

A Heterogeneous Cellular and Ad Hoc Network Architecture for Multipoint Streaming: A detailed performance analysis

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ABSTRACT

The current 3G-Cellular radio access network cannot support many concurrent high data rate unicast or multicast flows due to limited radio resources. We have proposed a heterogeneous wireless network architecture intended for point-to-multipoint services, to improve the availability of such services to mobile users. The architecture consists of a 3G-Cellular network, supported by a number of local ad hoc networks that are established on demand. In this framework the 3G multipoint-channel range is reduced while the unicast and signalling connections are maintained. Local ad hoc networks are used to forward the multicast data onto users located outside the shortened 3G multicast-channel range.

In this paper we present a performance analysis of multicast streaming on the heterogeneous network architecture. The simulation results are complemented with a sensitivity analysis identifying the impact that parameters like node mobility and traffic patterns will have. The results verify that the architecture and the routing protocol are able to provide multicast services with acceptable quality to the multicast subscribers, while conserving 3G-Cellular radio resources.

Keywords: Multicast, ad hoc, 3G/4G, Wireless internet, Multimedia.

1 INTRODUCTION

Streaming of multimedia content is believed to be an important service in future wireless networks (e.g. [1]). Multicast as a delivery mechanism offers a significant improvement of spectrum utilization for multipoint services; such transmission was introduced in 3G-Cellular networks with the Multimedia Broadcast Multicast Service (MBMS) [2]. However, two important spectrum saving techniques (fast power control and packet scheduling based on channel quality) used in 3G unicast are not available for a multipoint channel.

A 3G network has limited bandwidth capacity and can support only a handful of high data rate users simultaneously. Multicast transmissions are likely to put a significant load on the total capacity, since the power and level of interference is given by the maximum distance from the base station to the receivers. Thus it is anticipated that the demand for broadcast/multicast bandwidth may exceed the MBMS capacity as well. Consequently, off-loading traffic from the 3G cell to

other technologies is a possible way to improve the service availability. It is envisioned that the future 4G networks will consist of many cooperating wireless technologies in order to provide universal connectivity and opportunity for best suited services to users at all times. Several heterogeneous wireless networks architecture (using e.g. satellite, DVB-H/T and WiMAX) that intended to complement the 3G network for multicast/broadcast services, have already been proposed (an overview is given in [1]).

We believe a heterogeneous network architecture based on 3G-Cellular networks and assisting ad hoc networks is one likely solution for distribution of high data rate broadcast/multicast services [3]. Mobile devices that support both 3G (e.g. UMTS [4]) and IEEE 802.11b/g [5] is currently available (e.g. SonyEricsson P990i, NOKIA E70 and HP iPAQ).

In the heterogeneous network, the 3G-Cellular network will perform the AAA, like billing and authentication. The radio controller in the Cellular network will dynamically set the range of the 3G-Cellular multicast domain based on available resources; this includes identifying the boundary nodes between the 3G domain and the ad hoc domain.

The existing proposals for multicast routing protocol for ad hoc networks (e.g. [6]-[9]) do not address these control issues. Thus we have proposed an extended multicast protocol [10] that is based on standard ad hoc multicast routing principles. The protocol builds a spanning tree, and when large inefficiencies are discovered, the spanning tree is rebuilt; the cellular radio controller makes this decision. The value of the heterogeneous architecture depends on the Cellular network's ability to utilize the local ad hoc networks in order to reduce the 3G coverage needed for multicast streaming.

Our overall contribution is a framework to increase the availability of multipoint streaming services to wireless users; the contribution includes a detailed evaluation of the trade-off between the 3G coverage and the ad hoc spanning tree size. As the 3G coverage is decreased, the levels in the ad hoc distribution tree increases, resulting in more packet loss. The analysis is complemented by a sensitivity analysis of factors that affect the efficiency of the trade-off. Among the factors included are: node mobility, different traffic patterns, and multicast member densities. In addition we also perform a detailed analysis of the ad hoc part of the multicast routing protocol.

In the next section we summarize related work. Section 3 describes the heterogeneous architecture, and section 4 presents the routing scheme. In section 5 we give a simple theoretical analysis to show the expected channel range needed to cover a given number of multicast members. The simulation environment and results are discussed in section 6. Finally, section 7 concludes the paper.

2 RELATED WORK

Over the past few years, several approaches to a combined cellular and multihop network model for unicast traffic have been proposed. Some of them focus on higher total throughput and better QoS, while others attempt to increase network coverage, yet others focus on robustness for communication during relief operations. Multihop route decisions are based on channel quality, node position, available capacity or shortest path. To support the architecture, a few proposals use a single radio interface, while most designs require two different radio interfaces, one for the cellular channel and the other for the multihop wireless path.

Many of the significant heterogeneous architecture proposals are compared and briefly described in [11]. This article also discusses several open research areas for heterogeneous networks, from the physical layer through to the application layer. Other architectures and more recent proposals are presented in [12-20].

All the proposals mentioned above are intended for point-to-point traffic, whereas we have proposed an architecture intended for point-to-multipoint traffic. We believe the capacity improvement for unicast traffic on heterogeneous networks will in most cases be marginal due to high routing overhead. However, for high bandwidth multicast traffic the capacity gain is potentially much higher.

Similar to our work, the recent proposal from Park and Kaseria [21] focuses on multicast traffic in a heterogeneous network. Different from our proposal, they distribute the multicast traffic with unicast ad hoc flows. They concentrate on single multicast receivers with bad signal to noise ratio, while we attempt to further reduce the required cellular resources by reducing the overall range of cellular multicast distribution. Lao and Cui [22] also focus on multicast traffic, however they target the problem of multicast service admittance in the heterogeneous network.

A great many multicast routing protocols for ad hoc networks have been proposed (e.g. [6-9]); all of these are intended for stand-alone ad hoc networks. For our architecture where some central control information is available, we believe the routing protocol should be designed to use some of the valuable central information. Thus we have proposed an extended ad hoc-type protocol that utilizes available 3G-Cellular assistance.

A similar approach is taken in the BroadCast Based ad hoc Routing protocol (BCBR) [23] for unicast traffic; however this is a fully centralized protocol. In comparison, our protocol reduces the signalling overhead by exploiting passive neighbor information available in a multicast tree with high

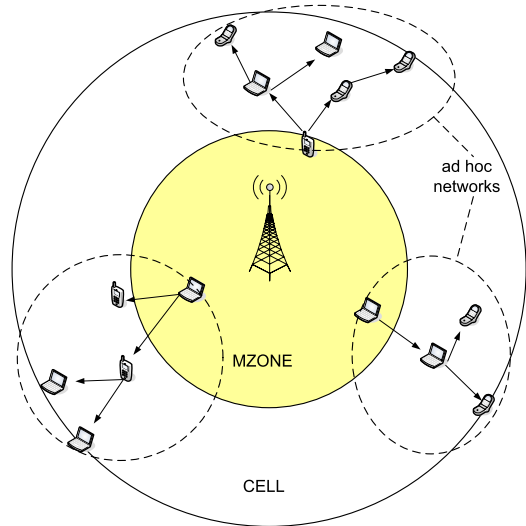


Figure 1: The figure pictures the heterogeneous architecture. MZONE represents the 3G-Cellular multicast domain.

traffic, and uses its ad hoc property to dynamically modify routes based on up-to-date neighbor information.

3 THE HETEROGENEOUS NETWORK ARCHITECTURE

We have proposed an architecture denoted as Cellular Network Assisted by Local Ad Hoc Networks (CeNALAN) [3]. The purpose of the architecture is to increase the availability of high-bandwidth multipoint services to mobile users. The method we use is to reduce the radio resources required in the 3G-Cellular network, by reducing the range of a 3G-broadcast channel, and use local ad hoc networks to forward the data onto users located outside the broadcast range.

In this architecture the 3G network administers Authentication, Authorization and Accounting (AAA) mechanisms, IP address assignments, and multicast group management. An ad hoc multihop network is established on demand by the 3G-Cellular network. Several local ad hoc forwarding networks may coexist and cover adjacent areas. One example of a CeNALAN network scenario is shown in Figure 1. The cellular network limits the range of the cellular multicast channel to a multicast zone (MZONE). All multicast terminals located inside MZONE are potential boundary nodes (multicast gateways MGTWs) between the 3G-Cellular distribution and an ad hoc multihop forwarding network.

Terminals that want to join a multicast service must register with the 3G-Cellular network. The cellular network executes a *Resource validation algorithm* to decide how the multicast data shall be distributed to the terminals. The algorithm returns one of the following choices:

- Unicast channels to each multicast terminal.
- Increase MZONE to accommodate the terminal.
- Connect to an existing ad hoc forwarding network.
- Establish a new ad hoc forwarding network.

- No resources available.

The cellular network continuously monitors the multicast terminals and dynamically changes the data distribution method based on e.g., cellular channel quality, location of terminals, and the amount of available cellular radio resources. Many of these mechanisms are already available in commercial 3G networks, thus for the discussion in this paper we assume that the *Resource validation algorithm* already exists.

4 ROUTING SCHEME

The proposed multicast routing protocol relies on the assumption that terminals within cellular coverage maintain signalling connection to a 3G base station.

Multicast group management is handled by the cellular network. When the base station receives a *join* it runs the *Resource validation algorithm* and informs the terminal how the multicast data will be distributed. *Join*, *leave*, and cellular hand-over situations are automatically handled by the 3G network. When a multicast gateway wishes to leave the multicast session, the base station will either attempt to establish a new ad hoc network to serve the affected multicast terminals, or attempt to have the affected terminals connect to existing forwarding trees in the neighborhood.

We assume the 3G-Cellular network has approximate information about the position of the multicast terminals, and use this information to aid the choice of multicast gateways.

A detailed description of the routing protocol is given in the research report [10]. An outline of the important characteristics is presented below:

Establish a multihop network: A standard query (flooded) - response mechanism is used to establish a local ad hoc forwarding network. When the base station finds that an assisting ad hoc network is needed, potential gateways are instructed to transmit a limited query and wait for response from the multicast terminals. A unique packet identification ensures that the query is transmitted only once on each link (except for queries that represents a better path.) The paths chosen by the unicast response build the multicast tree. The reliable 802.11b/g MAC [5] layer enables the protocol to identify unidirectional links.

The base station is informed whenever a multicast terminal is not able to connect to the multicast tree, or it experiences a very long path to the multicast gateway.

Add members to an existing network: A three-way handshake is used to connect terminals to an existing network. When the base station receives a *join* from a terminal in the vicinity of an existing ad hoc forwarding network, it instructs this terminal to broadcast a limited *connect query*. Terminals that are already connected to the multicast tree, respond to this message. The new member finally validates the best path.

Mobility in the multihop network: All terminals continuously monitor the ad hoc channel for neighbor data traffic. If a multicast terminal detects a parallel multicast flow, it will

join the adjacent branch whenever the new path offers a better route to a multicast gateway. The transferring terminal is attached to the new branch immediately after it has successfully unicast a *validate response* message on the new uplink. The previous uplink node is notified of the change with a *multicast-tree-leave* message. If this message cannot be delivered for some reason, a soft-state mechanism will eventually prune the leaving terminal from the old branch.

Link breaks in the multihop network: A broken link is detected when a terminal has not received data for a defined period of time. The downlink terminal attempts a local repair with a three-way handshake, similar to the handshake used when new members are added to a tree. In this case however, the query message holds the identification of the latest received multicast packet and the number of hops towards the gateway, to avoid routing loops. This message also serves as a notification to downlink nodes that an uplink node is attempting to repair a broken link (i.e. downlink nodes should refrain from doing so for a certain time.)

Refresh of the multihop multicast trees: The routing scheme does not include any periodic refresh of the multicast distribution tree. Maintenance of the routing tree depends on passive acknowledgments, detection of link breaks, and local link repairs. A multicast receiver will also switch to another tree/branch connection if a better path is overheard.

After some time with many local link repairs, the distribution tree will be less optimal and it might be beneficial to refresh the tree structure. A new multicast routing tree is established when the multicast gateways initiates a new query (flooded) - response message sequence. The 3G-Cellular network orders the gateways to refresh the multicast trees for the following reasons:

- The base station wants to add or remove a gateway.
- The base station wants to change the optimization strategy.
- Some terminals have reported “no connection” or a long path to the multicast gateway.

5 REQUIRED CHANNEL RANGE

The power and level of interference associated with a MBMS broadcast channel is given by the maximum distance from the base station to the receivers. We performed a simple calculation, to find the resources required to support a given number of multicast terminals in a cell with the standard 3G-Cellular MBMS [2] architecture. The amount of resources is here represented by the required range of the channel.

To find the channel range, we need to calculate the position of the multicast terminal that is furthest away from the base station. We assume the multicast members are uniformly scattered in the 3G-Cell. The expected maximum value of n independent random values is given by $n/(n+1)$, assuming the value of each $n \in [0,1)$. The area of a circle with radius R is equivalent to the sum of the circumferences for all radii $r \in [0,R]$. Thus we can think of the area of a circle as a long line, and can therefor find the area \bar{A} needed to

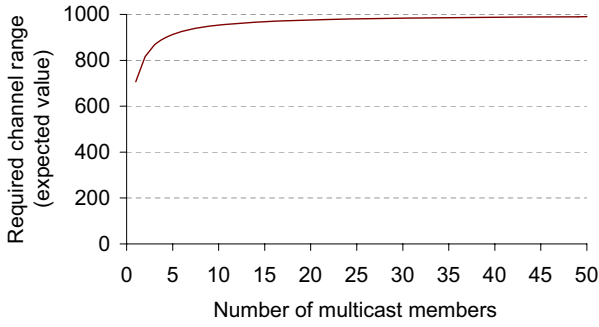


Figure 2: The figure shows the expected channel range needed to cover all multicast members as a function of the number of multicast members.

cover n multicast members by:

$$\bar{A} = \frac{n}{n+1} \times \pi R^2 = \pi \bar{r}_{max}^2$$

where R is the radius of the 3G Cell. The expected value for the channel range needed to cover all multicast terminals is then given by the radius \bar{r}_{max} of the calculated area:

$$\bar{r}_{max} = R \sqrt{\frac{n}{n+1}}$$

\bar{r}_{max} is plotted for $n = [1-50]$ and $R=1000\text{m}$ in Figure 2. As expected, the required channel range increases rapidly with increasing number of multicast members n . As much as 95% (average) of the cell area must be covered to support a small group of 10 multicast members. Thus, practically, a full range 3G MBMS broadcast channel is needed to provide multicast data to most multicast groups. This indicates that a resource saving architecture (e.g., the Heterogeneous Cellular and Ad Hoc Network Architecture) will be useful for most multicast group sizes.

6 SIMULATION SETUP AND RESULTS

6.1 Simulation Objectives

The reason for introducing local ad hoc networks in a cellular network in this context is to preserve the scarce radio resource in the 3G network, and thus increase the availability of resource demanding services. We showed in the previous chapter that the standard 3G-Cellular MBMS architecture must reserve a broadcast channel that cover the whole cell to support most multicast group sizes.

Bearing in mind that the path loss on the radio channel is proportional to somewhere between the 2nd and the 4th power of distance, the reduced MZONE range (broadcast channel range) with the heterogeneous architecture represents the cellular gain. Thus, our main goal is to identify the smallest MZONE where service quality is adequately preserved. To evaluate the heterogeneous network performance, we study the following parameters:

Average throughput: To get an overall opinion of total

throughput in the heterogeneous network, we measure the received data packets in percent of total packets for all receivers (average).

Throughput for different path lengths: An average value can hide large individual differences, thus we look at throughput for different path lengths in the network, to identify the throughput penalty for long paths in our architecture.

Number of nodes for each path length: We study how the different path lengths are distributed on all multicast members in the network, to get an idea of the network topology and throughput fairness.

Packet loss characteristics: For example an MPEG2 video stream can cope well with single packet loss, while long consecutive packet loss can not be treated. Thus it is important to discover the characteristics of the packet loss.

Forwarding load on relays: The operation of the ad hoc networks depend on the willingness of non-members to serve as relays, thus it is important to place as little forwarding load as possible on the relays, and to balance the load fairly.

Active gateways and relays: We register the number of active multicast gateways and relays needed to support the ad hoc connectivity during the simulation, to get a picture of the routing efficiency.

Signalling overhead: Any routing protocol should aim for a minimal signalling overhead; thus we register the average channel bandwidth required for signalling.

6.2 Sensitivity Analysis

To approximate different environments and service types, we have chosen to do a sensitivity analysis based on the following simulation parameters:

Different traffic patterns: We test whether the protocol perform differently for one high-bandwidth flow compared with several lower-bandwidth flows.

Relay mobility: Node mobility will vary in different environments; it is therefore important to verify how relay mobility affect the routing protocol.

Multicast-member density: Service popularity will vary, thus it is interesting to test the routing performance for different multicast member densities.

Routing-buffer size: Mobile devices must be power efficient and are equipped with minimal hardware; thus we study how the size of internal routing buffers and play-out-buffers affect the network performance.

6.3 Simulation Assumptions

The multicast protocol requires all terminals to have a signalling connection to the 3G base station. In our simulations we model this by a common 64Kb/s signalling channel. A 384Kb/s variable-range broadcast channel is used for broadcast of multicast data from the base station to the gateways. We assume the cellular signalling channel and the cellular broadcast channel are reliable and available for the total simulation time.

We add the size of the UDP [24], IP [25] and 802.11b/g

MAC/PHY [5] header to the data and signalling packets to reflect an actual load on the ad hoc network.

All multihop radio networks with a common radio channel have a trade-off between the bandwidth (range) of the channel and the required node density to form a connected network of terminals in a given area. We have chosen to use the lowest 802.11g bandwidth (6Mb/s) for most of our simulations for the following reason: The idea of extending the range of the 3G-Cellular network with an ad hoc structure is valid only for medium to high bandwidth channels, otherwise the 3G network has sufficient capacity. Second, the theoretical maximum throughput for an 802.11g channel is significantly lower than the given value [26]. Third, in an ad hoc network the capacity is typically between 1/4 to 1/7 of the channel capacity [27]. Thus, the most commonly used broadcast bandwidth for 802.11b/g (2Mb/s) will not suffice (in the simulation this assumption is verified).

The 6Mb/s channel type is also fairly robust (require low signal to noise ratio) and thus support an acceptable range. We have chosen to set an outdoor range of 265m with this bandwidth. We use a sensitivity range of approximately 750m, and a 10dB capture limit. The capture limit is only used when a weak packet arrives during reception of a stronger packet, not in the opposite situation when a strong packet arrives during reception of a weak packet, in this case both packets are dropped.

In our network, packets are lost due to three causes: Packets are dropped when the buffer in a relay is full, packets are lost due to interference from parallel transmission on the same 802.11 channel (collision), and packets are dropped when they arrive (out of order) at the multicast member later than the size of the service's play-out buffer. We have not included packet loss due to bit-error-probability from general background-noise. However, due to a long sensitivity range and a minimal caption function, this cause is to some extent compensated for.

We assume the 802.11-based radio transmission, and the 3G channel do not interfere.

6.4 Simulation Method

The routing protocol has been implemented in the J-Sim simulation environment [28]. The simulated network architecture is restricted to one cell with many ad hoc sub-networks. The 802.11-based ad hoc transmission range is modelled as a circuit while the 3G cell is modeled as a square due to internal implementations in J-Sim (see Figure 3). Although the circular cell is the preferred simplistic representation of a wireless cell, any obstacle (e.g. tall houses, hill tops etc.) will result in a coverage that is neither circular nor square. Thus for the conducted simulations that uses the simple free-space propagation model we believe the error introduced with the square representation of the 3G cell, will not be significant.

The free-space propagation model is an optimistic model for signal propagation in a city environment, thus our results might be accordingly optimistic. We have to some extent

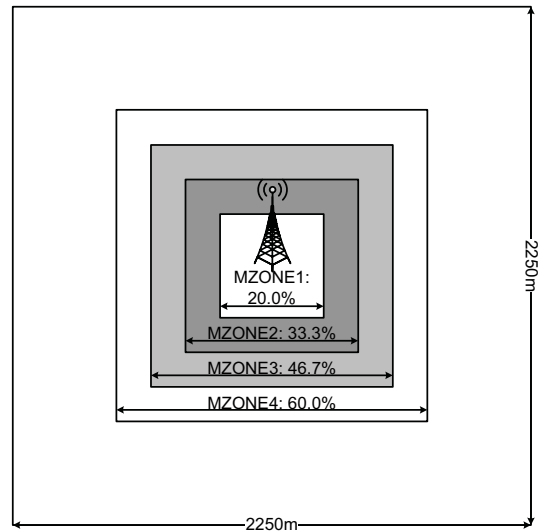


Figure 3: The figure shows the chosen J-Sim implementation of a radio cell and the three 3G multicast zones (MZONE) we use in the simulations.

compensated for this choice by setting the maximum transmission range (receiver sensitivity) to values somewhat worse than what a typical wireless adapter require (e.g. Cisco [29]).

We have chosen to model a fairly large cell (for city deployment) with a conservative terminal density. This is done to incorporate the early stages in service deployment, with limited infrastructure and few terminals that are willing to be relay. The cell size is 2250m x 2250m. (The odd number in the cell size is due to internal representation in J-Sim.) In this area, 300 terminals are uniformly scattered. These terminals are either multicast members or willing to be relays. We assume most multicast members are standing or moving slowly (maximum speed 5m/s). In some simulations the relays have a higher mobility (maximum speed 10m/s).

We used the Random Waypoint mobility model [30]. The reader should be aware that there are several well known problems with this model [31]: The average speed of mobile nodes decays with time, and the distribution of mobile positions tends to be denser towards the middle of the simulation area with time. For our simulation time of 150s these problems will not be significant.

We run most of our simulation scenarios with two traffic patterns. One set of simulations are run with one Constant Bit Rate (CBR) flow of 256Kb/s with packet size of 512 bytes (raw 802.11 bit rate is: 295Kb/s); in this scenario we set the multicast member density to be 1/2. A second set of simulations are run with 2 flows each with a CBR of 128Kb/s with 512 bytes packets (raw data rate: 2*147.5Kb/s). In this case one flow has a multicast member density of 1/2 and the other flow has a member density of 1/3.

For all simulation scenarios 10 simulations were done, and we present the average results here.

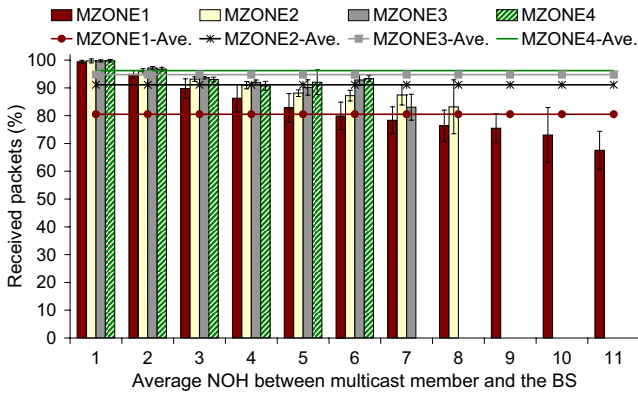


Figure 4: The figure shows the distribution of total received packets (%) as a function of the path length. The horizontal lines shows average received packets (%) for all terminals.

6.5 Simulation Results

The simulation results indicate that the heterogeneous network architecture can successfully support high-bandwidth multicast services whilst cellular radio resources are conserved. As shown in Figure 4, The overall throughput with the 3G multicast zone limited to between 1/3 and 2/3 of the full cell (MZONE2, MZONE3, and MZONE4 see Figure 3), are higher than 90%. For the smallest coverage (MZONE1) the architecture is not able to support an acceptable network throughput. The simulations shown in Figure 4 and the following figures are done for one CBR flow and a maximum node speed of 5m/s.

As expected, throughput decreases for increasing path lengths in the multicast distribution tree. The density of the path lengths is shown in Figure 5. When 3G coverage is reduced, the depth of the ad hoc multicast tree increases. For the smallest coverage (MZONE1) most of the paths consist of 7-9 hops. This is a consequence of the large area that must be covered by the ad hoc component of the heterogeneous network. Furthermore, few multicast gateways are available in MZONE1, resulting in sub-optimal gateway location. For the other scenarios, most nodes are connected with 6 hops or less, thus the majority of terminals receive a high percentage

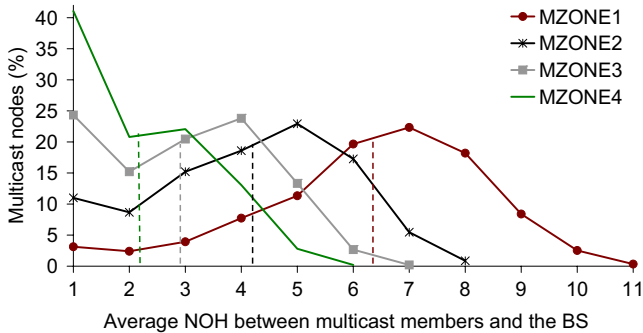


Figure 5: This figure pictures how all multicast members are connected to the base station (path length distribution) for the different MZONE sizes. The vertical lines represents the average path lengths.

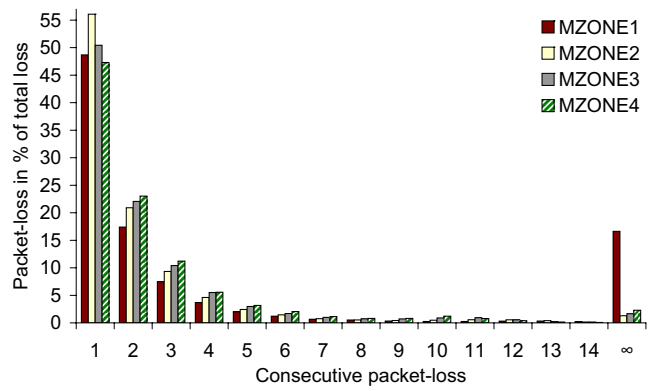


Figure 6: This figure shows how packets are lost for the different MZONE scenarios; single packet-loss or long breaks in the packet flow.

of the data flow.

Long multihop paths achieve a fairly high average throughput, however, the throughput vary considerably from one network topology to another, as represented by the standard deviation given in Figure 4.

Most packets are lost as single packets, as shown in Figure 6. The standard Packet Loss Concealment (PLC) technique, used to mask the effects of lost or discarded voice and video packets (e.g. [32]), is generally effective only for small numbers of consecutive lost packets. For MZONE1 a notable percentage of packets are lost in sequences of 15 packets or more. In this scenario some nodes are not able to connect to the heterogeneous network for part of the simulation time; this is counted as a long consecutive packet loss (thousands of packets).

Overall, the time spent as a multicast relay node is short and evenly distributed. Figure 7 pictures the time non-members must spend as relay for the whole simulation period. The results are shown as percentages of the 150 available non-members in the scenarios. Naturally, more time is spent as relay for small MZONES.

The results are similar for the gateways that must relay multicast traffic from the 3G network and on to the ad hoc networks. Relatively few gateways are used for all scenarios. Figure 8 displays the number of multicast gateways and relays required to form connected networks. Active gateways act as roots in the ad hoc networks. Passive gateways are inside MZONE coverage and receive multicast data from the base station, but do not forward the data on to an ad hoc network. The results are collected from snapshots of the complete simulated network each second, and averaged over the simulation time and over 10 simulations. For the smallest coverage (MZONE1) there is not enough gateways available to form efficient ad hoc networks. As already discussed, this contributes to the deep distribution trees shown in Figure 4.

The signalling overhead for the protocol is also very low. For all cases the relays need less than 1.2 Kb/s bandwidth (average) for signalling, and multicast members consume less than 2.2 Kb/s (average).

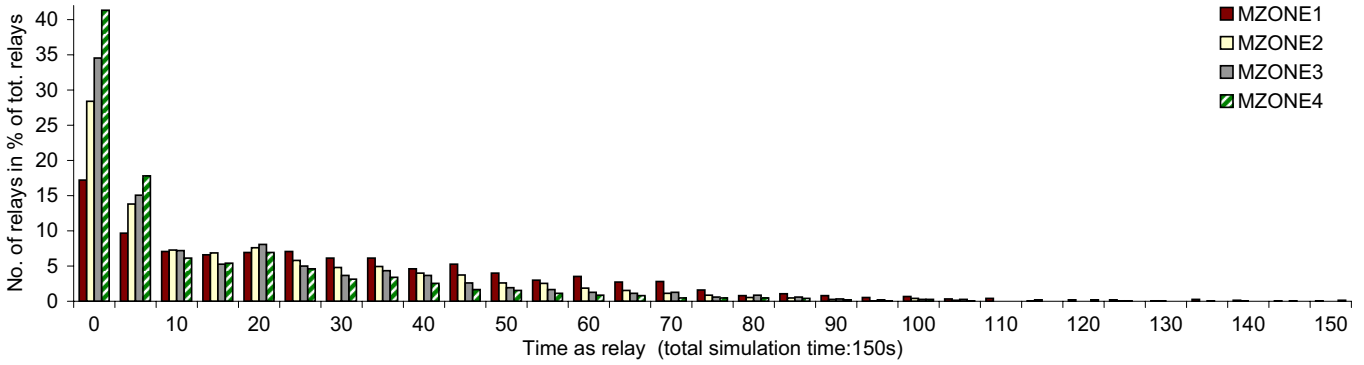


Figure 7: This figure shows the total time each node (not multicast members) has to operate as relay for the multicast service. The 0 bar represents the nodes that don't participate as relays at all, while the other bars, e.g. 10 represents the range <5,10]s.

6.6 Results of the Sensitivity Analysis.

From the results presented so far, we can conclude that a 3G coverage in the range of MZONE2 - MZONE3 is sufficient to provide acceptable quality of a multicast service for the heterogeneous architecture. Next, we analyze how the protocol performance depends on the chosen value for some significant simulation parameters. The sensitivity analysis is done for the effect of two multicast streams, different mobility patterns, different multicast membership densities and varying routing-buffer sizes. The analysis is done only for medium 3G coverage (MZONE2 and MZONE3). A larger number of parallel streams is outside the scope, since the carrying capacity of the 3G cell is limited.

The average throughput and path throughput for each of the two 128 Kb/sec CBR streams is shown Figure 9. One of the streams (Flow2) has a membership density of 1/3, while the corresponding density for the other stream (Flow1) is 1/2. The latter stream has a better delivery rate, since the flow with the lower density has fewer multicast gateways available in the 3G coverage; its ad hoc distribution tree must therefore have a higher portion of long paths. Streaming over two independent multicast-trees result in more parallel transmission, and therefore also more collisions due to hidden nodes on the shared 802.11b/g channel. Flow 1 is less affected by the high collision rate due to a significant redundancy in packet transmission; many nodes receive copies of

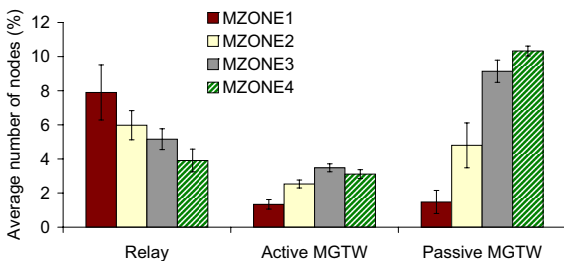


Figure 8: This figure shows the number of relays (average) required to maintain a connected network. We also show the number of (active + passive) potential multicast gateways (MGTWs) positioned inside the MZONE.

the data packet from several uplink sources. This redundancy is highest for a network with many multicast members.

With multiple streams, only the larger coverage (MZONE3) is able to support acceptable service quality to almost all multicast terminals. Thus we have chosen MZONE3 as the most likely trade-off between required cellular resources and the quality of the multicast service. The remaining sensitivity analysis is therefore restricted to this coverage. The scenario with one 256Kb/s CBR flow is used.

Node mobility is a fundamental parameter in mobile networks. We assume multicast members are moving slowly, however non-members might have a higher mobility. The simulation results showed that the average number of received packets is insensitive to the average speed of the relays in the simulation (a 0.5% reduction with a doubling of the speed to maximum 10 m/s). The increased speed of the relays only affected the packet loss for long delivery chains (> 6). This beneficial property can partially be explained by some redundancy in packet transmission (as discussed in the scenario with two flows). Secondly, an individual node is typically used for a short period as a relay, the distribution tree should therefore be less sensitive to the movement pattern of the nodes.

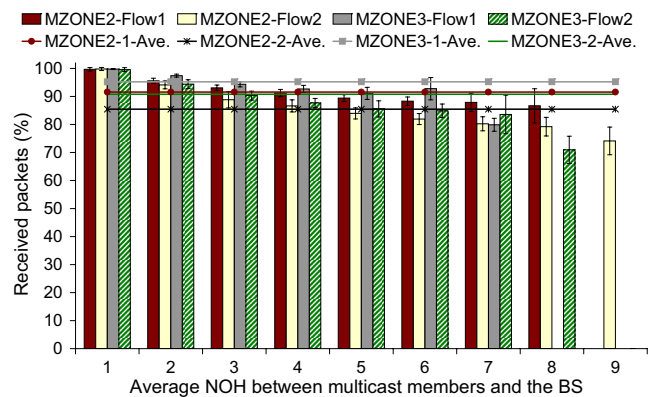


Figure 9: The figure shows the distribution of total received packets (%) as a function of the path length. The horizontal lines shows average received packets (%) for all terminals.

7 CONCLUSION

Four scenarios with different multicast member densities were studied. The chosen densities were: 10%, 25%, 33%, and 50%. The average throughput was similar for all densities (within the range of 2.5%). The detailed simulation results confirmed that a low multicast density reduces the number of available gateways, and thus slightly longer multi-hop paths are needed. On the other hand, less multicast members need to be connected, which reduces the size of the ad hoc networks and the total bandwidth required to forward multicast traffic; thus throughput is high also for long paths. These two effects compensate for each other. The low multicast densities require more non-members to participate as relays, however the load is still fairly distributed.

All simulations presented so far were run with a play-out-buffer size large enough to hold 20s (seconds) of the CBR traffic, and internal routing buffers able to store 4s of the traffic. The variance in packet delay turned out to be small, thus a play-out-buffer size of 1s will suffice. We also ran a set of simulations with internal routing buffer in the relays and multicast members reduced from 4s to 1s. The overall throughput was reduced with 0.1% for the 1s buffer size. All the other collected numbers showed similar insignificant difference for the two buffers sizes. Thus for a CBR traffic-type, the routing buffers can safely be reduce to a size able to store 1s of the multicast data flow. Bursty traffic however, might require somewhat larger buffers.

To verify our assumption of 6 Mb/s as the minimum common basic rate for the ad hoc network, the simulation was rerun for 2 Mb/s wireless rate. As expected, the ad hoc component was severely overloaded. Only the nodes closest to the base station received a reasonable fraction of the multicast packets.

The initial version of the multicast protocol used a basic query-response signalling where a multicast member responds to the first query it receives. Such behavior builds inefficient ad hoc networks with many parallel paths, which gives a high collision rate, and unnecessarily high ad hoc bandwidth consumption.

We modified the protocol with three mechanisms to improve the multicast tree topology:

- A short timer was included to allow the terminals to register the query from different paths, and select the best path among these for the reply.
- The queries were delayed for a short time in non-members, to prioritize multicast members in the multicast trees.
- Active multicast gateways were chosen based on their location.

The optimization improved the ad hoc network topology. The total average throughput increased with approximately 3%. However, the largest improvement was seen in the forwarding load on non-members; the basic routing protocol puts a heavy load on relays compared to the optimized solution.

The current 3G-Cellular networks provide the capacity to support only a handful high-bandwidth users in each cell. Thus it will be difficult to deploy multimedia-, or other high-bandwidth group-services on this architecture. We have proposed a heterogeneous network architecture, consisting of the 3G-Cellular network and assisting local ad hoc networks, to improve the availability of such services.

Detailed simulation results show that the heterogeneous architecture is able to distribute high-bandwidth multipoint services with acceptable quality. We model a challenging scenario of a large 3G cell with a fairly low density of mobile devices. For this case, the heterogeneous architecture allows a reduction of the 3G broadcast zone (MZONE) to approximately 45% of the cell range, while nearly 100% of the cell must be covered for most multicast group sizes with the standard 3G-Cellular MBMS architecture. Bearing in mind that the path loss on the radio channel is proportional to somewhere between the 2nd and the 4th power of distance, there is potential for a large reduction of 3G resource use with this MZONE. It is possible to use a shorter MZONE if a limit is set on the ad hoc path length. For an MZONE of 33.3% of the cell range and a limit of 5 routing hops, 75% of the interested terminals are supported with an acceptable throughput.

The large 3G cell size chosen in this study imply that long ad hoc paths are needed to cover a large portion of the cell; thus we expect to see even better throughputs for less MZONE coverage for smaller cells.

The protocol places a modest and well balanced forwarding load on terminals that are willing to be relays, and require little signalling overhead. We have assumed that nodes are willing to relay in the ad hoc part of the network, but only multicast members are willing to do relaying from the 3G coverage to the ad hoc networks. The validity of this assumption depends on the business model. A more collaborative business model where all users are willing to do both types of relaying would result in a better delivery rate. The design could then also be useful for multicast streaming with fewer members.

It must be noted that 802.11b/g technology used in the ad hoc networks are sensitive to network load, thus services must be advertised to be best effort and not always available. Nevertheless, we feel this architecture will be useful as a step towards the 4th generation of mobile networks.

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