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Multicast Retransmission Strategies for Content Delivery in Heterogeneous Mobile Internet Environments

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Abstract – *For efficient deployment of new reliable multicast applications in heterogeneous mobile Internet environments, appropriate retransmission strategies are proposed.*

The focus is the minimization of the protocol overhead for reliable transport taking into account behavior in mobile networks (f.i. loss and handover behavior) and application requirements (such as carousel file transfer, one-to-many download and media streaming combined with recording).

The proposed techniques are designed as building blocks for localized multicast error control supported by access routers. Considering IETF RMT standardization work, the discussed retransmission approaches 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 focusing on the benefits of the proposed multicast retransmission schemes for particular application scenarios are presented. ***Copyright © 2006 Praise Worthy Prize - All rights reserved.***

Keywords*: reliable multicast, retransmission, carousel, one-to-many download, error control, network simulation*

I. Introduction

For new application scenarios in converged fixed and mobile IPv6 environments including entertainment (on-demand music, on-line gaming, IPTV), one-to-many software downloads and infotainment (remote teaching, on-demand advertising, news distribution), it is expected that the reliable multicast transport will increase on importance

The IETF Reliable Multicast Transport (RMT) group has designed a reliable multicast framework based on building blocks [1], [2], which is aimed at flexible protocol configuration. An example is the IETF NORM protocol based on such components for multicast error and flow control used to support efficient and scalable reliable bulk data transfer across heterogeneous networks [3].

In this paper, application-oriented multicast retransmission schemes for mobile Internet environments are discussed, which are aimed at reducing the retransmission overhead considering new application scenarios with specific reliability requirements.

In particular, retransmission strategies are proposed in order to support scenarios based on repeated file transmissions (carousel), one-to-many reliable software downloads and streaming multicast combined with reliable storage (recording).

An important focus of the retransmission strategies is to provide efficient solutions for multicast in heterogeneous mobile networking environments, where longer packet losses are possible due to disturbances, handoffs and "ping-pong" effects.

The proposed retransmission strategies are applied to provide local error recovery based on access router support and can be integrated as local schemes in tree-based reliable multicast protocols.

The architecture implies that the access routers receive the data reliably from the multicast source, cache it and finally transfer the data to the attached mobile and fixed nodes belonging to the multicast group using the proposed retransmission schemes.

The reliable multicast transport strategies are discussed based on the QoS management architecture for the heterogeneous mobile IPv6 environment supporting mobile multicast [4], which is developed in the European Community (EU) IST project DAIDALOS (http://www.ist-daidalos.org).

The paper is organized in the following sections: Section 2 discusses the IETF Reliable Multicast Transport (RMT) standardization efforts and current research on retransmission schemes for scalable reliable multicast focusing on mobile environments.

A reliable multicast protocol architecture for heterogeneous mobile Internet environments is addressed in section 3. New application scenarios for mobile and fixed environments using reliable multicast transport together with appropriate application-specific retransmission strategies are presented in section 4.

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Simulations provided to show the benefits of the proposed retransmission strategies for reducing the retransmission overhead for specific application scenarios are discussed in section 5.

II. Overview of reliable multicast

The current standardization work at IETF and the state-of-the art on reliable multicast is overviewed.

II.1. IETF standardization of reliable multicast

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

As 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 to provide data reliability, congestion control, security, group membership and session management. Building blocks can be combined to build protocols with different complexities based on well-defined and standardized components [2], [7], [8].

Examples for building blocks used for configuration of reliable multicast protocol instances are:

- Multicast negative-acknowledgment (NACK) oriented retransmission scheme [1] and [2];
- Forward Error Correction (FEC) defined in RFC 3452 [8];
- TCP-friendly multicast congestion control (TFMCC) [9],
- Signaling mechanisms for generic router assist [10].

Reliable multicast protocols consist beside of the building blocks (i.e. standardized components) also of additional application-oriented functions.

In order to support congestion controlled reliable asynchronous delivery of content to an unlimited number of concurrent receivers from a single sender, the Asynchronous Layered Coding (ALC) protocol [7] integrates building blocks for layered coding transport, multiple rate congestion control and forward error correction (FEC).

The negative-acknowledgment (NACK)-oriented Reliable Multicast (NORM) protocol RFC 3940 [3], is defined based on the NACK-building block [1], [2].

For more complex reliable multicast protocols in order to reduce the overhead considering localized retransmissions, the Tree Based Acknowledgment protocol (TRACK) can be used, which supports automatic tree building, retransmission and session management [11].

Currently, the proposed RMT building blocks do not consider the specific multicast retransmission requirements in converged mobile and heterogeneous Internet infrastructures consisting of wireless networks and broadcast media.

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

II.2. B. Reliable multicast retransmission schemes

Survey of reliable multicast transport techniques in Internet is given in [12].

Dependent on the network infrastructure, the reliable multicast protocols are grouped into:

- Localized reliable multicast protocols, which could take into account specific characteristics of the network (satellite, DVB-T, wireless network). For instance, a protocol for reliable content delivery over satellites focusing on unidirectional links techniques is proposed in [13];
- Tree based (hierarchical) reliable multicast protocols using localized retransmission schemes. The nodes are organized in recovery regions and hierarchical topologies based on criteria, such as administrative domains, geographical proximity or distance from the sender (for example, see [14]).
- Reliable on-demand multicast schemes. They are based on asynchronous requests of multiple users of the same content with integration of caching techniques to synchronize the transmission to the different users [15].

Selective Negative Acknowledgments (NACKs)-oriented loss recovery is a scalable retransmission technique for multicast networks, which does not include hierarchical topologies [16].

In the NORM protocol [3] NACKs are sent to all members of the multicast group. They are enhanced with a timer based back-off mechanism to suppress NACKs and avoid NACK-implosion at the sender. The retransmissions are delivered by the sender after waiting a defined 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 an heterogeneous networking environment, appropriate reliable multicast retransmission schemes can consider the characteristics of particular networks. For instance, unicast NACK-based retransmission schemes are found to be a useful technique for unidirectional networks, such as DVB-T or satellites.

In [13], NACK-based schemes are proposed for reliable transport in Hybrid HAP-satellite architectures, where the satellite transmitter acknowledges receptions

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of the NACKs.

For the design of reliable multicast retransmission schemes in mobile networking environments, there are different goals, which target efficient resource utilization and reduced overhead. Such are:

- Optimization 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 a 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 specific network.

In order to reduce the multicast receiver's overhead in mobile environments, retransmissions requested by NACK-oriented techniques may be sent on dedicated retransmission channels [17], to which only the erroneous receivers are subscribed. A general framework for reliable multicast transport based on usage of separate channels for retransmission is discussed in [18].

The aim of reliable multicast in mobile networks is to reduce the processing overhead of the receivers and to avoid duplicated retransmissions. For this purpose, hybrid retransmission techniques based on switching between unicast and multicast retransmissions have been proposed [19].

Reliable multicast for the data link level in wireless networks is specified to consider power and memory limitation of mobile nodes [27]. Positive acknowledgments (ACKs) are collected at the back stations and sent to the source. In [28], a three-tiered 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 the Reliable Multicast Transport Protocol (RMTP) [21] are examples for tree-based reliable multicast, in which designated receivers or loggers at a certain level supply repairs to lower level designated receivers. In randomized tree based protocols, all members of a local region can perform retransmissions (see for instance Scalable Reliable Protocol [22]). Router and application-level assisted hierarchical tree retransmission schemes for reliable multicast are overviewed in [23]. 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 [26]. 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 [29]. The mobile node moving to a new access network reports its state to the mobile agent, who forwards the retransmissions from the old access network to the new access network.

A reliable multicast architecture based on a Multicast Subnet Agent (MSA) and Multicast Region Agent (MRA), acting as recovery node using the Reliable Range Based Multicast Protocol (RRBMoM) in a tree based hierarchical infrastructure, is described in [30].

In complex and large scale networking environments, deterministic tree based protocols consisting of localized network retransmission schemes could be used. In such schemes, repair groups are formed and arranged in tree-like hierarchies [31]. Each repair group has a repair head, which caches data packets and acknowledgments for retransmissions. The head may be re-selected based on changing network topologies.

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

III. Reliable multicast transport architecture

In the DAIDALOS architecture, 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 [4].

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

The reliable multicast architecture in DAIDALOS [32] consists of localized reliable multicast delivery parts including:

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

(2) 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 fig. 1:

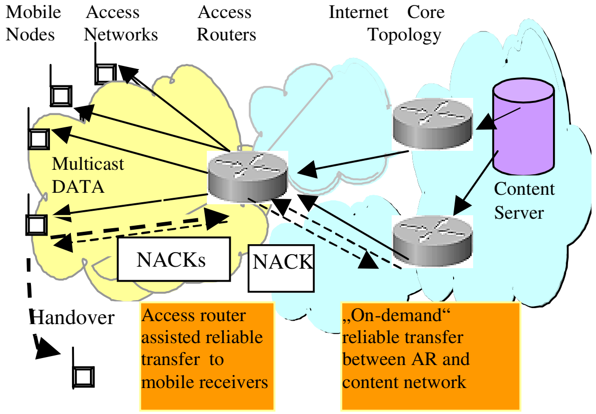

Fig. 1. General architecture for reliable multicast transport

Access routers are used to support mobility, context transfer of mobile node's services, resource reservation and retransmissions. 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 [4], it is proposed that access routers communicate using context transfer to allow the recovery 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 reliable transport from the server (source) 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 localized retransmission schemes allow reducing the overhead in 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 optimized for the particular network (satellite, wireless LAN, broadcast media).

IV. Application specific retransmission strategies

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

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

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

IV.1. 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 types (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. In addition, fixed users could join asynchronously such a 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 [33].

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

Some mobile receivers experiencing long lasting bursts of lost packets due to handover or disturbance effects 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 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 (f.i. 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. Retransmissions for block 4 will be served, because they do not exceed the retransmission limit.

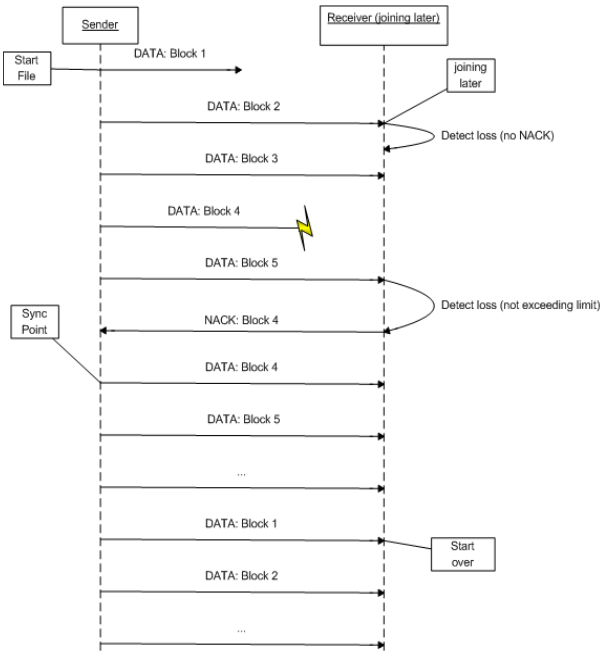

Fig. 2. Retransmission scheme for the reliable carousel multicast session

In case, that a receiver experiences a lot of packet losses due to disturbance, the receiver will suppress its NACKs (compare to Fig.2). 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).

IV.2. 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 [34].

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 also be delayed by retransmissions. A general-purpose multicast retransmission scheme, like the one integrated in NORM [3], is based on this principle.

To overcome this disadvantage 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 sent and buffers at the sender, the retransmissions are provided either at specific synchronization 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.

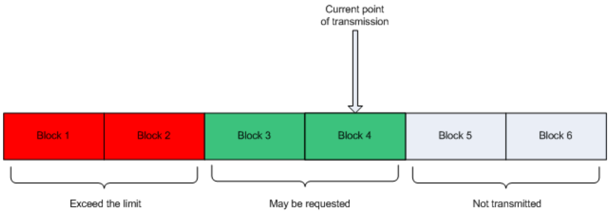

Fig. 3. Block limits in One-to-many downloads

As it is shown in fig. 4, data from block 3 and block 4 may be requested for retransmission, but not from block 1 and block 2. Clients, which 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 synchronization point.

In 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 synchronization point.

The requested blocks (4 and 5) included in the second NACK message will 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 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.

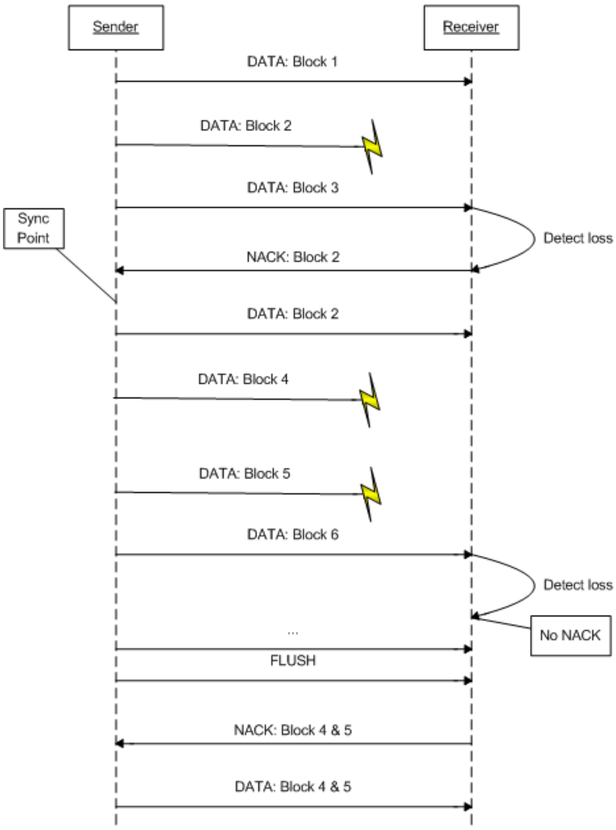

Fig. 4. Retransmission strategy for reliable one-to-many downloads

This strategy allows the reduction of repeated retransmissions based on aggregation of NACKs providing retransmissions at synchronization 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 reception earlier, which will produce a better goodput for non-erroneous receivers.

IV.3. 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 with VCR functionality (Video Cassette Recorder) minimizing the bandwidth requirements using multicast [35]. 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 fig. 5:

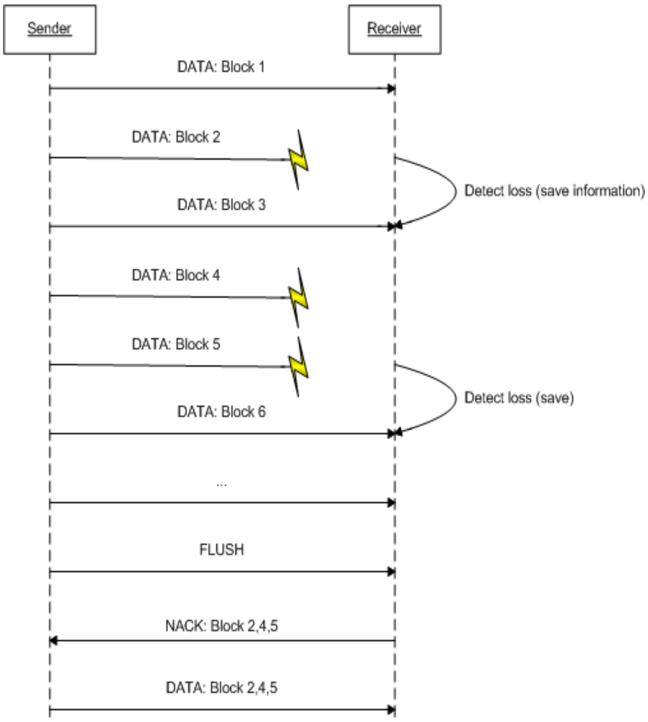

Fig. 5. Combined reliable media-on-demand and recording

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 [36] of the IETF NORM protocol [3], i.e. Negative-acknowledgment (NACK)-Oriented Reliable Multicast. It is enhanced with the proposed application-specific retransmission strategies discussed in the previous section.

In this paper, simulations are used, to show the benefits of the application-specific retransmission strategies compared to the NORM protocol.

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 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 reliable multicast receivers.

For the executed simulations, delayed receivers since begin of the reliable multicast transmission are distinguished with different delay intervals:

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

The loss pattern of the delayed receivers is shown in fig. 6, where x can be an interval of 0.5s, 1.0s, 5.0s, 10.0s and 15.0s in order to represent the different simulation cases.

The pattern is characterized by overlapping losses due to delayed receivers:

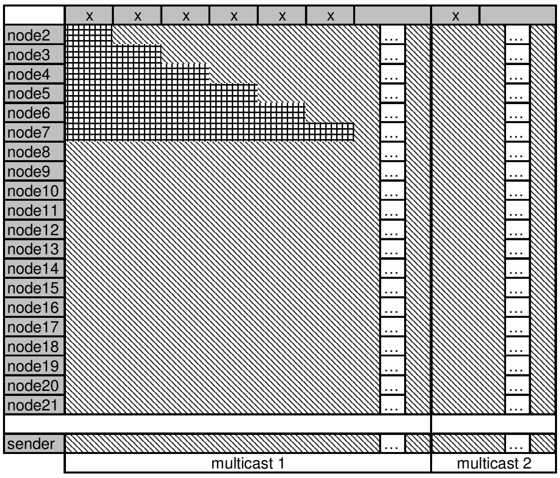

Fig. 6: Loss pattern of overlapping delayed receivers

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

The implemented carousel retransmission scheme needs no retransmissions for losses due to delayed receivers. Using the NORM protocol, the retransmission overhead (DATA + NACKs packets) is significant and depends on the length of the intervals, by which the receivers are delayed.

For each simulation case with delayed receivers, the saved retransmission overhead of the carousel strategy compared to NORM is shown in fig. 7.

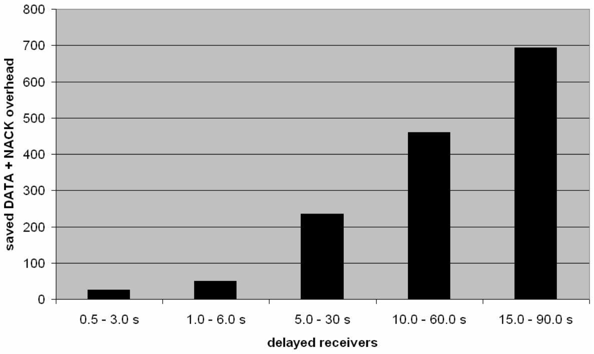

Fig. 7: Carousel scenario – reduced overhead (DATA + NACK) compared to NORM

Another benefit of the application specific carousel strategy compared to NORM is the smaller delay for the finishing of the multicast transfer for non-erroneous receivers. This is shown in figure 8:

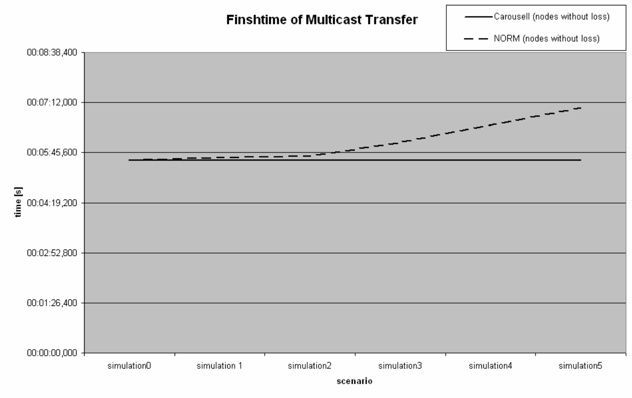

Fig. 8. Delay for finishing the transfer of carousel service compared to NORM

A similar scenario emulates non-overlapping disturbances in mobile network environment of 6 receivers (see figure 9).

It is used to show the benefits of the one-to-many reliable download. In this scenario x is 0.5s in sim1, 1.0s in sim2, 5.0s in sim3, 10.0s in sim4 and 15.0s in sim5.

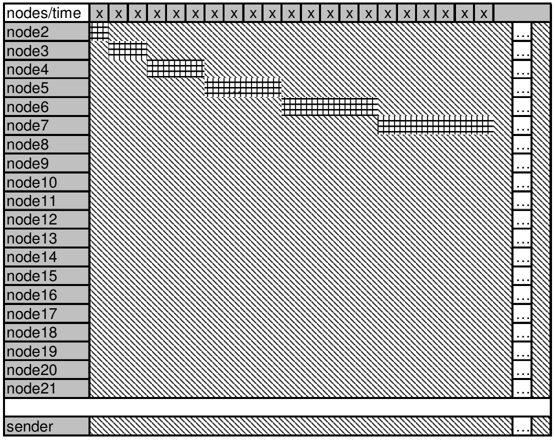

Fig. 9: Loss pattern of non overlapping disturbance intervals

Compared to NORM retransmission (see, fig. 10), the mean retransmission packet overhead of the one-to-many multicast download strategy for the different simulation cases is smaller.

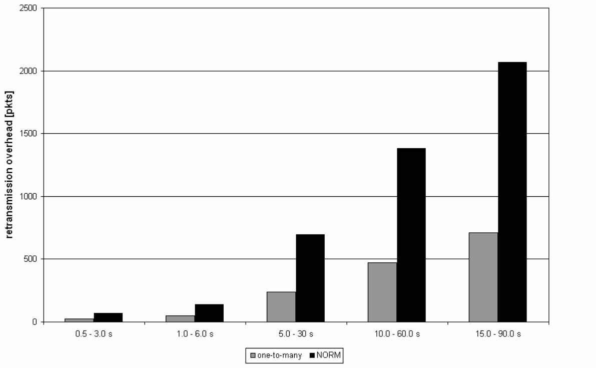

Fig. 10. One-to-many multicast download – mean retransmission overhead compared to NORM

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Similar to carousel, the finishing time of the one-to-many download (OTMD) transfer for the receivers, which have no packet loss, is smaller compared to NORM. The OTMD finishing time is impacted by the selected block size. The block size has influence when the retransmission is sent. A bigger block size is leading to immediate retransmissions, where a smaller block size causes delayed retransmission at the end.

Delayed retransmissions are resulting in a smaller finishing time for the non-erroneous receivers.

NORM is independent of the block size and sends only immediate retransmissions; therefore, the finishing time is greater in all cases, especially with increasing losses. The impact of the block size is seen in the fig. 11. 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.

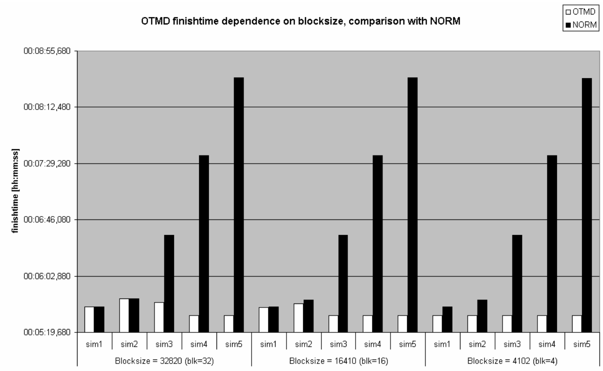

Fig. 11. Delay for finishing the transfer of receivers without error of one-to-many download compared to NORM

Enhanced delay for finishing of the multicast streaming with recording is achieved based on the simulation of the new scenario when six receivers have the depicted losses.

In fig. 12, the smaller delay for finishing of the multicast streaming compared to NORM is shown.

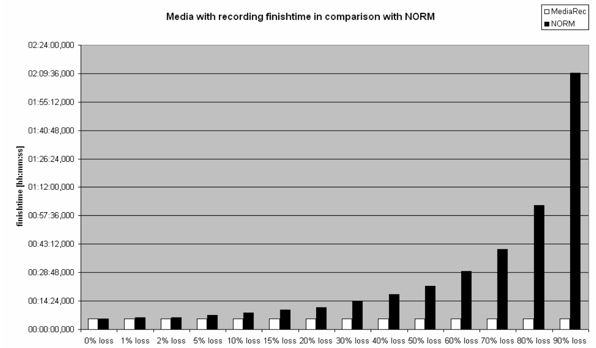

Fig. 12. Delay for finishing the transfer of receivers without error of multicast streaming compared to NORM

With increasing loss, the finishing delay of the non-erroneous receivers remains the same in the multicast media streaming, but in NORM it increases significantly.

VI. Conclusion

Design, implementation and simulation of appropriate retransmission schemes for multicast carousel, one-to-many download and multicast streaming combined with recording was discussed. The retransmission schemes were designed to take into account application-specific requirements, as well as disturbances of mobile network environments.

Compared to the IETF NORM protocol, the simulations have shown that the new strategies behave better in the discussed application scenarios, especially for multicast receivers without losses.

The simulations include loss patterns with delayed receivers and disturbances typical for mobile environment. The finishing times for non-erroneous receivers in all application-specific retransmission schemes was shown to be better than NORM. The retransmission overhead dependent on the loss pattern in the most cases was smaller compared to NORM, due to higher aggregation of retransmission data, as the retransmissions are sent at the end of transfer.

The presented reliable multicast schemes are part of the DAIDALOS QoS oriented mobile architecture for heterogeneous environment supporting multicast receivers [4].

In the proposed reliable multicast transport, 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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