Reliable Multicast Transport for Heterogeneous Mobile IP environment using Cross-Layer Information

Ilka Miloucheva, Karl Jonas, Nilson Reyes, Jens Mahnke, Riccardo Pascotto

Abstract: **Reliable multicast transport architecture designed for heterogeneous mobile IP environment using cross-layer information for enhanced Quality of Service (QoS) and seamless handover is discussed. In particular, application-specific reliable multicast retransmission schemes are proposed, which are aimed to minimize the protocol overhead taking into account behaviour of mobile receivers (loss of connectivity and handover) and the specific application requirements for reliable delivery (such as carousel, one-to-many download and streaming delivery combined with recording). The proposed localized retransmission strategies are flexible configured for tree-based multicast transport. Cross layer interactions in order to enhance reliable transport and support seamless handover is discussed considering IEEE 802.21 media independent handover mechanisms. 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.**

***Index terms*: reliable multicast, retransmission, mobile multicast, seamless handover, carousel, one-to-many download, access router, IEEE 802.21**

I. INTRODUCTION

Mobile multicast/services allow video and audio streaming, multimedia content delivery, carousel and reliable file download to multiple mobile receivers with mobile phones, pocket TV's, portable radios and other mobile terminal devices. Such services can be provided for the entertainment industry (life broadcast TV, voting, browsing, audio), broadcast distribution for weather, travel and financial news, as well as web file delivery, business with e-mail, e-commerce and logistics integrated in mobile devices.

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Because of the diversity of mobile multicast services, there is a challenge for new reliable transport mechanisms, which are taking into consideration the heterogeneous mobile networking environment and the specifics of application.

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

Our particular focus on reliable multicast for heterogeneous mobile environments considers application-oriented multicast retransmission based on optimisation and support for seamless handover.

In particular, retransmission strategies are proposed in order to provide scenarios for:

- Repeated file transmissions (carousel),
- One-to-many reliable software downloads and
- Streaming multicast combined with reliable storage (recording).

The schemes are designed for heterogeneous mobile networking environments, where longer packet losses are possible due to disturbances, handoffs and "ping-pong" effects.

The proposed retransmission strategies are applied for flexible local error recovery based on access router support and can be integrated 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. Cross-layer information is used to optimise the application-specific retransmission schemes and to support the seamless handover and intelligent access network selection considering the media independent handover strategies, such as IEEE 802.21 [50].

The reliable multicast transport is discussed based on the QoS management architecture for the heterogeneous mobile IPv6 environment [4], which is developed in the European Community (EU) IST project DAIDALOS [37].

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 transport architecture for heterogeneous mobile Internet environments based on access router support and cross-layer interaction for seamless handover is described in section 3. New application-specific mobile multicast retransmission strategies are presented in

- The multicast / broadcast transfer is combined with additional bidirectional network for return channel and point-to-point service provision [39]. IPDC involves streaming and file casting services for multimedia content delivery using the “push” service concept. The protocol stack allows the provision of audio and video streaming, carousel, reliable content distribution and multicast file delivery using unidirectional transport (FLUTE) [42], RTP/RTCP and UDP protocols on top of DVB-H. IPDC service offer can be obtained from the Electronic Service Guide (ESG) [40].
- *Multimedia Broadcast and Multicast Service (MBMS)* standardized by 3rd generation partnership project (3GPP) [43]) and Universal Mobile Telecommunication Systems (UMTS). MBMS specifies multicast and broadcast transmission, allowing multiplexing and triple play service delivery. MBMS uses a Broadcast Multicast Service Center (BM-SC) offering interfaces for service providers including functions for authorization and authentication, as well as QoS requirements.
- *Dynamic interactive multimedia scenes (DIMS)* [44]. DIMS is a recent 3GPP standardization effort for constrained devices aimed at the delivery of rich media services over combined unidirectional broadcast links (DVB-H) and mobile 3G networks (UMTS).

Considering new business scenarios, there are different strategies for reliable mobile multicast deployment particularly combined with streaming and real-time transfers. Examples are on-demand advertisement and news, on-line games, on-demand media and content, delivery, interactive mobile TV delivery. Reliable multicast/broadcast services can be applied to support one-to-many file downloads, content delivery to multiple users, mobile TV with interactive channels.

For on-demand content delivery, in order to reduce transfer costs, reliable mobile multicast is proposed based on resource reservation in advance and aggregation of different (spaced in time) user requests to the same content [45].

Reliable multicast can be used to transfer high priority (emergency) data to multiple users, such as alerts to mobile devices in critical networking infrastructures.

Emergency broadcast/multicast service is investigated in [47] for transmission of earthquake and tsunami information in

section 4. Simulations showing the benefits of the proposed strategies for reducing the retransmission overhead for specific application scenarios are focus of section 5.

II. Reliable Multicast Transport for mobile applications

A. Applications using reliable mobile multicast

Mobile multicast services are standardized recently in different frameworks (IPDC [39], [40], [41], MBMS [43] and DIMS [44]). Such efforts include:

- *IPDataCast (IPDC) for delivery of interactive mobile multicast/broadcast over DVB-H [41].*

delay tolerant networks (RFC 4838 [46]) using FLUTE protocol defined in RFC 3926 [42]).

In DAIDALOS architecture, a particular focus are scenarios for reliable on-demand content delivery (video, audio, data) in heterogeneous mobile IPv6 environment including broadcast (DVB-H) and mobile networks (UMTS, WIMAX, WLAN) [32].

B. IETF reliable multicast transport

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). Blocks can be used to support specific tasks for data reliability, congestion control, security, group membership and session management. Examples for building blocks 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],
- Signalling mechanisms for generic router assist [10].

Protocols with different complexity can be configured based on combination of building blocks [2], [7], [8]. For instance, Asynchronous Layered Coding (ALC) integrates building blocks for layered coding transport, multiple rate congestion control and forward error correction (FEC) [7].

The negative-acknowledgment (NACK)-oriented Reliable Multicast (NORM) protocol (RFC 3940 [3]), is defined based on the NACK-building block [1], [2]. In the NORM protocol [3], NACKs are sent to all members of the multicast group. A timer based back-off mechanism is used to suppress NACKs and avoid NACK-implosion at the sender. The retransmissions are delivered by the sender after waiting a given time 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.

The Tree Based Acknowledgment protocol (TRACK) is designed for automated tree configuration, retransmission and session management using generic router assist [11], [56]. IETF RMT building blocks are basically designed with focus on fixed Internet infrastructures. To extend this framework, application-specific retransmission schemes considering mobile Internet access network environment are proposed in this paper.

C. Evaluation of reliable multicast schemes for mobile environment

The aim of reliable multicast in mobile networks is to *reduce the processing overhead of the receivers and to avoid duplicated retransmissions*. Survey of reliable multicast transport techniques in Internet is given in [12]. Dependent on the network infrastructure, the reliable multicast techniques are grouped into:

- Localized reliable multicast, which can consider specific characteristics of the network (satellite, DVB-T, wireless network). For instance, a protocol for reliable content delivery over satellites focusing on unidirectional networks is described 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].

In heterogeneous mobile Internet environments, *appropriate reliable multicast schemes can be used dependent on the characteristics of particular networks.* For instance, unicast NACK-based retransmission is 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 of the NACKs. Selective NACK-oriented loss recovery is a scalable retransmission technique for multicast networks, which does not include hierarchical topologies [16].

For the *design of reliable mobile multicast schemes,* there are different goals:

- Optimization of retransmission and control overhead based on retransmission scheme developed for the specific application requirements;
- Avoiding of duplicated retransmissions using delayed retransmissions and aggregation of retransmission requests;
- Retransmissions 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.

For efficient multicast transport in mobile environments, retransmissions requested by NACK-oriented techniques can be sent on *dedicated retransmission channels* [17]. To such retransmission channels 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]. Hybrid retransmission techniques based on switching between unicast and multicast retransmissions can be used dependent on the capabilities of the mobile network [19].

Reliable multicast for the data link level in wireless networks can be designed 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 reliable retransmission scheme for wireless networks is proposed, based on “supervisory” hosts collecting ACKs and forwarding them to the source.

Tree-based reliable multicast protocols can be used for heterogeneous mobile Internet environment. In such schemes, repair groups (for instance routers) 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 can be re-selected based on changing network topologies.

Log based reliable multicast [20], and the Reliable Multicast Transport Protocol (RMTP) [21] are examples for tree-based reliable multicast, in which designated receivers 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 retransmissions 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 retransmissions and group membership processing. 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. The Reliable Range Based Multicast is a tree based protocol using Multicast Subnet and Region Agents, acting as recovery nodes [30].

III. Architecture for Reliable Mobile Multicast

A. Reliable multicast framework for heterogeneous mobile Internet environment

The reliable multicast supporting the multimedia content delivery platform of the EU IST project DAIDALOS is designed for heterogeneous mobile Internet environment including wireless and unidirectional broadcast networks [4]. The heterogeneous mobile IPv6 infrastructure integrates services and protocols for QoS based mobile communication connecting mobile users in access networks (WiFi, WiMAX, TD-CDMA, and Bluetooth, DVB-H) via access routers to the IP core. In order to support seamless handover for mobile services using heterogeneous access networks different technologies have been developed and evaluated in the DAIDALOS context, such as:

- Context Transfer applied for transfer of states (control data) between access routers related to the mobile node's services [4], [48];
- Candidate access router discovery and optimization of next access network selection using CARD [49];

For support of different patterns for movement of mobile services and users, in the second stage of the DAIDALOS project, mobility technologies including IEEE 802.21 [50] and Network-Based Localized Mobility Management ([51], [52]) are focus of research.

Reliable multicast mechanisms in DAIDALOS are aimed to support content (data), real-time, video and audio delivery to groups of mobile receivers. *Access routes* are used in the architecture to connect mobile users with possible multiple network interfaces and sessions to IPv6 core and multimedia content delivery platform. In case of handover, *intelligent network selection* based on cross-layer information exchange and IEEE 802.21 services [50] is applied, which considers data link, network and transport QoS requirements of users and applications.

The proposed reliable multicast framework (fig.1) involves a flexibly *configurable tree based reliable multicast protocol* for fixed core and mobile access network infrastructures using *localized retransmission schemes* [32].

Based on the mobility requirements, the retransmission schemes are classified in:

(1) *Fixed (core specific) retransmission* schemes focusing on reliable multicast transfer from the server(s) at core networks to access router(s);

(2) *Mobile (access network specific)* retransmission schemes specifying the reliable multicast transfer from access routers to attached mobile nodes, particularly considering the specific characteristics of the access networks (data link and MAC layer) and using caching of data at access routers.

The core and network specific localized retransmission scheme can be based on acknowledgment strategies considering specific capabilities of the data link and MAC layer. For instance, the underlying network can include reliable download service based on MBMS [53].

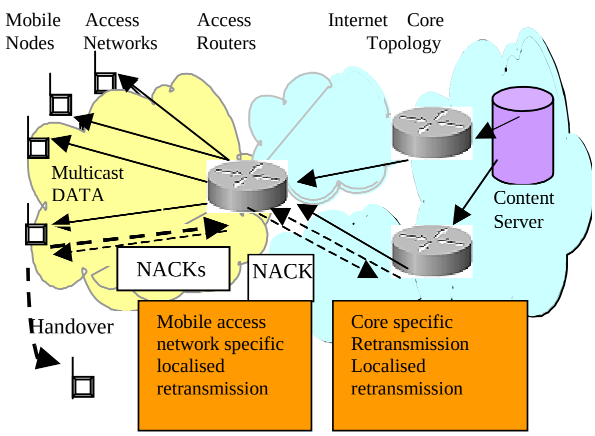

Fig. 1. General framework for reliable multicast transport for heterogeneous mobile IP environment using localized retransmission

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 can be used as cost efficient solution. When satellites or unidirectional broadcast media (DVB-H, DVB-T) are used, then the NACKs from the receivers to the sender in the unidirectional network environment can be sent. It is done using an IP tunnel established by means of additional bidirectional access network using the link layer tunnelling mechanisms [35].

Because of the multicast/broadcast character of these particular networks, multicast retransmissions are applied.

Dependent on the specific multicast application, the retransmission schemes can be tuned to support enhanced QoS delivery to the mobile users. For instance, application-specific schemes can be used aimed at enhanced QoS provision and better resource utilization.

The efficiency of the reliable multicast service can be expressed by multicast performance metrics.

Metrics describing the multicast p*rotocol overhead* (such as amount of retransmission and control packets, congestion overhead) are used to analyse the utilization of the infrastructure by the reliable multicast protocol.

Other metrics are aimed to *measure QoS parameters (multicast performance metrics) from the view point of individual* *or the multicast group as whole.*

Such metrics include:

- Bandwidth and cost of the multicast tree (considering data, control and retransmission packets),
- Delay to multiple receivers,
- Throughput,
- Time for reliable content delivery,
- Time of the construction of a multicast delivery tree,
- Tree recovery in case of error.

B. Optimization of reliable mobile multicast transport based on cross-layer information

Cross-layer protocol optimization is a new paradigm, which is focussed at adaptation of specific protocol functions and parameters in order to improve the protocol operation.

For instance, adaptation of the rate at the data link layer can be based on the evaluation of the application traffic [54]. In satellite environment, cross-layer protocol optimization considering interactions of application, transport, MAC and physical layers is surveyed in [38].

We consider the reliable mobile multicast architecture proposed in the previous section and focus on the cross-layer optimization of localized multicast transport in heterogeneous mobile network environment.

Cross-layer optimization of the handover of reliable mobile multicast transport is based on layer-specific information, which can be *passed in both directions*, top-down (from multicast application and service) and bottom-up (from the data link, MAC and network layer).

The following figure shows the cross-layer optimisation framework for reliable mobile multicast transport based on DAIDALOS considering heterogeneous mobile IPv6 network environment:

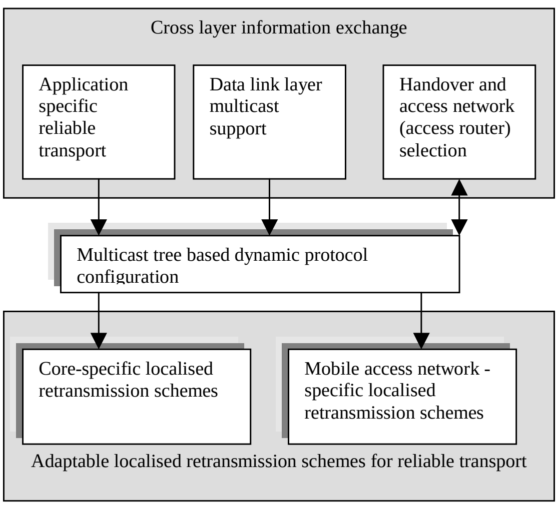

Fig. 2. Cross-layer optimization of reliable mobile multicast transport

The cross-layer optimization of the reliable mobile multicast transport includes following components:

Application-specific configuration of retransmission techniques. For instance, the multicast retransmission module at the mobile receivers is configured to send NACK acknowledgments dependent on the application specific requirements, which can save resources and power. In section IV, we describe such strategies.

- Adaptation of the retransmission scheme *dependent on the particular MAC and data link layer* (satellite, wireless LAN, broadcast network). Possible actions can be based on avoidance of FEC processing at the upper protocol layers in case that the data link layer already supports the FEC algorithms.
- *Seamless handover and selection of next access network and router for the reliable multicast session.* When the mobile node is losing the connectivity and must perform a handover, a new access router (access network) should be selected for the reliable multicast session. To support seamless handover, the selection of the next access router and network is based on different kind of cross layer information, such as:
  - Measured performance parameters at data link layer;
  - Support of reliable multicast at transport layer;
  - QoS management information about resource reservation;
  - Policy management data for consideration of business goals.

  The next access network selection can consider how much packets will be lost during the handover and in which extend the reliable multicast service will be disturbed. IEEE 802.21 framework allows the seamless handover of mobile nodes with multiple network interfaces using cross-layer information.

  The standardization efforts focused on the IEEE 802.21 describing Media Independent Handover Mechanisms (MIH) are aimed to define services for managing and exchanging of information, events and control messages between network devices and modules (communication services and protocols at different levels) [50].

  Possible interactions of the reliable mobile multicast service with other communication layers for seamless handover based on IEEE 802.21 are shown in figure 3:

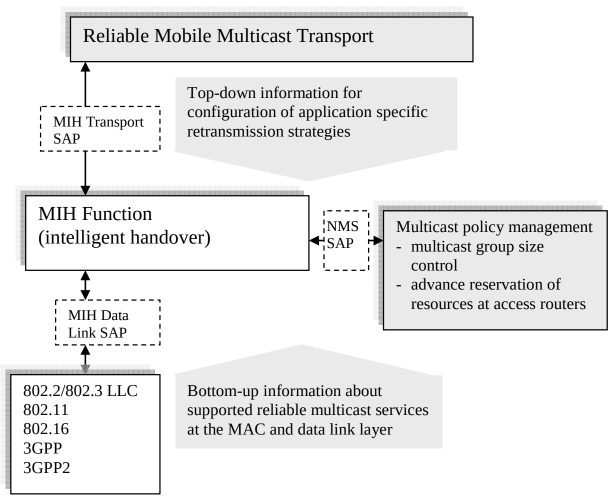

Fig. 3. Usage of IEEE 802.21 MIH for reliable multicast support

IV. Application-specific reliable multicast retransmission schemes

This section describes application specific retransmission schemes for heterogeneous fixed and mobile network environments, which can be used to configure dynamically the multicast transport.

The focus is to show, the reduction of the retransmission overhead and the enhancements of the QoS for the mobile users (for instance improved delay for multicast file delivery) for the specific kind of application.

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 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. 4). 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 will 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 (for example 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.

In case, that a receiver experiences a lot of packet losses due to disturbance, the receiver will suppress its NACKs (see, Fig.4). The carousel (repeated file transfer) allows in the next round to receive the missing packets.

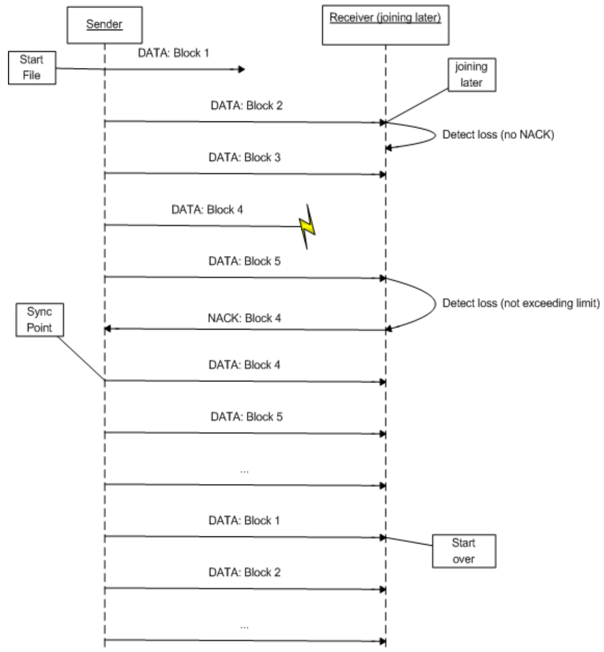

Fig. 4. Retransmission scheme for the reliable carousel multicast

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 [34]. Reliable multicast for one-to-many download requires that all mobile receivers, which subscribed to a session using different access networks, 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 loses 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 using delayed retransmissions is proposed in this paper.

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 QoS experience of the mobile users, 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.

The delayed retransmissions are based on partitioning of the transmitted data into blocks based on which the retransmissions are done. The block size impacts the amount of retransmissions.

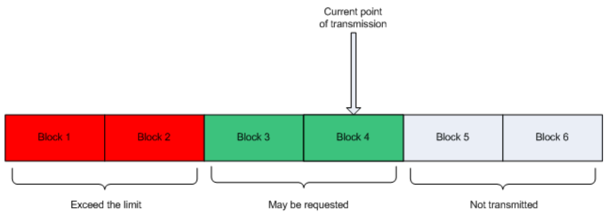

Fig. 5. Block limits in One-to-many downloads

As it is shown in fig. 5, data from block 3 and block 4 can 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. 6, 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.

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.

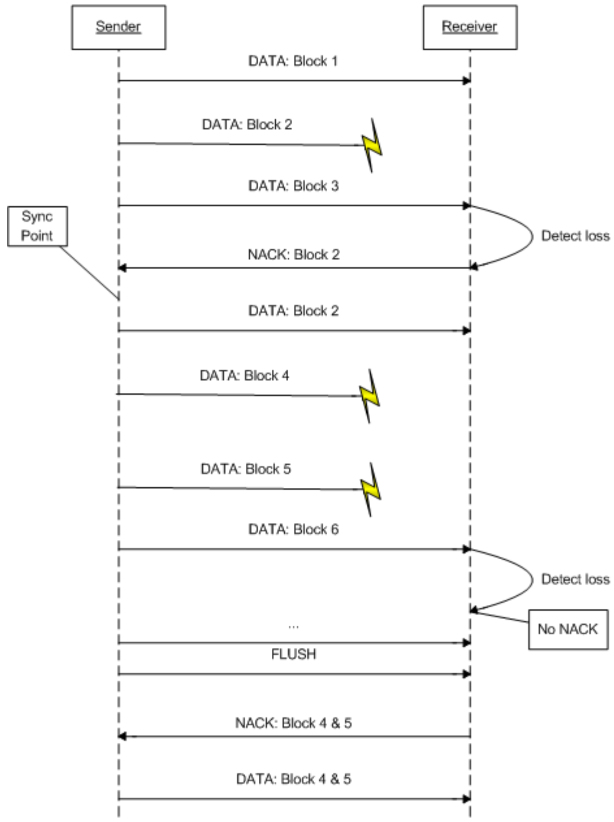

Fig. 6. Retransmission strategy for reliable one-to-many downloads

Non-erroneous clients benefit from that, 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 QoS experience for non-erroneous receivers.

C. Media streaming combined with recording

The trends in mobile TV are to provide new enhanced experience in delivering movies and television programs to fixed and mobile users combining video streaming with VCR (Video Cassette Recorder) functions [35]. Interactive mobile TV scenarios are based on:

- Rate-controlled streaming multicast, which can tolerate packet loss during the presentation, but is delay sensitive;
- Reliable storage of the received media after the presentation for later usage without loss and corruption.

When streaming video and audio services combined with recording are delivered to groups of mobile receivers, the lost packets are retransmitted at *synchronization points* common for all receivers of the group.

NACKs will be sent as soon as a FLUSH message arrives and indicates such synchronization point. A synchronization point can be established for a specific piece of the media data, such as TV movie, news, sport event delivery, advertisement or other program content. The scheme is shown in fig. 7:

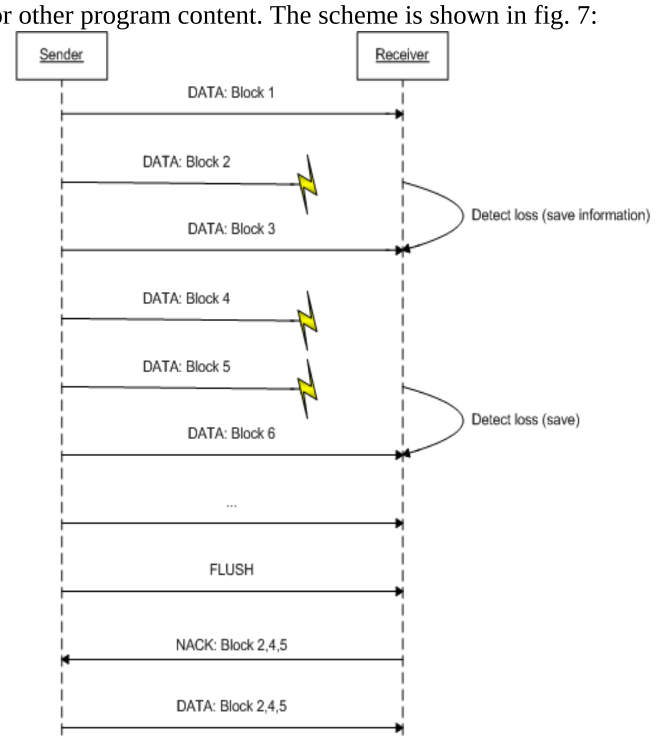

Fig. 7. Synchronisation point for combined media streaming and recording

The benefits of the introducing of synchronisation points for combined media streaming with recording are:

- Delay restricted transfer to meet the requirements of streaming services;
- Reducing of duplicated retransmissions using aggregation of the NACK-requests from all receivers and retransmitting them at the end of the content delivery.

V. Implementation and Performance Analysis of Application-Specific Reliable Multicast

A prototype implementation of the application-specific multicast retransmission schemes is integrated in the Fedora Core 4 Linux operating system. The implementation is compared to the public domain sources [36] of the IETF NORM protocol [3], i.e. Negative-acknowledgment (NACK)-Oriented Reliable Multicast. To show the benefits of the application-specific retransmission, simulations are used.

The simulation environment is built based on 11 Mbit/s WLAN (IEEE 802.11b - Wireless Local Area Network) connecting 20 receivers to IP core using multicast access router. In all scenarios, it is assumed that a file of 2.5 Mbyte is transferred from the access router to the multicast group.

In the first scenario, the performance of the carousel transport service is simulated. It is assumed that 6 receivers (called delayed receivers) are joining later the reliable multicast transport.

The *loss pattern of the delayed receivers* is shown in fig. 8, where the x axis denotes the intervals, in which the receivers lose packets. The y axis shows the mobile nodes, where the packet loss happened. In the loss pattern (fig. 8), some nodes (2 to 7) lose packets, because they subscribed later to the reliable multicast service:

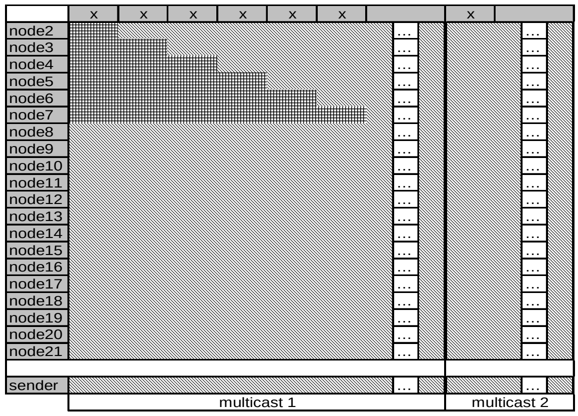

Fig. 8. Loss pattern for delayed receivers

In the simulation, we assume different lengths of intervals with packet losses at the receivers. The loss pattern (fig. 8) is parameterized with the following lengths of packet loss 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 performance of the carousel scenario is analyzed for different lengths of loss intervals.

The results have shown that for each simulated packet loss delay (delayed receiver), the implemented carousel retransmission scheme does not require retransmissions. Compared to this, using the NORM protocol, the retransmission overhead (DATA + NACKs packets) is significant and depends on the length of the loss intervals.

In fig. 9, the results showing the saved retransmission overhead of the carousel strategy compared to NORM are given:

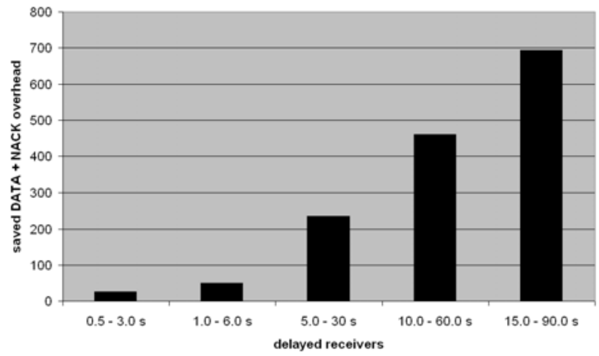

Fig. 9. Carousel scenario – reduced overhead (DATA + NACK) compared to NORM

Further 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 10:

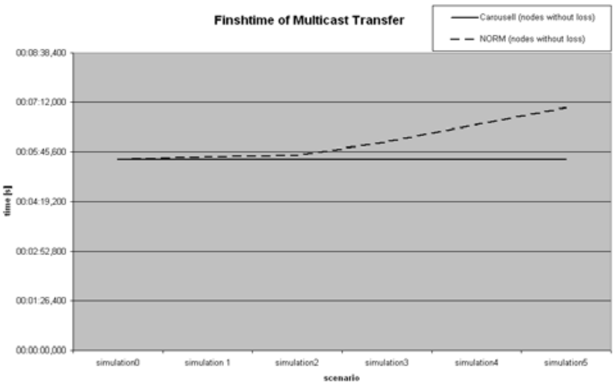

Fig. 10. Delay for finishing the transfer of carousel service compared to NORM

In the next simulation scenario analyzing the performance of the one-to-many reliable download, another loss pattern is used (see, fig. 11). This loss pattern is focused on the mobile nodes (2 to 7), which lose packets in non-overlapping packet loss intervals.

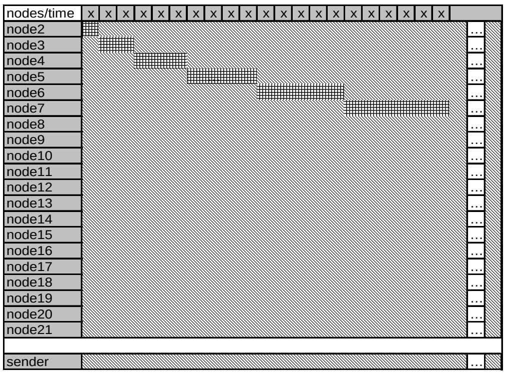

Fig. 11. Loss pattern of non overlapping loss intervals of different nodes

In this scenario, the packet loss pattern is parameterized with the following lengths of packet loss intervals:

0.5s in sim1, 1.0s in sim2, 5.0s in sim3, 10.0s in sim4 and 15.0s in sim5.

The results of the simulation aimed to show the mean retransmission overhead per receiver are given in fig. 12.

In comparison to NORM retransmission, the mean retransmission overhead of the one-to-many multicast download strategy, proposed in this paper, is smaller for the different simulation cases (packet loss intervals).

Similar to the carousel service, the finishing time of the one-to-many download strategy for the receivers, which have no packet loss, is smaller compared to NORM.

In the one-to-many reliable download (see, section IV.B), the *block size* is one parameter, which impacts the performance. A bigger block size is leading to immediate retransmissions, where a smaller block size causes delayed retransmission at the end of the transfer.

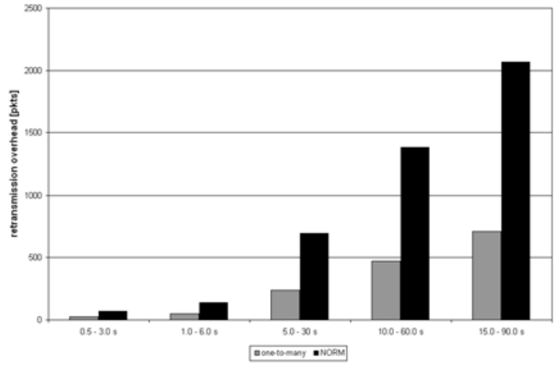

Fig. 12. One-to-many multicast download – mean retransmission overhead compared to NORM

Delayed retransmissions are resulting in a smaller finishing time for the non-erroneous receivers. In NORM, only immediate retransmissions are used, therefore, the finishing time of the non-erroneous receivers is greater, especially with increasing losses.

The different time for finishing of the reliable multicast transfer for non-erroneous nodes in the proposed one-to-many reliable download strategy and NORM is seen in the fig. 13.

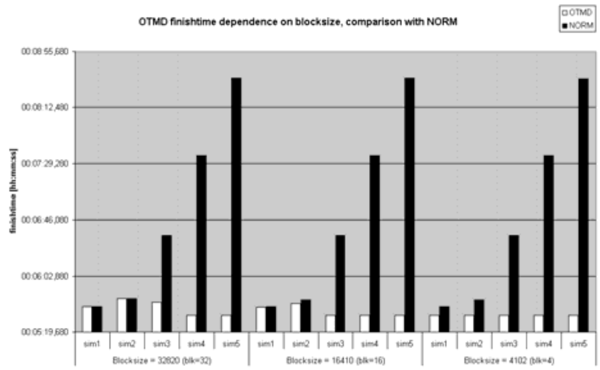

Fig. 13. Delay for finishing the transfer of non-erroneous receivers (one-to-many download strategy compared to NORM)

The next scenario (fig. 14) shows the benefit of the streaming multicast transfer combined with recording. Compared with NORM, the time for the transfer of the file is lower (delay restricted transfer), because the retransmissions are done at the end of the file transfer.

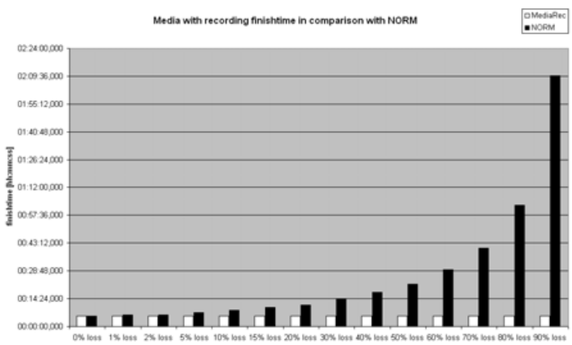

Fig. 14. Delay for finishing the transfer of receivers without error of multicast streaming compared to NORM

With increasing loss, the delay of the non-erroneous receivers to finish the multicast service remains the same, but in NORM it increases significantly.

VI. Conclusion

Design, implementation and simulation of reliable multicast transport mechanisms were discussed. Compared to the IETF NORM protocol, the simulations have shown that the new strategies behave better for loss patterns considering delayed receivers and disturbances typical for mobile environment.

The finishing times for non-erroneous receivers in all application-specific retransmission schemes were 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.

Cross layer optimisation of reliable mobile multicast was proposed based on application-specific configuration of retransmission strategies and usage of IEEE 802.21 for seamless handover.

Such optimised reliable mobile multicast transport will allow the deployment of new distribution applications with enhanced reliability for critical infrastructures, rescue and emergency scenarios. The specific requirements for reliable multicast transport used for these services in heterogeneous mobile access networks are focus of further research.

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References

[1] B. Admason, C. Bormann, M. Handley, J. Macker: *Negative Acknowledgment (NACK)-oriented reliable multicast (NORM) building blocks,* RFC 3941, Nov., 2004.

[2] C. Adamson, M. Bormann, J. Handley, J. Macker: *Multicast Negative-acknowledgment (NACK)-Building Blocks,* Internet-Draft, March, 2006.

[3] B. Adamson, C. Bormann, M. Handley, J. Macker: *Negative-acknowledgment (NACK)-Oriented Reliable Multicast (NORM) Protocol,* RFC 3940, November, 2004.

[4] I. Miloucheva, O. Menzel, K. Jonas: *Efficient QoS-based mobile multicast using context transfer, Journal of Communications Software and Systems,* JCOMSS, Vol. 2. Numb. 2, June 2006.

[5] B. Whetten, L. Vicisano, R. Kermods, M. Handley, S. Floyd, M. Luby: *Reliable Multicast Transport Building Blocks for One-to-Many Bulk-Data Transfer,* RFC 3048, 2001.

[6] R. Kermode, L. Vicisano: *Author Guidelines for Reliable Multicast Transport (RMT) Building Blocks and Protocol Initiation documents,* RFC 3269, April, 2002.

[7] M. Luby, M. Watson, L. Vicisano: *Asynchronous Layered Coding (ALC) Protocol Instantiation,* Internet Draft, Work in Progress, April, 2006.

[8] M. Watson, M. Luby, L. Vicisano: *Forward Error Correction (FEC) Building Block,* RFC 5052, August 2007.

[9] J. Widmer, M. Handley: *TCP-Friendly Multicast Congestion Control (TFCCC) Protocol Specification,* RFC 4654, August 2006.

[10] T. Speakman, L. Vicisano: *Reliable Multicast Transport Building Block – Generic Router Assist – Signalling Protocol specification,* Internet Draft, Work in Progress, July 2002.

[11] B. Whetten, D.M.Chiu, M.Kadansky, S.J.Koh, G.Taskale: *Reliable Multicast Transport Building Block for TRACK,* Internet Draft, Work in Progress, 2003.

[12] M. Yamamoto: *Multicast Communications – Present and Future*, IEICE Trans. Commun, Vol. E86-B, No.6, June 2003.

[13] J. Fang, F. Akyildiz, *A Reliable Multicast Protocol for Satellite IP Networks,* IEEE GLOBECOM, Taiwan, November 2002.

[14] J. Baek, J.-F. Pâris: *A Tree-Based Reliable Multicast Scheme Exploiting the Temporal Locality of Transmission Errors,* Proceedings of the 24th International Performance of Computers and Communication Conference (IPCCC 2005), Phoenix, AZ, pages 275–282, April 2005.

[15] A. Mahanti: *On-demand Media Streaming on the Internet: Trends and Issues,* Comprehensive Examination Paper, 2001.

[16] R. B. Adamson*: Quantitative Prediction of NACK-oriented reliable multicast feedback,* Proceedings IEEE MILCOM, October 2002.

[17] J. Mahnke, N. Reyes, I. Miloucheva: *Protocol Mechanisms for Reliable Multicast in Mobile IPv6 Environment,* IPS-MoMe Workshop, February 2006.

[18] S. K. Kasera, G. Hjalmtysson, D.F. Towsley, J. Kurose: Scalable *Reliable Multicast Using Multiple Multicast Channels,* IEEE/ACM Transactions on Networking, Vol. 8, No.3, June 2000.

[19] C. M. Cordeiro, D.H. Sadok, J. Kelner: *Establishing a Trade-off between Unicast and Multicast Retransmission Modes for Reliable Multicast Protocols,* 8th International Symposium on Modelling, Analysis and Simulation of Computer and Telecommunication Systems, 2000.

[20] H. Holbrock, S. Singhal, D. Cheriton: *Log-based receiver reliable multicast for distributed interactive simulation,* ACM SIGCOMM, vol. 25, p. 328-341, October 1995.

[21] J. Lin, S. Paul: *RMTP: A Reliable Multicast Transport Protocol*, IEEE INFOCOM, p. 1414-1424, March 1996.

[22] S. Floyd, V. Jacobson, C. Liu, S.McCanne, L. Zhang: *A reliable Multicast Framework for Light-weight sessions and application level framing,* IEEE/ACM Transactions on Networking, December, 1997.

[23] P. Radoslavov, Ch. Papadopoulos, R. Govindan, D. Estrin: *A Comparison of Application-Level and Router-Assisted Hierarchical Schemes for Reliable Multicast,* IEEE/ACM Transactions on Networking, Volume 12, Issue 3, June 2004

[24] T. Speakman, et al.: *PGM Reliable Transport Protocol Specification,* RFC 3208, December 2001.

[25] L. Lehmann, S. Garland, D. Tennenhouse: *Active reliable multicast,* IEEE INFOCOM, San Francisco, p. 381-389, 1998.

[26] H. Omar, T. Saadawi, M. Lee: *An integrated platform for reliable multicast support in the regional mobile-IP environment,* Mobile Computing and Communications Review, Vol. 6, Number 2, 2002.

[27] A. Acharya, B.R. Badrinath: *A framework for delivering messages in networks with mobile hosts,* Mobile Networks and Applications, Vol. 1, No. 2, p. 199-219, 1996.

[28] K. Brown, S. Singh: *ReIPM: Reliable Multicast for Mobile Networks, Journal of Computer Communications,* Vol. 21, No. 16. p. 1379-1400. 1998.

[29] Y. J. Ke, W. Liao: *Reliable Mobile Multicast Protocol (RMMP): A Reliable Multicast Protocol for Mobile Networks*

using Mobile IP, Wireless Communication and Networking Conference (WCNC), p. 1488-1491, Sept., 2000.
[30] S. LiMin, Y. Liao, W. Zhimei: *A Reliable Region Based Hierarchical Mobile Multicast Protocol for IPv6 Network,* 5th IFIP TC6 International Conference on Mobile and Wireless Communication Networks (MWCN), October, 2003.
[31] N. Malhotra, S. Ranjan, S. Bagchi: *LRRM: A Randomized Reliable Multicast Protocol for Optimizing Receiver Latency and Buffer Utilization,* 24th IEEE Symposium on Reliable Distributed Systems, p. 215-225, 2005.
[32] I. Miloucheva, H. J. Einsiedler, D. Gomes, K. Jonas: *QoS based multicast architecture for heterogeneous mobile IPv6 environment,* ICT Conference, Madeira, May 2006.
[33] R. Akester: *A Resilient Multicast Protocol for Digital TV over 802.11 Wireless Networks,* Transactions on Information Science and Applications, Issue 3, Volume 1, 2004.
[34] O. Holland, A.H. Aghvani: *Dynamic Switching between One-to-Many Download Methods in All-IP Cellular Networks:* IEEE Transactions on Mobile Computing, Volume 5, Numb. 3, March 2006.
[35] I. Miloucheva, J. Moedeker, D. Wagner, R. Pascotto, K. Jonas: *Support of interactive QoS based services in hybrid broadcast and mobile IPv6 environment,* IST Mobile and Wireless Summit, Hungary, Budapest, 2-4 July, 2007.
[36] NORM v1.3b7, Navy source implementation of NACK oriented reliable multicast, October 2005.
[37] *Designing Advanced network Interfaces for the Delivery and Administration of Location independent, Optimized personal Services,* EU IST DAIDALOS project, www.ist-daidalos.org.
[38] G. Giambene, S. Kota: *Cross-layer protocol optimization for satellite communications networks: a survey*, International Journal of Satellite Communications and Networking, Volume 24, Issue 5 , Pages 323 – 341, September, 2006.
[39] ETSI: TR 102 473 v1.1.1 (2006-04): *Digital Video Broadcasting (DVB); IP Datacast over DVB-H: Use Cases and Services.*
[40] ETSI: EN 302304 v1.1.1, *Digital Video Broadcasting (DVB); Transmission System for Handheld Terminals (DVB-H),* Nov. 2004.
[41] ETSI: TR 102 471, *Digital Video Broadcasting (DVB); IP Datacast over DVB-H: Electronic Service Guide (ESG).*
[42] T.Paila, M. Luby, R. Lehtonen, V. Roca, R. Walsh: *FLUTE - File Delivery over Unidirectional Transport,* RFC 3926, October 2004.
[43] Technical Specification Group Services and System Aspects; Multimedia Broadcast / Multicast Service; Architecture and functional description, 3GPP TS 23 246 V.6.9.0.
[44] D. Gomez-Barquero, N. Cardona, A. Bria, J. Zander: *Affordable Mobile TV Services in Hybrid Cellular and DVB-H Systems,* IEEE Network, January/February 2007.
[45] I. Miloucheva, D. Hetzer, R. Pascotto, K. Jonas: *Resource Reservation in advance for QoS based Mobile Applications,* International Review on Computers and Software (IRECOS), ISSN 1828-6003, Vol. 2, No. 1, January 2007.
[46] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, H. Weiss: *Delay-tolerant networks architecture*, RFC 4838, April 2007.
[47] D. Kutscher, J. Greifenberg, K. Loos: *Scalable DTN Distribution over Uni-Directional Links* in ACM, NSDR Kyoto, Japan, August, 2007.
[48] J. Loughney, M. Nakhjiri, C. Perkins, R. Koodli: *Context Transfer Protocol (CXTP),* RFC 4067, July 2005.
[49] M. Liebsch, A. Singh, H. Chaskar, D. Funato, E. Shim: *Candidate Access Router Discovery (CARD),* RFC 4066, July 2005.
[50] Draft Standard for Local and Metropolitan Area Networks: *Media Independent Handover Services,* IEEE P802.21/D04.00, February 2007.
[51] J. Kempf (ed*.): Problem Statement for Network-Based Localized Mobility Management (NETLMM),* Request for Comments: 4830, Category: Informational, April 2007.
[52] J. Kempf (ed.): *Goals for Network-Based Localized Mobility Management (NETLMM),* RFC 4831, April 2007.
[53] M.Luby, T.Gasiba, T. Stockhammer, M. Watson: *Reliable Multimedia Download Delivery in Cellular Broadcast Networks,* IEEE Transactions on Broadcasting", Vol. 53, N0. 1, March, 2007.
[54] J. Villalon, P. Cuenca, L. Orozco-Barbosa, Y. Seok, T. Turletti: *Cross-Layer Architecture for Adaptive Video Multicast Streaming Over Multirate Wireless LANs*, Selected Areas in Communications, IEEE Journal on Volume 25, Issue 4, p. 699 - 711, May 2007.
[55] *Policy Based Management of Heterogeneous Networks for Guaranteed QoS,* European IST project NETQOS, www.ist-netqos.org.
[56] B. Whetten, D. Chiu, M. Kadansky, S. J. Koh, G. Taskale: *TRACK Protocol Instantiation over UDP: Tree Acknowledgment based reliable multicast,* Internet Draft, draft-whetten-rmt-track-pi-00.txt, October 28, 2002.
[57] I. Miloucheva, D. Wagner, P. A. A. Gutierrez: *Architecture for dynamic management of QoS policies for heterogeneous Internet environments,* Int. Conference on Mobile Applications, Services and Technologies (NGMAST07), Cardiff, Wales, UK, 12-14 September, 2007.

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