Cooperative Recovery in Heterogeneous Mobile Networks

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***Abstract*—In multicast/broadcast services over infrastructure-based/cellular wireless networks (e.g. 3G cellular networks, WiMax, DVB), data is transmitted to multiple recipients from an access point/base station. Multicast greatly improves the network efficiency to distribute data to multiple recipients as compared to multiple unicast sessions of the same data to each receiver individually, by taking advantage of the shared nature of the wireless medium. However it is difficult to guarantee the reception reliability of multiple multicast/broadcast recipients because the wireless medium is error prone and each receiver experiences different channel conditions. An additional difficulty is that multicast/broadcast services in many networks such as 3G multimedia multicast services do not provide a reverse communications channel for the receivers to request the retransmission of lost data packets. This research proposes a novel method to provide QoS support by using an *assistant network* to recover the loss of multicast data in the principal network. Wireless devices are connected to the principal network to receive the multicast data. A wireless device may lose some of the multicast data sent over the principal network. The wireless devices form an assistant network to recover the lost multicast data cooperatively from their peers. The performance of this recovery mechanism has been investigated using extensive simulation experiments.** [1]

I. INTRODUCTION

With the increasing popularity and demand for wireless connection-based multimedia services and the sophisticated capabilities of mobile devices, mobile multimedia multicast/broadcast services have become an important component of wireless networks. One of the most important characteristics of wireless multicast is highly efficient communications because of the shared nature of the wireless medium. Currently 2.5G and 3G cellular networks are offering multimedia services like Mobile TV. Broadcasting networks especially designed for mobile broadcasting like DVB-H [1], DMB [2] and MediaFLO [3] are currently under deployment. In addition to these dedicated mobile broadcasting networks, 3G cellular networks have been extended to support Multimedia Broadcast Multicast Service (MBMS) [4] .

One challenge in providing such services is to guarantee the reception reliability of multiple multicast receivers because the wireless links are error prone and multiple receivers experience heterogeneous channel conditions. The multicast/broadcast services in many networks such as Digital Video Broadcasting (DVB) and 3G multimedia broadcast/multicast services [5], [6] do not provide any reverse communication channel for the receivers to request the retransmission of lost data. In many wireless multicast/broadcast systems, forward error correction codes (FEC) are used to protect against multipath fading and interference and reduce the packet errors. However the wireless channel conditions are time-varying and the multiple receivers in a multicast experience heterogeneous channel conditions. The FEC codes are often designed for the worst channel conditions to ensure an adequate reception quality for all the receivers in the desired service area. This results in a large overhead in terms of radio resources in infrastructure-based multicast networks. Another technique to improve reliability and throughput is to use multiple antennas. However, this approach incurs high cost and complexity for wireless systems at the base station and the wireless devices. Therefore it is a key and challenging task to support good quality multicast service to multiple mobile receivers while efficiently utilizing radio resources and improving the throughput and QoS of infrastructure-based cellular wireless networks.

In this paper we are proposing a solution using an integrated system resilient to packet loss, to provide high-quality multicast services over wireless networks.

The proposed scheme assists the principal infrastructure network (e.g., 3G) by dynamically setting-up a cooperative assistant recovery network (e.g., WiFi) among neighboring devices that use the same service. Each device is equipped with two physical radio interfaces. One interface is connected to the principal network and is responsible for receiving the downstream multicast data. The other interface is used to setup the assistant recovery network. The devices recover lost multicast data packets in their principal network by requesting them from their recovery network. A device, by initiating a cooperative recovery procedure in its assistant recovery network, requests and receives lost data from the devices that are in the neighborhood. These neighboring devices use the same service and have correctly received the particular data packets. In this way the devices recover lost data and thus improve the QoS for the particular service.

We show that neighboring devices of the multicast services

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in the principal network encounter heterogeneous data loss, and the probability of multiple receivers losing the same data is extremely low. Any device deploying cooperative recovery can recover lost multicast data packets as long as one of the peer devices in the assistant recovery network has successfully received those packets.

Simulation results show that the proposed scheme works very efficiently and recovers almost all the lost data, in most of the cases, taking advantage of uncorrelated packet losses at the wireless devices.

The rest of the paper is organized as follows. In section II, we briefly describe the related work. In section III, we present the basic Cooperative Recovery System Architecture and Section IV describes our Cooperative Recovery Protocol design. Section V evaluates the performance of the protocol and presents extensive simulation results. We discuss a few related issues in Section VI. Finally, in Section VII, we conclude this paper.

II. RELATED WORK

Several approaches have been proposed to improve the quality and throughput of a cellular/infrastructure network with the assistance of an ad hoc network. In a reported system [7], mobile devices with good link quality to the base station act as relays for devices with poor link quality. In this system, a single wireless interface is used for both relay and infrastructure modes. The total cell throughput achieved in this hybrid-mode network is bounded by the available cellular bandwidth.

In another reported system [8], two types of wireless interfaces are used to integrate cellular and ad hoc networks. In this scheme, high-bandwidth wireless channels in ad hoc mode (IEEE 802.11) are used to relay the unicast traffic of the cellular network (3G) for improving cellular throughput and coverage range.

In a third reported system [9] [10], multicast data is transmitted to a relay node over a short range within the cellular network (3G) and is forwarded to the remaining subscribing nodes by the relay node via high speed ad hoc networks (IEEE 802.11).

In [11] the system deploys ad hoc relaying devices to relay traffic from one cell to another, to avoid congestion problem due to unbalanced traffic in a cellular system.

All the above approaches use a relay node to forward the cellular traffic to the destination nodes via an ad hoc network. The cellular network and the ad-hoc network can use a single wireless interface (3G) or two types of wireless interfaces (3G and WiFi). The downlink data is sent to the relay node from the base station and then forwarded to the destination nodes via a single-hop or multihop ad hoc network. The uplink data (if there is any) goes through a reverse path. That is, the destination nodes always receive or transmit data through the relay node in the ad hoc network path. In such approaches, the relay node always helps the destination nodes, without gaining any direct benefit. Thus there is only one way cooperation between relay node and other devices. Such systems may generate a bottleneck at the relay node, a fact that can lead to inefficiency of the network.

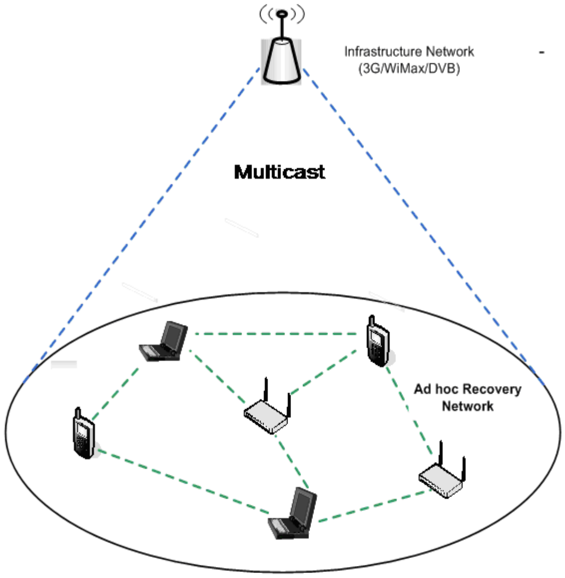

Fig. 1: System architecture with ad hoc recovery network formed by wireless devices

In our scheme, solutions to the above problems are proposed. The key concept of this new mechanism is the notion of ‘Peer Cooperation’ among the devices in the assistant recovery network. Here, a device can be a partner with any other device and provide or request lost data from each other. Lost data in the 3G network are recovered in the ad hoc WiFi network by dynamic requests that are triggered each time a device experiences loss of a data packet. The proposed scheme does not require a centralized relay node. Additionally, the devices, by cooperating in the recovery network, exchange only the lost data packets, eliminating redundancy in the two networks. Recovery in assistant network is independent of the helping device’s channel condition. This eliminates the need to attract a device with good channel condition or low data loss rate to participate in the recovery network by giving attractive incentives.

As a result, this scheme improves the multicast reliability and quality of services for all the involved devices by taking advantages of the spatial diversity and cooperation among devices to recover the lost multicast data.

III. COOPERATIVE RECOVERY SYSTEM ARCHITECTURE

A typical network system considered for cooperative recovery consists of two co-existing wireless networks in an area: a *principal network* and an *assistant network*.

The principal network is an infrastructure-based cellular wireless network with base stations. Although we consider a 3G cellular network in this paper, this approach can be extended to other types of cellular networks such as WiMax, WiFi or DVB networks. The assistant network can be an ad hoc cooperative network formed by the devices in a peer to peer architecture.

As an example, the radio interface for the assistant network can be IEEE 802.11 [12] [13]. The Cooperative Recovery system architecture is based upon the fundamental idea of using spatial diversity and channel heterogeneity of peer devices to recover lost data packets by deploying an assistant recovery network. The principal network provides downlink multicast/broadcast services from the base station to the devices. Examples of such services are video/audio streaming or other multimedia services. The assistant network helps improve the QoS and transmission reliability of the multicast services in the principal network by recovering the lost data packets among peer devices. This hybrid scheme is depicted in Figure 1.

We assume that each wireless device is typically equipped with two physical radio interfaces. One interface is connected to the backhaul principal network and is responsible for receiving the downstream multicast data from the base station/access point (principal interface). The other interface is connected to the assistant network and is used to recover the lost data packets of the principal network (assistant interface). We consider IEEE 802.11 in our Cooperative Recovery system architecture, because of its popularity and wide deployment.

In the case that the principal network and the assistant network use the same radio technology, for example, IEEE 802.11, a wireless device may use a single physical interface. The single physical interface can be split into two logical interfaces, one to access the principal network and the other to access the assistant network.

Wireless devices receive data from the backhaul principal network through the principal interface. At the same time they run the Cooperative Recovery protocol to dynamically form an ad hoc cooperative network and cooperate to recover the lost multicast data packets from other peers over the assistant network. A multicast data packet can be lost to a wireless device, but may be correctly received by other wireless devices due to their spatial diversity and channel heterogeneity.

This recovery method improves the multicast reliability and QoS for all the involved peers by cooperation among the peers to recover the lost multicast data packets. It also helps to extend the coverage of the principal network as shown in our simulations in Section V.

The effect of the degree of dependence of packet loss at multiple wireless devices in a multicast session is very critical for a cooperative recovery strategy. Consider a simple wireless network scenario where source S is multicasting data to devices A and B. Packets sent from the source are received corrupted by devices A and B independently with probabilities p_1 and p_2, respectively ($p_1, p_2 \ll 1$). The probability that a particular multicast data packet is lost by both the devices A and B is p_1 x p_2, which is very low. Considering a recovery network of N wireless devices, the probability that at least one of the devices in the network receives a particular packet non-corrupted is $(1 - \prod_1^n p_n) \approx 1$. In the analysis given above we assume that a helper device is only using the originally received packets to help the requester. However, this may not always be true. In the cooperative recovery scheme all the stations in the recovery network are doing the recovery almost simultaneously. It is very likely that a helper device may have recovered part, if not all of its lost data, by the time any other device requests for recovery from this helper. In such a case the helper could provide more data than it originally received from the multicast session on its principal interface.

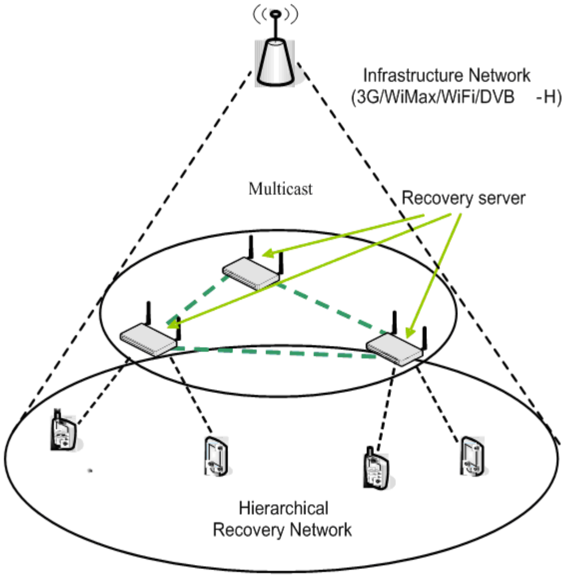

Fig. 2: Alternative System architecture using a hierarchical ad hoc recovery network with dedicated proxies/servers

As an alternative embodiment, dedicated recovery servers/proxies can be deployed. These recovery proxies are also equipped with two radio interfaces, one for the principal network, and the other used to join the assistant recovery network. Referring to Figure 2, it is possible that a hierarchical assistant network is formed by the proxies and the wireless devices. The proxies receive the data packets from the principal network and provide the lost packets to other peers over the assistant network. A dedicated proxies may not receive all the necessary data packets from the principal network. In the hierarchical supplementary network, a proxy can recover its own lost packets through other proxies. A wireless client device recovers its lost packets from a recovery proxy.

For our simulation cases we consider a system architecture where no proxies are deployed and the wireless devices form an ad hoc assistant recovery network.

IV. COOPERATIVE RECOVERY PROTOCOL DESIGN

As explained above, the wireless devices receive the multicast service from the principal network, dynamically form an assistant ad hoc network to recover lost multicast data packets. In order to recover the lost multicast data packets from the peers, a wireless device needs to discover, establish and maintain the partnership with the peers via the assistant network. The detailed functionality of the protocol can be

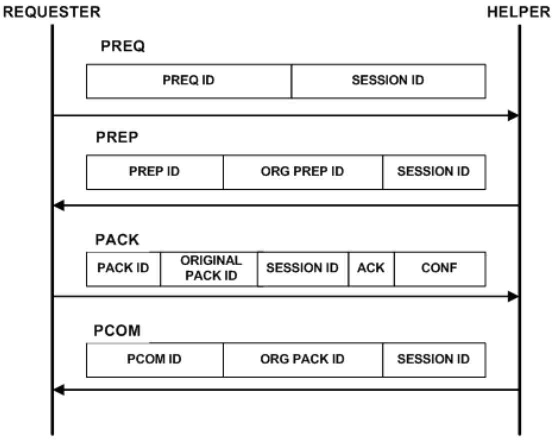

Fig. 3: Partnership establishment

explained in three phases: *Peer Discovery and Partnership Establishment, Partnership Maintenance* and *Data Recovery*.

A. Peer Discovery and Partnership Establishment

Any device might wish to cooperate with other peers for data recovery, hoping that in this recovery process, it would be able to recover the data that it might have lost. Any node may participate if its broadcast/multicast reception on its principal interface is not satisfactory. Data recovery with the Cooperative Recovery Protocol is independent of helper device's channel conditions. Hence this protocol design is not required to attract a device with good channel condition/low data loss rate to be a part of the recovery network by giving it any additional *credits*. Devices with heterogeneous data losses try to set up an ad hoc network with other neighboring devices to recover their loss.

This phase is responsible for peer discovery and partnership establishment. As depicted in Figure 3, a requester (Wireless Device trying to establish/join the assistant network) sends a Partnership Request (PREQ) message by broadcasting in the assistant network when it determines that it needs to discover and establish the partnership with other peers. The PREQ message contains the source address, destination address, the PREQ message ID, the session ID for cooperative recovery and the time-to-live (TTL). The source address is the IP address of the PREQ originator for its assistant network interface. The destination address is the IP broadcast destination address of this message in the assistant network. The time-to-live field (TTL) indicates the number of hops that the PREQ messages will propagate in the assistant network. The session ID for cooperative recovery identifies the multicast session in the principal network for which the requester (PREQ originator) wants to recover its lost packets through the cooperation of the peers over the assistant network. It is the ID carried in the multicast data packets which identifies the session that they belong to in the principal network. When a wireless device receives a PREQ message from its assistant network interface, it determines whether it will become a partner candidate of the requester wireless device (PREQ originator) for the requested session.

A decision can then be made by the partner candidate device (PREQ receiver) based on whether it has enough processing power, battery power and bandwidth in the assistant network and based on the number of other peers with whom it has already established partnership for recovery. The partner wireless device receiving the PREQ updates the TTL field in the PREQ message by reducing its value by one. If the updated value of TTL field is greater than zero, the PREQ receiver forwards/broadcasts the PREQ message to its neighbors in the assistant network. If the updated value of the TTL field becomes zero, it discards the PREQ message.

Based on the above criteria, if the device wants to serve the requester device for the recovery of lost packets, it sends a unicast Partnership Reply (PREP) to the requester. The PREP message contains the original PREP message ID, the session ID and the PREQ message ID. If the wireless device has already established a partnership with the requester for the session specified in the PREQ message, it ignores this PREQ message. After the requester receives a PREP message from a potential partner candidate, it will decide whether to form a partnership with this device. The requester then sends a unicast Partnership Acknowledgement (PACK) message to each peer device from which it received a PREP message to join or not to join the partnership. The PACK message contains the original PREP message ID, the PACK message ID, the session ID, an acknowledge flag and a confirmation flag. The acknowledge flag defines whether the partnership candidate has been selected as partner by the requester. The confirmation flag indicates whether the partner needs to send a Partnership Confirmation (PCOM) message back. After the partner device receives the PACK message, it sends a unicast Partnership Confirmation (PCOM) message to the requester (PACK originator) if the confirmation flag is set in the PACK message. The PCOM message is used in case the lower layer transport protocol does not have a reliable end-to-end transport mechanism (e.g., UDP). When the lower layer does not provide transport reliability, the requester (PACK originator) may set the confirmation flag in the PACK message that it sends. If the lower layer provides a reliable transport mechanism (e.g., TCP), it can depend on the lower layer to deliver the PACK message successfully. After these messages are successfully exchanged, the partnership between the requester and the peer is established.

All of the above control messages are transmitted over the assistant recovery network. Note that a partner device may receive multiple copies of the same PREQ message, which is propagated in multicast/broadcast through different paths in the assistant network. The device only propagates the first copy of the PREQ message. The device replies to the first copy of the PREQ message with a PREP if it decides to form the partnership with the requester for the specific session. The above control messages may be lost. To ensure the delivery of these control messages in the absence of any feedback from the remote partner candidate, PREQ and PACK retransmission

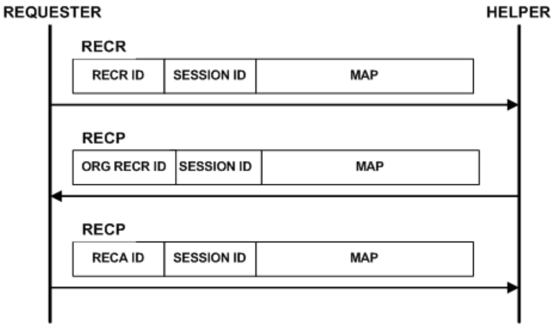

Fig. 4: Data recovery

timers are implemented.

A wireless device may establish partnership with one or multiple partner devices for recovering a session. If the number of the partners is less than the desired number of partners, the wireless device may try to discover and establish more partners using the above method periodically. The desired number of partners can be configured at the wireless device.

Any peer in the partnership may terminate the partnership by sending a Partnership Termination (PTER) message to the other peer.

B. *Partnership Maintenance*

After a partnership is established between two devices, they maintain it by exchanging Keep-Alive messages between them. A Keep-Alive (KA) unicast message is sent periodically with period K_INTERVAL from the requester to the peer to maintain the partnership. The Keep-Alive message contains the source and destination addresses of the KA message, the keep-alive message ID, the session ID and the time-to-live (TTL). The peer replies with a unicast Keep_Alive_Reply (KAR) message to the requester (KA originator) after the KA message is received. If a KAR message is not received within a KAR_TIMEOUT after the KA message is sent, the requester (PREQ originator) retransmits a KA message with a new KA message ID. The requester may retransmit a keep-alive message for a maximum number of KEEP_ALIVE_RETRIES_LIMIT times if the KAR message is not received from the peer. If the KAR message is still not received from the peer after the maximum number of retransmissions has been reached, the requester device (i.e. the PREQ originator) assumes that the partnership with this peer is ended. The requester may find a replacement partner using the above peer discovery and partnership establishment procedure. If a partner device with an established partnership with the requester (PREQ originator) has not received the keep-alive message from the requester device for a time interval KEEP_ALIVE_LIMIT, it assumes the partnership with the requester device has ended.

C. *Data Recovery*

After the partnership is established, in order to recover the lost packets of the session from the peers over the assistant network, both peers cache the data packets of the specified session received from the principal interface. A wireless device can detect a multicast data packet loss for a session received from the principal network by a gap in the packet sequence numbers in the packet headers. If a wireless device does not receive certain multicast data packets from its principal interface, it will try to recover the lost data packets from its partners via its assistant network.

A recovery method is depicted in Figure 4. The wireless device sends a Recovery Request (RECR) message to one or multiple partners. The RECR message contains the source address, destination address, the session ID, the RECR message ID, the requested packet map or list. The requested packet map or list identifies the packets that the RECR originator requests from the partner(s). After receiving the RECR message, the partner determines which requested packets it can offer. The partner sends a Recover Reply (RECP) message to the requester device (RECR originator). The RECP message contains the source and destination addresses, the session ID, the original RECR message ID, and the offered packet map or list. The offered packet map or list identifies the packets that this partner can offer. The RECR originator determines which lost packets can be recovered from a specific partner according to the offered packet map or list in the RECP message from this partner. If more than one partner can offer the same packet, the RECR originator may select a partner to obtain this packet based on criteria such as the path quality and PDU drop rate. The RECR originator then sends a Recovery Acknowledgement (RECA) message to the partner. The RECA message contains the source address, destination address, the session ID, the RECA message ID, the packet map or list. The packet map identifies the packets that the requester decides to request from this partner. The partner sends the corresponding packets to the requester according to the packet map in the received RECA. If the partners can not offer all the requested packets, the requester can send a RECR to other partners with an updated packet request map.

V. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the Co-operative Recovery Protocol in improving the QoS of the 3G Broadcast/Multicast services using an assistant recovery network. In Section V-A we describe our methodology for the evaluation, and in Section V-B we describe the various experimental scenarios we considered to test the performance of the protocol and the corresponding results.

A. *Methodology*

To simulate the Cooperative Recovery Protocol, we assumed that there are wireless devices whose principal/multicast interface is 3G and the secondary/recovery interface is a 802.11b WLAN. All the wireless devices receive the same multicast session on their 3G interface at a rate high enough to keep the playout buffer in the devices full all time. We set a playout deadline of 600 milli-seconds before an application reads the

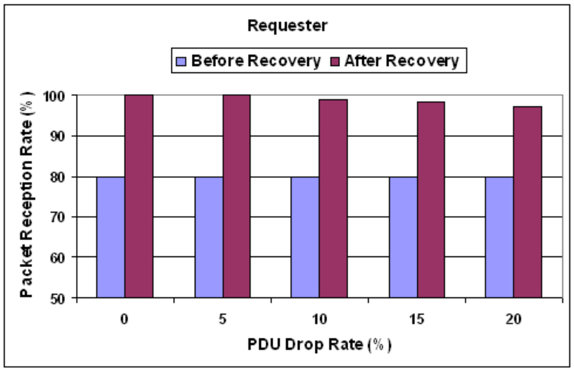

Fig. 5: Effect of PDU drop rate at the requester

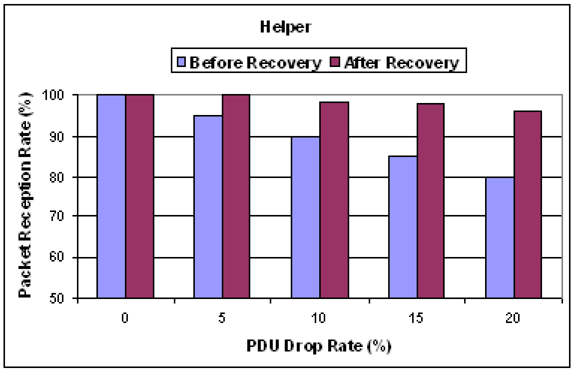

Fig. 6: Effect of PDU drop rate at the helper

buffer. Any data recovered after the playout deadline expires is discarded. The multicast session is an encoded video stream. The length of the clip is such that when it is encoded and packetized using the UMTS (Universal Mobile Telecommunication Systems) packetization it generates around 45000 RLC-PDUs (radio link control-protocol data units) of 160 bytes each. We used the wireless module of OPNET Modeler [14] as our simulation platform. As OPNET Modeler does not support a wireless device with a dual interface (viz., 3G and 802.11b), we simulated the reception of the 3G multicast session by assuming that we get a series of PDUs to the process above the transport layer.

All the experimental scenarios are considered to be in an urban environment where channel conditions of individual 3G receivers differ substantially over a short range (5m) [15]. We generated these PDU drop traces for each receiver with a different average PDU drop rate by using published experimental data in [16] [17]. A PDU drop trace consists of a binary sequence where each element represents the status of a PDU frame. Binary Sequence '1' represents a corrupt PDU, while '0' represents a correct PDU. In the following discussion, we use PDU loss rate to represent 3G channel conditions.

We expect that external traffic on the secondary recovery network will affect the performance of the recovery process. In the experiments we present here, we consider no external traffic on the secondary network, since in this work we primarily focus on study of the joint recovery mechanism between the two heterogeneous networks.

We use two metrics to evaluate the performance of our Co-operative Recovery Protocol. We compare the ***before recovery*** and ***after recovery PDU drop rates*** at the wireless devices to evaluate the effectiveness of the protocol in recovering the lost data in the principal network, as well as the improvement in throughput of the wireless devices.

B. Experiment Scenarios and Results

1) Dependency on PDU drop rate: We consider a simple scenario in order to observe the details in the protocol behavior and to study the dependency of the recovery procedure on PDU drop rate. Only two wireless devices participate in this scenario. We call them *requester* and *helper*. Both the devices are receiving the same multicast session on their principal/3G interface. The channel quality of the requester is poor. It can receive only 80% of the PDUs of the multicast session on its 3G interface. On the other hand, we vary PDU drop rate at the helper device to emulate a channel quality that degrades from good to poor. When the channel quality is good the helper device receives almost all the PDUs of the 3G multicast sessions. When its channel quality is poor it drops up to 20% of the PDUs.

Figure 5 shows the PDU drop rate at the requester before and after the recovery. Initially when the channel condition of the helper device is good and channel condition of requester is poor, the recovery procedure turns out to be beneficial for the requester as it manages to recover all the lost PDUs from the helper.

As the channel condition of the helper device starts degrading, the requester is not able to recover all the lost PDUs from the 3G multicast session. However, after the recovery process, the requester manages to have a significantly lower PDU drop rate than before the recovery. For example, when the helper experiences 10% PDU drop rate, the requester manages to have an after recovery PDU drop rate of only 3%.

Figure 6 shows the PDU drop rate at the helper device before and after the recovery. When the channel condition of the helper

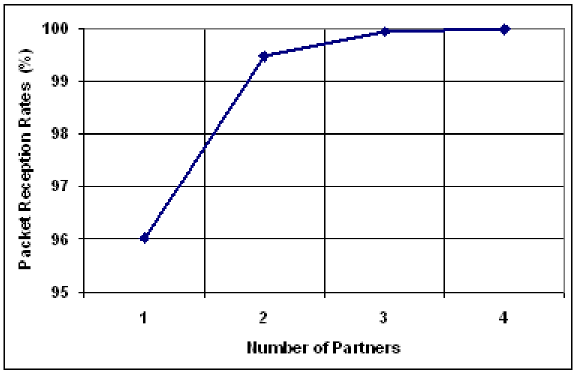

Fig. 7: Effect of number of helpers

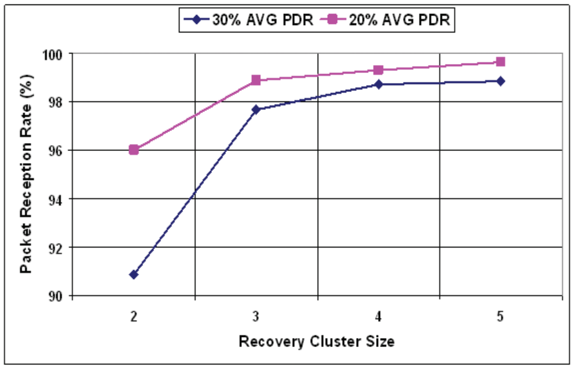

Fig. 8: Effect of recovery network size

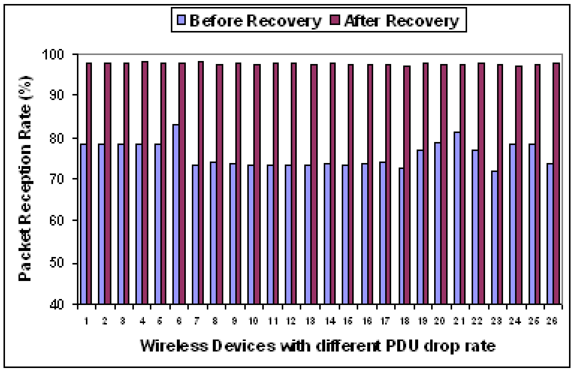

Fig. 9: Throughput improvement

device starts degrading, it starts utilizing the recovery procedure for requesting its lost PDUs from the requester. The recovery procedure turns out to be beneficial for both, requester and helper, even when the channel condition for both of them is poor. For example, when PDU drop rate of the requester and helper is as high as 20%, both of them still manage to recover sufficient PDUs from each other to give an after recovery PDU drop rate of 4%.

2) Dependency on the number of helpers: In this scenario, we study how the number of helper devices per requesting device affects the performance of the cooperative recovery protocol. We consider eighteen wireless devices with a 30% PDU drop rate per device. We start with the condition that every wireless device can have at most only one device acting as its helper in the recovery. Then we increase the number of helper devices per requesting device from one to four. As seen in the Figure 7, we can observe an initial significant increase in the average recovery ability as the number of helpers per requester device increases. Also it can be seen that the improvement in percentage recovery does not significantly improve for a higher number of helpers per requester. This signifies that two or three helper devices have enough diversity in their PDU loss pattern in order for any device to recover almost all of the lost PDUs even under very poor channel conditions.

3) Effect of Recovery Network Size: Here we study the effect of recovery network size on recovery efficiency. We fix the PDU drop rate of all the wireless devices to 20% and restrict each device to have two helper devices. Then we increase the number of devices in the ad-hoc recovery network from two to five. We repeat the same experiment with a PDU drop rate set to 30%. The experimental results are depicted in Fig.8. We can infer that as the number of devices in the network increases, the average recovery in the network also increases till a certain point after which it saturates. This is due to the fact that when a requester is recovering its lost data packets from a helper device, the helper device simultaneously is in the process of recovering its lost data from other nodes in the network. Thus the helper is able to offer the requester not only the data packets it had received from the principal network but also the data packets it recovered from the assistant recovery network. Thus as the number of devices in the recovery network increases, the probability that a device finds its lost PDU in the cluster also increases. However, as we have fixed the maximum number of helpers for any device in the recovery network to two, it is not possible for the devices to recover all the PDUs, and after a certain size of the network, recovery saturates.

4) Throughput Improvement and Fairness: In this section we study the behavior of the protocol in a dense environment. We consider 26 wireless devices in a small office area. These devices have PDU drop rates ranging from 5% to 30% according to the varying wireless channel condition experienced by them. As depicted in Figure 9, all the devices recover almost all the lost multicast PDUs. The experiment shows us that in a realistic dense environment the proposed protocol works efficiently. All devices with good or bad channel conditions benefit from cooperative recovery, which provides certain fairness. Furthermore, cooperative recovery assists the 3G network in increasing the coverage range and fairness by providing a recovery mechanism to the devices with poor channel conditions.

5) Multihop Scenario: For all the above scenarios, all the wireless devices formed a single hop IEEE 802.11 WiFi assistant recovery network. Here we consider a scenario consisting of 13 wireless devices forming a multihop ad hoc wireless assistant recovery network. We set the PDU drop rate at each of these wireless devices randomly over a range from 5% to

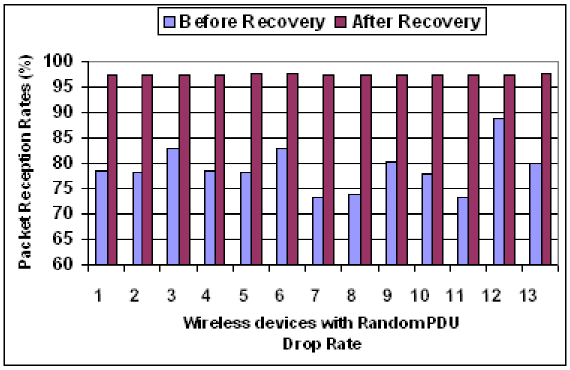

Fig. 10: Multihop Recovery Scenario

30%. As can be seen from Figure 10, the after recovery PDU drop rate at all the wireless devices is less than 4%.

6) Recovery Delay: From all the above simulation results it can be seen that in an assistant recovery network with a reasonable PDU drop rate at each wireless device, all the devices in the network are capable of recovering almost all the lost data with an after-recovery PDU drop rate of less than 4%. In this section we study the recovery delay for the wireless devices in single hop and multihop scenarios. During these experiments we calculated the peak recovery delay for each device. To study the delay in multi-hop scenario we forced devices to form a partnership with another device a few hops away. Other wireless devices acted as relays in between these two devices. As expected, it can be seen from Figure 11 that the recovery delay for each device increases with increasing number of hops between a wireless device and its helper, however the observed peak delay was less that the set threshold (playout deadline). Note that with a higher number of hops, the observed recovery delay sometimes exceeded the playout deadline and the recovered packets were discarded, but such occurrences were rare.

Fig. 11: Peak Recovery Delay

7) Video Encoder/Decoder Simulation: To further evaluate the performance of the Cooperative Recovery Protocol, we simulated a 3G video broadcasting service. We designed a simulation which encoded a video with the PDU drop traces we generated, and then decode the video giving us the PSNR values for the video. To conduct this experiment we generated a 3G PDU trace as explained before. We ran our Cooperative Recovery Scheme, where the wireless devices formed a cooperative recovery network and recovered lost packets from other peers. Here we considered a 8% to 15 % random PDU drop rate for a 15 wireless device ad hoc recovery network. We ran the simulation with the random traces we generated, and with the PDU traces after Cooperative Recovery, and found that the protocol significantly improved the QoS of the 3G video broadcast service (see Table I). The sample results shown in Figures 12 and 13 are for a wireless device which had a 11% PDU drop rate in the principal 3G network and then has a PDU drop rate less than 3% after it recovered the lost data using the recovery scheme.

VI. DISCUSSION

In this section we discuss several issues related to the Cooperative Recovery Scheme.

A. Partner Selection

For optimum performance from the assistant recovery network, appropriate helper device selection is very crucial. In our approach, whenever a requester wireless device broadcasts its request for a helper, any device which receives this request can agree to help the requester. A requester has a choice of helper devices. In our current simulation, a requester selects any two devices as its helpers on a first in first select basis. It is possible to optimize this partner selection process by implementing an appropriate algorithm which considers various criteria like good channel conditions among all the available partners, proximity with the requester, mobility of nodes, PDU drop rate of the partners and battery power.

B. Mobility of Wireless Devices

For simplicity, we only consider stationary wireless devices forming an ad hoc assistant recovery network. It is possible to extend the design to allow wireless devices to have mobility. This will require a protocol extension for a requester wireless device to discover that a partner device is moving out of its transmission range and its needs to find another peer to recover its packets. Alternatively the helper device could find a relay node in between and could establish a connection with it to relay the packets to the requester node, without terminating the on-going partnership.

C. Recovery Proxy

In the current protocol design we assume an environment where any requester is able to find at least one peer wireless device which is in its communication range. But it is possible that a wireless device is not in the immediate communication range of a requester device. Such a situation could be addressed by deploying certain dedicated recovery proxies at critical locations. These recovery proxies are also equipped with two physical radio interfaces, one for the principal network, the other to join the assistant network. They too may not receive all the multicast data packets from the principal network. A proxy can recover its own lost packets through other proxies. A wireless device would recover its lost data from a recovery proxy.

TABLE I: PSNR Values

PSNR(dB)	Y	U	V
Before Recovery	21.31	24.23	25.27
After Recovery	35.62	38.49	39.54

Fig. 12: Image before recovery

Fig. 13: Image After Recovery

VII. CONCLUSIONS AND FUTURE WORK

In this paper we present a Cooperative Recovery Scheme, which is a novel method to enhance QoS support for multicast services over a principal network (3G). Under this scheme, devices that receive the same multicast service, set up an assistant recovery network to recover the loss of multicast data received from the principal network. On top of this scheme, we designed and applied a simple mechanism to avoid bottlenecks and maintain fairness in the recovery network by deploying partner selection policies. In future work we plan to extend the recovery model by using a hierarchical architecture with dedicated proxies in the assistant recovery network. Furthermore, we will investigate possible security implications that are introduced in the network due to the heterogeneity of two different networks. Finally we plan to implement the proposed protocol using socket programming in order to study its efficiency in a real environment.

REFERENCES

[1] "DVB-H," *http://www.dvb-h.org/*.
[2] "DMB," *http://www.t-dmb.org/*.
[3] "MediaFLO," *http://www.mediaflo.com/*.
[4] "3GPP Specifications TS 26.346: Multimedia Broadcast/Multicast Service," *http://www.3gpp.org*, 2004.
[5] "3GPP TS 23.246 Multimedia Broadcast/Multicast Service (MBMS); Architecture and functional description," *http://www.nokiausa.com/A4410146*.
[6] B. Bhargava, X. Wu, Y. Lu, and W. Wang, "Mobile Broadcast/Multicast Service (MBMS) White paper," *TeliaSonera*.
[7] G. N. Aggelou and R. Tafazolli, "On the Relaying Capability of Next-Generation GSM Cellular Networks," in *Personal Communications, IEEE*, vol. 8, pp. 40–47, Feb 2001.
[8] H. Luo, R. Ramjee, P. Sinha, L. Li, and S. Lu, "UCAN: a unified cellular and ad-hoc network architecture," in *In Proceedings of the 9th Mobicom International Conference*, pp. 353–367, Feb 2003.
[9] J. C. Park and S. K. Kasera, "Enhancing Cellular Multicast Performance Using Ad Hoc Networks," in *IEEE Wireless Communications and Networking Conference*, vol. 4, p. 2175 Ű 2181, March 2005.
[10] R. Bhatia, L. Li, H. Luo, and R. Ramjee, "ICAM: Integrated Cellular and Ad-Hoc Multicast," *IEEE Transactions on Mobile Computing*, vol. 5, pp. 1004 – 1015, Aug 2006.
[11] H. Wu, C. Qiao, and O. Tonguz, "Integrated Cellular and Ad Hoc Relaying Systems: iCAR," *IEEE Journal on Selected Areas in Communications*, October 2001.
[12] "802.11 HotSpot," *http://www.80211hotspots.com.*
[13] "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *ANSI/IEEE Std 802.11, 1999 Edition*.
[14] "OPNET," *http://www.opnet.com.*
[15] M. Gudmundson, "Correlation Model for Shadow Shadow Fading in Mobile Radio Systems," *Electronics Letters*, vol. 27, pp. 2145–2146, November 1991.
[16] M. Hassan, M. Krunz, and I. Matta, "Markov-based channel characterization for tractable performance analysis in wireless packet networks," *IEEE Transactions on Wireless Communications*, vol. 3, pp. 821 – 831, May 2004.
[17] P. Ji, B. Liy, D. Towsley, and J. Kurose, "Modeling frame-level errors in GSM wireless channels," *Global Telecommunications Conference*, vol. 3, pp. 2483 – 2487, Nov 2002.
[18] M. Bakhuizen and U. Horn, "Mobile broadcast/multicast in mobile networks," *Ericsson Review*, 2005.
[19] D. B. J. Y.-C. H. J. Broch, D. A. Maltz and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," in *Proceedings of ACM MOBICOM*.
[20] C. E. Perkins and E. M. Royer, "Ad-hoc On Demand Distance Vector Routing," in *Proceedings of IEEE Workshop on Mobile Computing Systems and Applications (WMCSA)*.
[21] D. B. Johnson and D. A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," *Mobile Computing*.
[22] "IEEE 802.16 WirelessMAN," *http://www.ieee802.org/16/*.
[23] T. S. Rappaport, "Wireless Communications: Principles and Practice," 1996.
[24] A. Konard, B. Y. Zhao, A. D. Joseph, and R. Ludwig, "A Markov-Based Channel Model Algorithm for Wireless Networks," *Wireless Networks archive*, vol. 9, May 2003.