Efficient reliable multicast strategies for content delivery to mobile users

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Abstract

On-demand services are aimed at efficient delivery of media contents over Internet infrastructures to multiple customers requiring the same content asynchronously. To achieve this, multicast techniques and appropriate network infrastructures could be used. This paper discusses architecture and retransmission techniques for reliable multicast transport supporting on-demand content delivery in converged mobile and fixed broadband environment.

The main focus of the paper is the cost efficient provision of on-demand content delivery based on reliable multicast transport structured into core-network reliable transport (from content server to access router) and access-network retransmission schemes (from access routers to mobile nodes). Considering the application model, network delivery context and on-demand service requirements (carousel, bulk data, streaming), appropriate retransmission schemes based on access router support are proposed.

***Index Terms* –** Reliable Mobile Multicast, Transport Protocol

I. INTRODUCTION

A key strategy for service providers and Telecoms is the integration of cost efficient and QoS based multimedia content delivery on-demand within the framework of user-centric broadband infrastructures and multiple (triple) play service bundles [28].

On-demand services target efficient delivery of media and data contents over Internet infrastructures to multiple customers. Multicast transport schemes for on-demand services are diverse, because they have to aggregate asynchronous content requests of users and support various application models.

These services will allow new business scenarios including entertainment (on-demand music, on-line gaming, IPTV) and infotainment (remote teaching, on-demand advertising, news distribution) in converged fixed and mobile IPv6 environment. For cost efficient provision of on-demand services, the integration of QoS based multicast transport architectures is an important factor [31]

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Reliable multicast transport is expected to increase on importance with the introduction of new on-demand content delivery scenarios with diverse application models and specific QoS and scalability requirements, such as:

- News and advertisements delivery in carousel mode to multiple receivers;
- Software distributions and updates based on multicast file downloads;
- Video-on-Demand, Music and other media on-demand;
- Streaming services such as IPTV combined with reliable transport schemes.

Integration of cost efficient multicast strategies is an important factor for the success of these services. In this paper, new concepts for cost efficient reliable multicast transport of on-demand services are proposed based on:

- Separation of end-to-end reliable multicast transport into core and access network reliable multicast transport schemes interacting over caching strategies at access routers;
- Flexible selection of multicast retransmission schemes for core and access network dependent on application content delivery model and specific network characteristics.

The multicast transport is proposed based on the framework of the QoS based mobile architecture for heterogeneous IPv6 environment developed in the European Community (EU) IST project DAIDALOS.

The paper is organised in the following sections.

Section 2 is focussed on the current state-of-the-art on reliable multicast for on-demand content delivery, as well as concepts and current research on cost efficient reliable multicast transport.

Section 3 discusses requirements for reliable multicast based on new business scenarios for converged mobile and fixed environment.

Section 4 introduces networking architectures (DAIDALOS and satellites) involving access networks for reliable mobile multicast.

Section 5 discusses retransmission strategies, which could be used in core and access networks to reduce network bandwidth costs.

Section 6 addresses performance analysis of implemented multicast retransmission strategies.

Section 7 concludes this paper.

II. RELIABLE MULTICAST FOR ON-DEMAND CONTENT DELIVERY

1) STATE-OF-THE-ART

On-demand content delivery is characterised with:

- Asynchrony, as clients can request for the media at different times;
- Non-sequentially, because the clients may access the media starting at different parts at the media object.

Protocols and mechanisms for on-demand delivery are surveyed in [32], [8]. In such protocols, multicast is used to reduce the required bandwidth and provide quickly QoS based delivery to huge amount of receivers. The bandwidth reduction is accomplished by dynamically aggregating receivers that make requests to the same content closely spaced in time, so that they share the same multicast streams. Caching allow to synchronise transfer to multiple users, which require the content asynchronously. On-demand multicast routing with caching of streaming data at routers or proxies in order to aggregate receivers with asynchronous requests is discussed in [19]. In different approaches, the IP multicast [2] is used for on-demand services to serve multiple requests by a single stream. Due to the synchronous nature of multicast, clients either wait for the next scheduled multicast session at the cost of some start-up delay [5], or participate in more than one sessions simultaneously [35].

In the past, the main focus addressed the usage of multicast strategies for Video-on-Demand (VoD) streaming multicast [32], [10], [7]. In order to provide efficient multicast, VoD applications and multicast strategies are designed to consider asynchronous behaviour of multiple users, as well as their planned and predicted behaviour.

Approaches integrated into VoD protocols are:

- Periodic broadcasting based on scheduling repeated broadcasts of the video (or equal video segments) at pre-scheduled times [34], [20]. Each schedule includes bandwidth and buffering requirements for receiving multiple segments simultaneously. The required client start-up delay could decrease exponentially with increasing server bandwidth used to multicast the segments [34].
  Batching [20] is similar approach using multicast for multiple clients requesting the same video within given batching interval. Periodic broadcast is used for Near Video on Demand (NVOD).

- Patching [9] makes use of multicast and unicast. Users join multicast groups without waiting and buffer the received video, while receiving a unicast patch stream from the server for the portion of data they have missed.

- Stream merging algorithms aggregate the clients requesting the same media, adjusting the playback rate [16], [35]. Adaptive piggybacking allows the media playback rate of on-going streams to be altered so that different media streams can merge, when the streams reach the same position in the media object. Bandwidth skimming protocols use a hierarchical multicast-stream-merging to dynamically aggregate clients into larger groups that share streams together [12].

While in the past streaming on-demand for VoD got a lot of research interest, with the introduction of new applications, such as multiple (and triple) play bundles, the reliable multicast transport for on-demand content delivery increases on importance.

Considering new business scenarios, diverse applications based on reliable multicast strategies, particularly combined with streaming and real-time transfers, are deployed. Examples are IPTV, High Definition (HD) TV, True VoD, "rich" Video Conferencing, On-demand advertisement and News, On-line Games, virtual home networking, hosting of private contents and advanced teleworking.

Although some strategies for reliable multicast content delivery could be obtained from the streaming on-demand protocols, issues especially concerning the retransmission overhead have to be focussed in reliable multicast for on-demand transport.

Reliable multicast, which considers scenarios based on asynchronous requests for content delivery of multiple users, is particularly addressed in [32], [18].

A special approach is the tree-based reliable multicast [17]. Application-Layer Multicast (ALM) could be used for scalable reliable on-demand delivery [14].

One important issue for reliable multicast transport arising from the diversity of multiple (triple) play business scenarios [28], is the consideration of different application models for on-demand services in order to provide cost efficient appropriate reliable multicast transport schemes.

2) COSTS OF MULTICAST TRANSPORT FOR ON-DEMAND DELIVERY

Protocols for on-demand delivery using multicast and caching differentiate in the bandwidth requirements for multiple users accessing asynchronously the same media.

There are different approaches, which could be used to describe performance and cost issues of reliable multicast protocols for on-demand delivery.

Metrics could consider efficiency of multicast routing, aggregation of users for on-demand delivery, overhead of multicast retransmission techniques and QoS experience of the users of the content delivery application.

In particular, the following approaches describing costs and performance of multicast communication could be used:

- *Metrics describing efficiency of scalable on-demand streaming*. The bandwidth for VoD is calculated based on the used compression and encoding) methods (MPEG2, MPEG4), number of subscribers; number of broadcast channels, concurrent user rate for VoD [34], [35]. Metric considering parameters, such as economics of scale, average length of the multicast routing path, the total length of multicast distribution tree and multicast group size, is discussed in [34]. In addition to link usage (as measured by tree costs), the efficiency of protocols for on-demand delivery is evaluated in terms of bandwidth requirements, delay and traffic concentration metrics. QoS evaluation of multicast streaming protocols considering network and server requirements is discussed on [29].

- *Costs of multicast routing*. The objective of multicast routing protocols is the construction of a multicast delivery tree routed at the source of multicast group and optimizing given cost (bandwidth, traffic distribution), QoS parameters (delay, packet loss) or other criteria. Resource usage and cost depend on the chosen multicast routing algorithm and the tree management approach [36], [27].

- *Aggregation overhead metric*. In case of inter-group tree sharing, metrics to describe efficiency of aggregated multicast are used, which express the reduction of the multicast trees and thus multicast router states for multiple multicast groups [30].

- *Metrics describing reliable transport overhead.* Metrics, such as data recovery latency, receiver exposure, data traffic overhead, control packet network overhead are used in [39] to describe performance and costs of related to application-level and router-assisted reliable multicast.

In this paper, in order to compare overhead of different reliable multicast transport strategies, multicast tree costs derived from bandwidth requests for data, control and retransmission packets of the particular retransmission scheme are obtained.
A network is modelled as an undirected graph G(V,E) with a multicast distribution tree T given by the length :

$L(T) = \sum c_{ij}$.

Assuming that each edge (i, j) is assigned the same cost c_{ij} , then the total costs C_{m_user} per receiver for multicast session could be calculated based on the bandwidth required for data, retransmissions and control packets:

(F1)

$$C_{m\_user} = \frac{C_{data} * L(T) + C_{retr} * L(Tr) + C_{ctrl} * L(Tc)}{N}$$

where

N = receiver number (multicast group participants);
C_{data} = Amount of data;
C_{retr} = Amount of retransmissions;
$L(T_{retr})$ = length of Tretr $\subseteq$ T used for retransmission;
C_{ctrl} = Amount of control data;
$L(T_{ctrl})$ = Tree length required for control packets.

Quantifying the reliable multicast tree costs on this way allow to focus on simple metrics, which could be used to compare retransmission strategies for new on-demand scenarios including IPTV and bulk data considering required bandwidth.

Using this metric, the costs for the content delivery could be reduced:

- Reducing the length of multicast distribution tree, the trees for control and retransmissions.
- Reducing the bandwidth for retransmissions and control.

For this purpose appropriate networking environments and retransmission strategies could be used, which are addressed in the next sections.

III. SCENARIOS USING RELIABLE MULTICAST

The bandwidth required for multicast retransmissions could be reduced, when the specific scenario is taken into consideration.

Today, business scenarios for user centric infrastructures and multiple (triple) play service bundles include diverse applications, which combine streaming and reliable transfer. Such applications are ranging from True Video on-demand to the enhanced video experience involving combinations with other services, such as Web, Email and Voice calls.

Example application scenarios requiring different error control and retransmission schemes are described in this section.

a) News and advertisements delivery in carousel mode to multiple receivers

News and advertisement are sent periodically to multiple receivers in carousel mode. The receivers may join asynchronously the multicast delivery.

If some receivers are joining the multicast group later, they will receive the service reliably starting at the time they join the delivery. Missing data can be received later, when the transmission is re-sent in the specified period.

Important for this service are retransmissions bounded by some deadline t. Such a reliable service is also called resilient multicast [38], which implies that some delayed receivers would not receive reliably the content in given intervals of time, if they experience great disturbance.

b) Software and content distributions based on reliable multicast bulk data transfer

Software and media content could be delivered using reliable multicast data transfer.

This service is elastic in the sense of throughput.

Late receivers joining the requests over control packets (NACKs) would request retransmissions in order to receive the missing data. Depending on the length of the file and buffers at the sender, the retransmissions could be provided immediately, at specific synchronisation points or at the end of the file transfer.

c) Streaming services combined with reliable transport schemes for storage of streaming content.

New scenarios based on IPTV, Video-on-Demand (VoD), Music and other media on-demand services are requesting the concurrent view of the service in streaming mode with its reliable storage for later access on-demand. Multicast True VoD (TVoD) systems are aimed to support VCR (Video Cassette Recorder) – like interactivity, while improving service efficiency and minimising the bandwidth requirements using multicast.

The trends in VoD protocol design are to provide new enhanced VoD experience in delivering movies and television programs to asynchronous fixed and mobile users. This advanced VoD experience scenarios include functions for:

- QoS based delivery, allowing that each client begins its playout with minimal delay;
- Record now, watch later or leverage 30 min. buffer - Digital Video Recorder (DVR)
- "Start over" - Come to the program later but start at the beginning (DVR and VOD);
- Support of interactive requests needed for personalization, allowing skip ahead/ back and fast forward;
- Broadcasting of common content based on "fat" multicast pipes to aggregation routers (proxies);
- "Beyond Movies on-demand" considering localised content, karaoke and improved "pitch";
- Scalable delivery to a vast amount of heterogeneous fixed / mobile users.

IV. NETWORK ARCHITECTURE FOR RELIABLE MOBILE MULTICAST

A. RELIABLE MULTICAST TRANSPORT FOR CONTENT DELIVERY

The DAIDALOS architecture [1] provides an advanced Service Provisioning Platform for mobile multimedia QoS-oriented services in heterogeneous IPv6 environment.

The focus lies on transport services for content delivery in IPv6 environment including different kind of access networks based on wireless technologies (WiFi, WiMAX, TD-CDMA, and Bluetooth) and broadcast media (DVB-T, DVB-H). Components for QoS provisioning and resource reservation, performance measurement, accounting, authorisation, and security handling are included to consider convergent fixed and mobile services at inter-domain, core and access network level.

The mobile multicast transport is aimed to support asynchronous and synchronous multicast schemes for streaming, reliable and real-time content delivery considering mobile users with multiple interfaces.

Based on the DAIDALOS access router architecture, it is possible to separate the end-to-end reliable multicast transport into core and access network based reliable delivery parts.

In [25], multicast architecture for reliable content delivery is proposed based on the interactions between the content provisioning platform and access routers managing the reliable transfer to the mobile nodes.

The end-to-end multicast transport (see Figure 1) is provided based on:

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

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

This is especially useful, because DAIDALOS uses diverse access networks with different characteristics, which could experience different packet losses.

In case of separation of the end-to-end reliability functions, it is possible locally at access networks and at core network segment to retransmit the data without to use the whole network infrastructure.

Thus, the bandwidth for control packets and retransmissions could be reduced using smaller sub-trees.

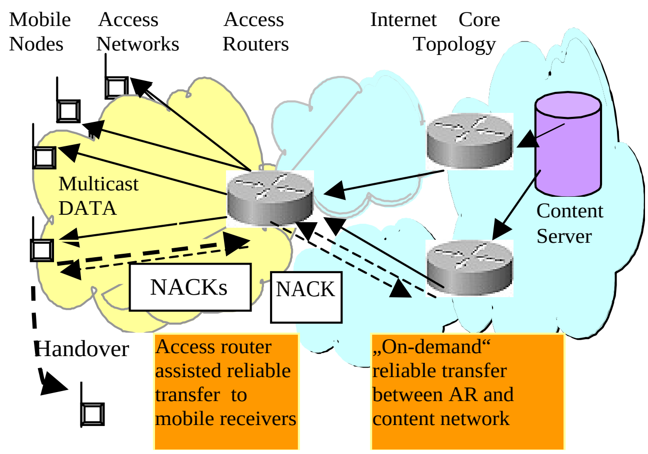

Fig. 1: General architecture for reliable multicast transport

Access routers are used to provide retransmissions and caching schemes as well as context exchange, as it is described in [31 [25].

B. SATELLITE BASED RELIABLE MULTICAST ARCHITECTURE

The core network of DAIDALOS is based on IPv6 router interconnections, which could lead to very complex multicast tree infrastructures.

Especially for large scale or global multicast, such an infrastructure is not efficient, because of the huge amount of multicast router states and the wasting of multicast capabilities.

Having in mind content delivery for the large Internet, there are a lot of proposals using satellites as simple gateways to connect fixed, wireless and broadcast networks, as shown in figure 2.

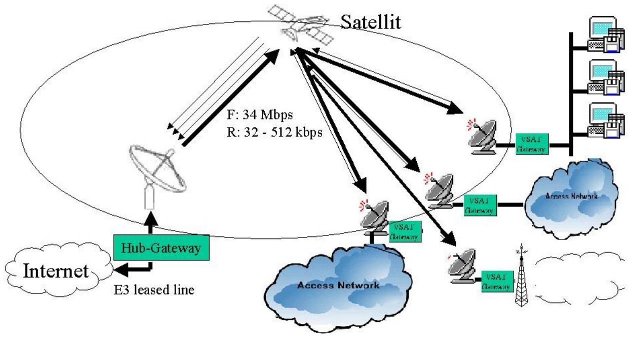

Fig. 2: Satellite based network architecture for multicast content delivery

V. RETRANSMISSION STRATEGIES FOR COST EFFICIENT TRANSPORT

A. COST EFFICIENT TRANSPORT BASED ON ACCESS ROUTER ASSISTANCE

Regarding reliable multicast transport, different schemes could be used, as for instance the NACK - Oriented Reliable Multicast (NORM) protocol standardised by IETF [23], application level reliable multicast [33], router assisted light weight [22] and hierarchical multicast [39].

In these schemes, retransmissions based on NACK repair requests are used, which could be sent in multicast or unicast mode to require retransmissions. Dependent on the strategy used, the NACKs are sent to all participants, to the neighbour routers (proxies) or only to the source of multicast session.

One way to reduce the multicast tree costs for retransmissions is to use router assisted hierarchical multicast [39]. Although saving retransmission bandwidth, the scheme is complex, because on all routers there is a need to keep states for reliable multicast transport.

The reliable multicast scheme proposed in the framework of DAIDALOS for mobile environment uses only the access router assistance for reliable multicast. This allows to benefit from the separated reliable transport and to use “optimal” retransmission schemes at the core and access networks dependent on the specific network technology.

The main benefit is the cost saving based on reduced tree structures.

Given is a multicast distribution tree T, which consists of the:

- Core sub-tree ($T_{core} \subset T$) with a root multicast source and leaves multicast routers and
- Access network sub-tree ($T_{an} \subset T$) with an access router as root and mobile nodes as receivers.

Dependent on the link, where the packet loss occurs, the retransmissions and control data of access router assisted reliable transfer are reduced.

For the case that retransmissions happens in T_{core} , we have

Tree length

$L(T'_{retr}) <= L(T_{core}) < L(T)$ and $L(T'_{ctrl}) <= L(T_{core}) < L(T)$

Reduction of bandwidth cost

$\Delta b = (C_{retr} + C_{ctrl}) * (L(T) - L(T_{an}))$

Similar for the case that retransmissions happens in T_{an}

Tree length

$L(T'_{retr}) <= L(T_{an}) < L(T)$ and $L(T'_{ctrl}) <= L(T_{an}) < L(T)$

Reduction of bandwidth cost

$\Delta b = (C_{retr} + C_{ctrl}) * (L(T) - L(T_{core}))$

B. RELIABLE MULTICAST BASED ON SEPARATE RETRANSMISSION CHANNEL

There are different approaches to integrate retransmissions in reliable multicast transport:

- Retransmissions “to-all” based on the multicast distribution tree, as for instance used in NORM [40];
- Retransmissions done by receivers useful in specific environments like satellites;
- Local retransmissions [17];
- Hierarchical router assisted retransmissions [39];
- Application oriented retransmission strategies [14].

For scalable multicast, the reliable multicast based on separate retransmission channel is discussed in [37], [25].

This approach is useful for on-demand services, which includes huge amount of large scale distributed receivers and high bandwidth requirements.

The separate retransmission channel approach involves retransmissions from the root (source or access router) using the sub-trees T’retr, which include receivers experiencing packet losses, i.e. at least there is a $c_{ij} \in$ T’retr , which experiences packet loss.

There are no retransmissions involving the sub-tree, which experience no losses.

Resources are saved based on:

- Reducing the network bandwidth required for a multicast session;
- Reducing the receiver overhead to process retransmitted packets, which are already received without errors.

In mobile environment using access router assistance, the processing overhead of mobile receivers and access routers can be reduced on this way.

C. RELIABLE MULTICAST CONSIDERING SPECIFIC APPLICATION MODELS

Cost efficient multicast retransmission strategies could be designed regarding the specific application models for content delivery. Considering the application model, there are different approaches to send NACKs in order to require cost efficient retransmissions.

a) Carousel retransmission scheme

Derived from the carousel scenario, the node that joins a multicast distribution tree at a time t_s, expects reliable delivery beginning at t_s independent of the sent packets Δp, which are already transmitted.
This means that for Δp no NACK is sent and the number of retransmitted data and control packets is reduced.

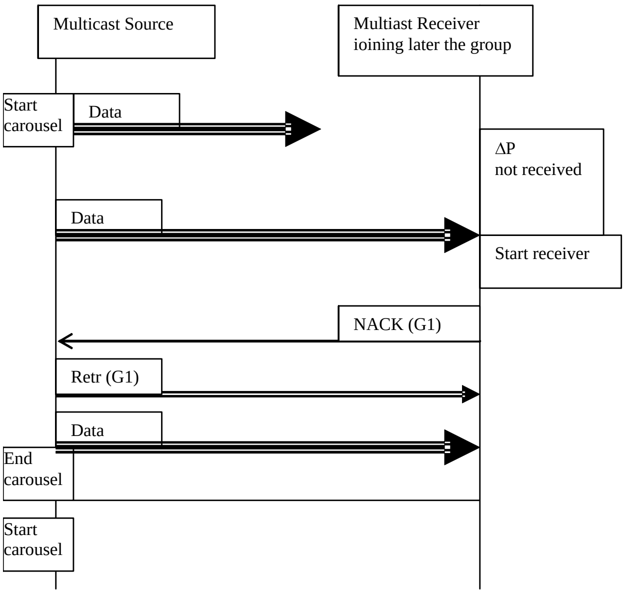

Fig. 4: Carousel retransmission requests

Considering environment with frequent join and leaves of the multicast receivers, also handovers, this strategy allows the saving of retransmissions for late nodes, which loose packets at file beginning.

b) Reliable multicast bulk data transfer

NACKs could be sent in multicast or unicast mode, when a receiver detects packet loss.
When frequent joins and leave is experienced, due to handover, the immediate sending of retransmissions for received NACKs could cause repeated retransmissions of the same data.
Especially in scenarios, where the service is not real-time (such as bulk data transfer), the response to the NACKs could be delayed, in order to aggregate NACKs for later joining receivers.
Delayed retransmissions could be sent at:

- The end of the transferred file;
- Some well defined synchronisation points in order to support minimum transfer rate.

This strategy is shown in figure 5:

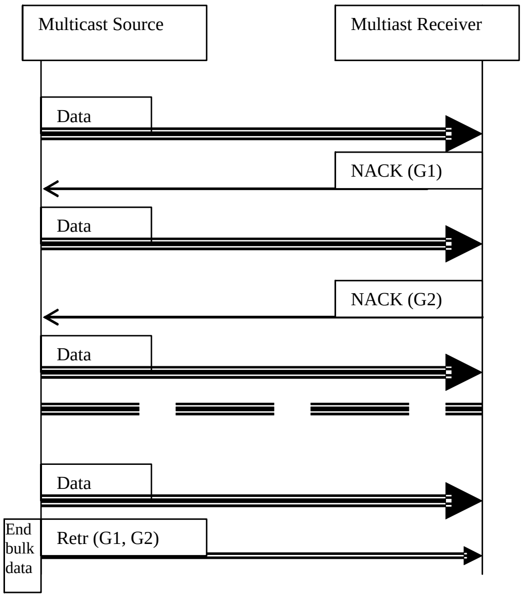

Fig. 5: Delayed retransmissions for reliable multicast bulk data

The strategy allows reduce the repeated retransmissions based on aggregation of same requests for retransmissions.

c) Combining streaming and reliable multicast

Streaming video and audio transmission, which are displayed immediately with possible packet losses due to delayed packets, could be combined with a retransmission schemes to store reliably the media for later replaying.
Important for this scheme is that the retransmissions for the NACK packets are sent within a short time interval.
Later retransmissions are not useful for the presentation of the streaming data, but are requested for its storage without packet loss.
Therefore retransmissions, which could not be sent in time, could be multicast later, which allow to aggregate NACK requests of different receivers.
Similar to the reliable multicast bulk data retransmission, later aggregated retransmissions could be sent at the end of the stream.

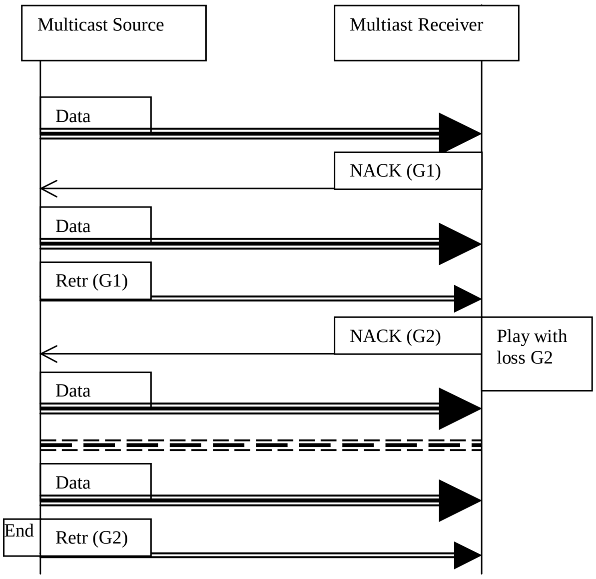

Fig. 6: Combined streaming and reliable multicast

VI. OVERHEAD ANALYSIS OF RELIABLE MULTICAST AT ACCESS NETWORKS

A prototype implementation of the access router part of the scalable reliable multicast protocol was developed and integrated in the Fedora Core 4 Linux operating system.

The implementation includes a mobile multicast error control scheme based on retransmissions to a dedicated multicast group (one retransmission channel). The suitability of this error control for mobile environment is studied based on comparison with the "retransmission-to-all" scheme integrated in the experimental IETF NORM protocol, i.e. Negative-acknowledgment (NACK)-Oriented Reliable Multicast [40]. For the analysis, the public domain sources of NORM are used [41].

The testing environment is based on an access network based on IEEE 802.11b - Wireless Local Area Network (WLAN) technology. In the laboratory testbed, a WLAN card providing connectivity at 11 Mbit/s, mobile terminals (Pentium 4) and one access router serving as file transmitter are included. In the test case, a file of 1 Mbyte length is transferred reliably from the access routers cache to 4 multicast receivers using the mobile multicast error and flow control and a rate of 125 KByte/sec. There is no other traffic on the network and no handover or roaming is experienced.

The scenario includes artificially emulation of disturbances on one mobile node based on artificial packet loss, which could be found in realistic wireless environment. The behaviour of two retransmission strategies is studied:

- Dedicated retransmission channel for mobile communication;
- Retransmission "to all" multicast receivers (NORM).

The total number (Nt) of Protocol Data Units (data, retransmissions, CTRL and NACK packets) processed at all receivers is calculated and the mean processed data volume (Nm) to receive reliably the file per receiver is obtained.

The graphic describes the impact of the emulated disturbance at one receiver on the mean processed data volume (Nm) for receiving the file:

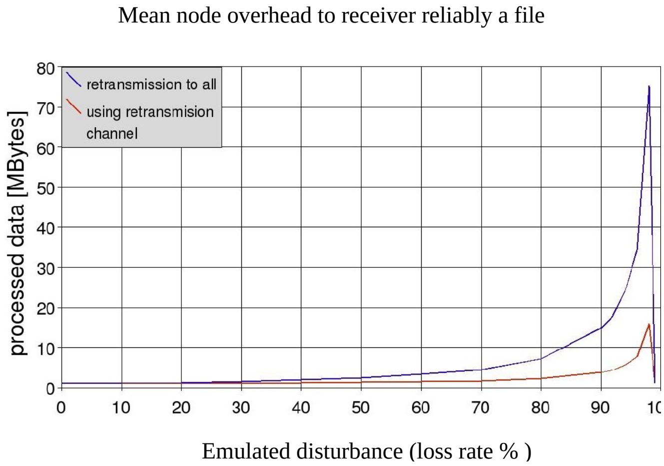

Fig. 7: Impact of packet loss rate on Nm comparing different retransmission strategies

The overhead required for retransmission using a dedicated channel behaves exponentially and is smaller than the overhead using retransmissions to all multicast receivers. In the case of enabling of a loss rate of 98 %, when using the retransmissions of NORM implementation [41], the reception of all receivers breaks down. In this case, when dedicated channels for retransmissions are used, only the transmission to the saturated receiver breaks.

The usage of dedicated retransmission channels could be shown to be efficient for scenarios with very high numbers of receivers and small retransmission groups. The experiments with 10 receivers and more over WLAN have shown that the mean processed overhead per mobile terminal slightly increases, when the receiver number gets higher, but only small number of receivers experience disturbances.

VII. CONCLUSION

This paper addresses innovative concepts for reliable multicast transport supporting efficiently the requirements of content on-demand services. The efficiency of multicast transport schemes in order to save network resources (i.e. amount of network bandwidth per user) depends on the design of content delivery application and the selection of multicast transport mechanism according to the application model (for instance periodical transfers of same content or unique transfer to multiple users).

A general advantage of a multicast architecture supporting on-demand content applications is the integration of different multicast transport mechanisms depending on application model and usage of appropriate core and access network reliable multicast schemes in order to provide cost efficient end-to-end service delivery.

The described multicast protocol architecture is currently under test and simulation.

In the final version of the paper, more results considering the *reduced retransmission overhead due to appropriate error and flow control strategies will be included.*

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