronously the multicast carousel content delivery. Also fixed users could join asynchronously such service to obtain for instance actual weather information.

In the carousel scenario, when receivers are joining the multicast group later, they receive the content reliably starting at the time they join the delivery and not from the beginning of the multicast transfer. Retransmissions are sent within some specific delay bound T also known as resilient multicast [35].

Some mobile receivers experiencing long lasting bursts of lost packets due to handover or disturbance will request a huge amount of retransmission packets. To avoid high bandwidth consumption by retransmissions, using resilient multicast only a limited number of retransmission packets will be sent. As the carousel service application re-sends the information files periodically, the missed content may be received in the next turn.

The retransmission scheme for carousel is described in detail using a NACK-oriented protocol building block (figure 2):

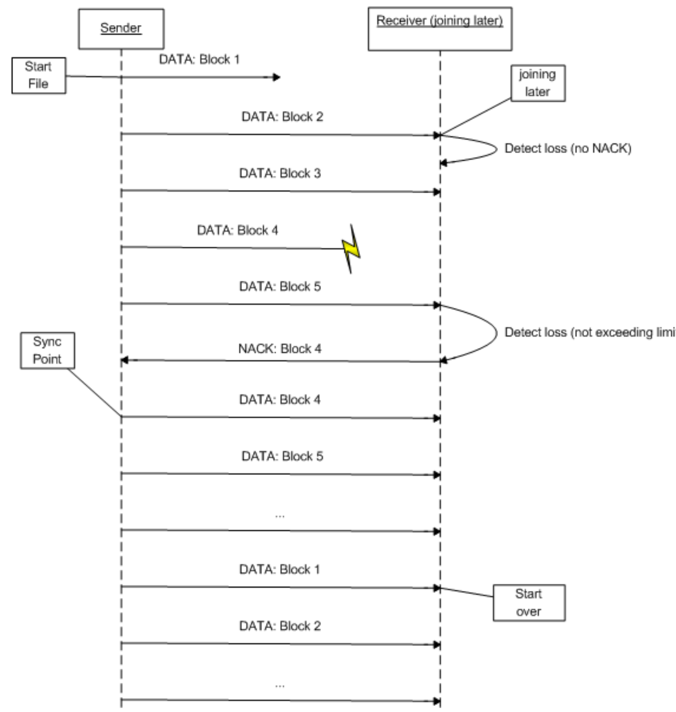


Fig. 2: Retransmission scheme for the reliable carousel multicast session

The later joining receiver (after block 2) will not send a NACK message to request retransmissions for the period before his join.

When a receiver detects a packet loss (in block 4), it sends a NACK request to the sender, which will collect and aggregate all incoming NACK messages and will afterwards (after a timer expires) multicast the retransmissions to the receivers. Retransmission of Block 4 will be answered, because it does not exceed the retransmission limit.

In case, that a receiver experiences a lot of packet losses due to disturbance, the receiver will suppress its NACKs. The carousel (repeated file transfer) allows in the next round to receive the missing packets.

Compared with reliable multicast transport protocols trying to retransmit all packets independent of the joining time, this strategy allows:

- Reduction of the retransmitted packets, when avoiding retransmissions of later joining receivers;
- Saving of network bandwidth for retransmissions to mobile receivers with long lasting packet losses, due to disturbance, handover or ping-point effect (when the mobile node is at the border of two cells and moves repeatedly between them).

*B. Reliable one-to-many download*

Software and media content could be delivered to multiple receivers in heterogeneous mobile and fixed environments using reliable multicast, n-times unicast or reliable broadcast [36].

Reliable mobile multicast for one-to-many download requires that all receivers, which subscribed to a session, get reliably the sent data. The transmission could be controlled by a flow control scheme similar to TCP, which adopts the sender's rate to the rate of slower receivers.

A problem of reliable multicast is that when a receiver looses packets, and needs retransmissions, then all other receivers, which have received reliably the data, will be also delayed by the retransmissions. A general-purpose multicast retransmission scheme, like the one integrated in NORM [4], is based on this principle.

To overcome this and to reduce the overhead (DATA and negative acknowledgments – NACKs), the reliable one-to-many download proposed in this paper is based on delayed retransmissions. Depending on the length of the file and buffers at the sender, the retransmissions are provided either at specific synchronisation points or at the end of the transferred file.

Delayed retransmissions allow the aggregation of NACK requests in mobile environments more efficiently considering losses of mobile nodes, caused by handovers and local disturbances.

After joining a one to many download multicast session, a receiver may experience losses of any kind and therefore send a NACK request to the server per multicast, so that other receivers may suppress NACKs with same content (NACK suppression).

To reduce the transmission time for non erroneous receivers and increase therefore the goodput, it is important to suppress NACKs requesting a wide range of loss data, because servers would need a lot of time to answer these requests and non erroneous clients would have to wait a long period until the next packets arrive.

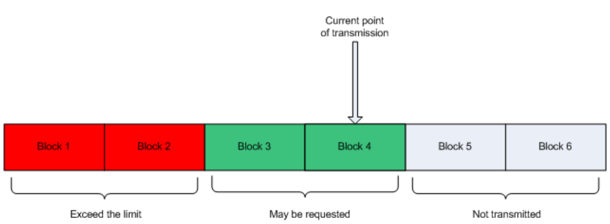


Fig. 3.: Block limits in One to many downloads

As it is shown in figure 3, data from block 3 and block 4 can be requested for retransmission, but not from block 1 and block 2. Clients, which would experience great bulk losses, may only send NACKs for segments in the current and the last block. NACKs for "older" blocks will be sent when the server indicates the end of transmission with a FLUSH message.

NACKs inside the limit will be answered at the next synchronisation point.

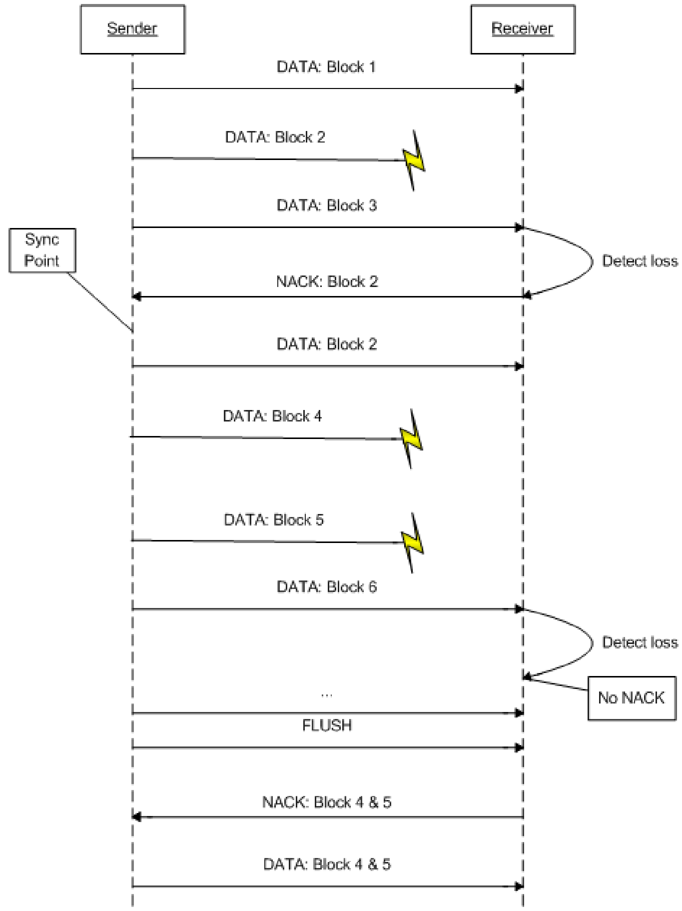


Fig.4: Retransmission strategy for reliable one-to-many download

In the fig. 4, the first NACK contains the missed Block 2, which does not exceed the retransmission limit. The Source answers with a retransmission at the next synchronisation point. The requested blocks (4 and 5) included in the second NACK message will be not be retransmitted, because they exceed the retransmission limit of the current (6) and last block (5). At the end of the example, the server sends flush messages, to retrieve any remaining NACKs from the clients. The receiver, which experiences this loss, answers with the NACK containing block 4 and 5. The server re-sends the blocks and if no other NACKs are pending, the server closes the transmission session.

This strategy allows the reduction of repeated retransmissions based on aggregation of NACKs providing retransmissions at synchronisation points or at the end of the file. Non erroneous clients benefit from this strategy, because the great part of retransmissions will be sent at the end and therefore non erroneous clients may finish the multicast delivery earlier, which will produce a better goodput for the non erroneous receivers.

*C. Media streaming combined with recording*

The trends in video on-demand content delivery systems are to provide new enhanced Video-on-Demand (VoD) experience in delivering movies and television programs to asynchronous fixed and mobile users combining streaming delivery with VCR functionality (Video Cassette Recorder) minimising the bandwidth requirements using multicast [37].

Such and other new on-demand media scenarios based on IPTV, VoD and audio consist of streaming services combined with reliable storage of the media data at the receiver.

Streaming on-demand services are based on rate controlled transfers, which can tolerate packet loss during the presentation, but are delay sensitive.

The idea is to tolerate losses during the streaming media transfer, but to store the media after the presentation for later usage without loss and corruption.

When the user requires streaming on-demand services combined with recording, the lost packets are retransmitted at the end of the delivery of the streaming media. NACKs will be sent as soon as a FLUSH message arrives and indicates the end of transmission.

The scheme is shown in figure 5:

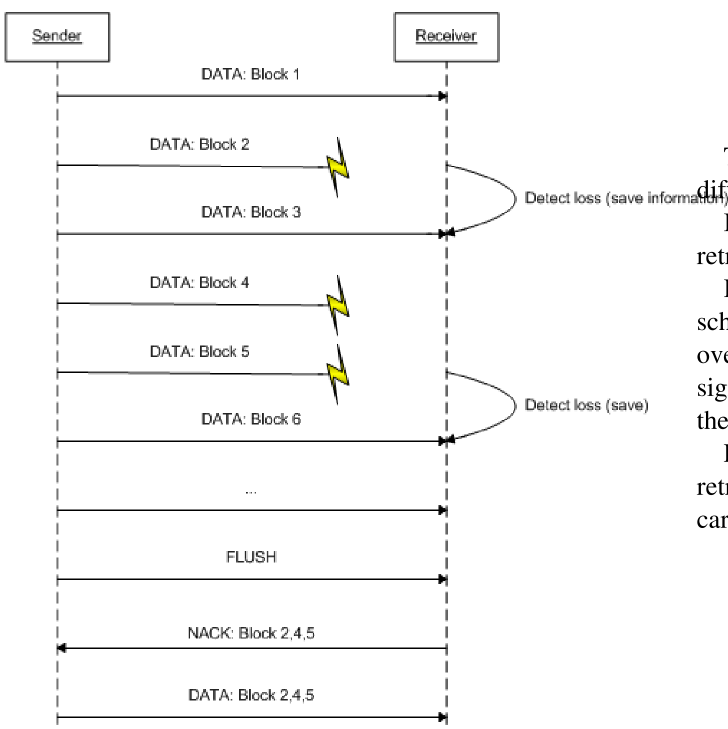


Fig. 5: Combined reliable media-on-demand and recording

## V. IMPLEMENTATION AND OVERHEAD ANALYSIS OF MULTICAST RETRANSMISSION SCHEMES

A prototype implementation of the multicast retransmission schemes is integrated in the Fedora Core 4 Linux operating system.

The implementation is based on the public domain sources [11] of the IETF NORM protocol [4], i.e. Negative-acknowledgment (NACK)-Oriented Reliable Multicast, which are enhanced with the proposed application-specific retransmission strategies discussed in the previous section.

The general-purpose NACK retransmission scheme of NORM is changed to support retransmissions only to receivers, which are experiencing packet losses. This is based on the usage of a special multicast retransmission address, at which the receivers with packet loss can dynamically listen [30].

In this paper, simulations are used, to show the benefits of the application-specific retransmission strategies. The simulation environment is built based on 11 Mbit/s WLAN (IEEE 802.11b - Wireless Local Area Network) connected to a given multicast access router, which supports the reliable multicast transport.

The scenario includes an access router (see, figure 6). connecting a WLAN with 20 receivers, thereof 6 are joining later the reliable multicast transport. A file of 2,5 Mbyte is transferred from the access router to the multicast receivers.

Delayed receivers since begin of the reliable multicast transmission are distinguished with different delay intervals:

1. case (0.5s – 3.0s): 0.5 s., 1.0 s., 1.5 s., 2.0 s., 2.5 s., 3.0 s.
2. case (1.0s – 6.0s): 1.0 s., 2.0 s., 3.0 s., 4.0 s., 5.0 s., 6.0 s.
3. case (5.0s – 30.0s): 5.0 s., 10.0 s., 15.0 s., 20.0 s., 25.0 s., 30.0 s.
4. case (10.0s – 60.0s): 10.0 s., 20.0 s., 30.0 s., 40.0 s., 50.0 s., 60.0 s.
5. case (15.0s. – 90.0 s.): 15.0 s., 30.0 s., 45.0 s., 60.0 s., 75.0 s., 90.0 s.

The overhead of the carousel scenario is analysed for the different cases of delayed receivers.

In case of usage of application-specific carousel service, no retransmissions are required.

However, using a general-purpose NACK retransmission scheme, which retransmits all lost packets, the protocol overhead (DATA + NACKs packets) due to retransmissions is significant and depends on the length of the intervals, by which the receivers are delayed.

For each of the cases with delayed receivers, the saved retransmission overhead using the application-specific carousel retransmission strategy is given in figure 6.

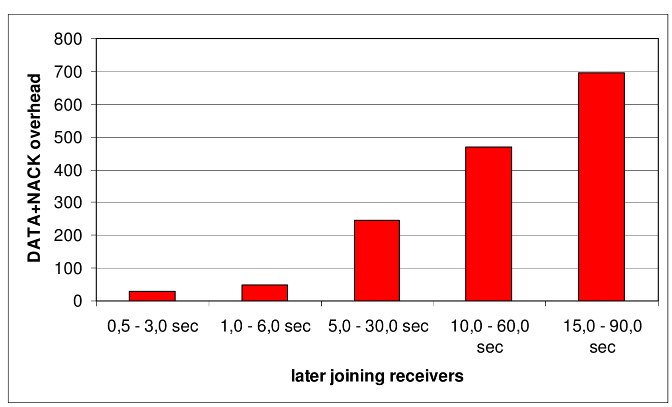


Fig. 6: Carousel scenario – reduced overhead (DATA + NACK)

The same scenario is used to show the one-to-many reliable download benefits.

Figure 7 shows the different time for finishing the download at the receivers without lateness and receivers with later joining of the group.

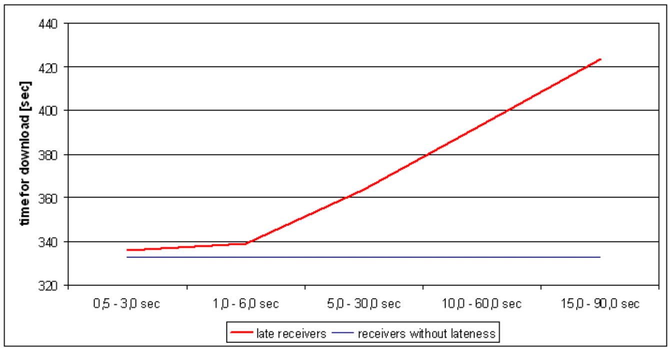


Fig. 7: Delay for finishing the transfer of one-to-many download

The results have shown that non erroneous clients benefit from the one-to-many download specific scheme, because the delay of the non erroneous clients to receive the file is significantly smaller than the delay of the erroneous clients

In addition, the overhead is reduced using the application-specific one-to-many multicast download strategy compared to general-purpose NORM retransmission (figure 8).

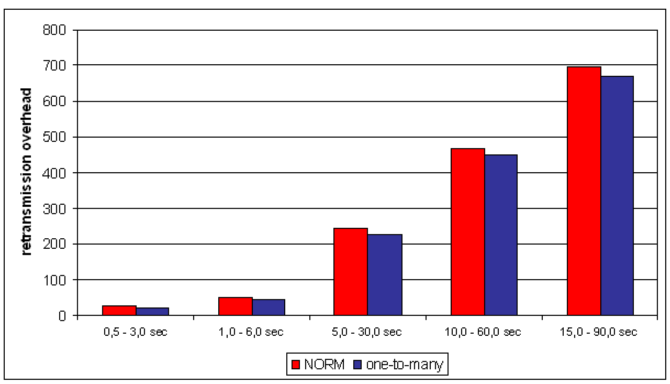


Fig. 8: One-to-many multicast download – overhead of application-specific and general purpose retransmission

## VI. CONCLUSION

This paper has shown the benefits of application-specific retransmission schemes for efficient resource utilisation in converged mobile and fixed environment. Access routers are used to retransmit the data to the mobile multicast receivers. Further work is to integrate these local schemes in a tree based reliable multicast protocol for heterogeneous mobile environment.

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