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MULTICAST ROUTING FOR AD HOC NETWORKS WITH A QUALITY OF SERVICE SCHEME FOR SESSION EFFICIENCY

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Abstract - The conceptual shift in expectations of wireless users from voice towards multimedia, from availability towards acceptable quality, and from stand-alone towards group-oriented computing has a big impact on the needs of today's networks in terms of mobility, quality of service (QoS) support, and multicasting. Ad hoc networks can provide users with these features. However, it is necessary to develop QoS multicasting strategies for them. This paper defines the building blocks of an ad hoc QoS multicasting (AQM) protocol, which achieves multicasting efficiency by tracking resource availability in a node's neighbourhood based on previous reservations, and announces the QoS conditions at session initiation. When nodes join a session with certain QoS requirements, this information is used to select the most appropriate routes. AQM is compared to a non-QoS scheme with emphasis on service satisfaction for sessions. By applying QoS restrictions, AQM improves the multicasting session efficiency. The results show that QoS is essential for and applicable to ad hoc networks.

Keywords - Ad hoc networks, quality of service, multicast routing, mobile multimedia, wireless communications.

I. INTRODUCTION

The communication system of the future will probably consist of a fixed network with a wired backbone, an infrastructured mobile network with base stations, and at the peripherals, ad hoc mobile networks, which will be connected to the main internetwork via ad hoc switches [1]. While current systems are primarily designed for one specific type of application such as speech, video or data, the next generation will integrate various functions and applications. Therefore, it is essential that wireless and multimedia be brought together [2].

Ad hoc networks are communication groups formed by wireless mobile hosts without any established infrastructure or centralised control, which are becoming increasingly popular as a result of these developments. In this regard, they have to support multimedia applications. However, it is a significant technical challenge to provide reliable high-speed end-to-end communications in ad hoc networks, due to their dynamic topology, distributed management, and multihop connections [3]. Thus, quality of service (QoS) for multimedia becomes a critical issue, which is closely related to resource allocation. It is important to utilise resources effectively. Multicasting is a promising technique to provide a subset of the network with the service it demands while not jeopardizing the bandwidth requirements of others. The advantage of multicasting is that packets are multiplexed only when it is necessary to reach two or more receivers on disjoint paths. As a result of their broadcasting capability, ad hoc networks are inherently ready for multicasting.

In this paper, the ad hoc QoS multicasting (AQM) protocol is presented to improve multicasting efficiency through QoS management. AQM tracks the availability of QoS within a node's neighbourhood based on previous reservations, and announces it at session initiation. During the join process, this information is updated and used to select routes which can satisfy the QoS requirements of the session. Thus, AQM significantly improves the efficiency of multicast sessions. The rest of this paper is organised as follows. Recent research on ad hoc multicasting is summarised in Chapter II. AQM is introduced in Chapter III. The performance of the proposed system is evaluated in Chapter IV. Concluding remarks and future work are presented in Chapter V.

II. AD HOC MULTICASTING OVERVIEW

There are various multicast routing protocols for ad hoc networks in the literature. None of them addresses the QoS aspect of ad hoc communication, which is becoming increasingly important as the demand for mobile multimedia increases. Some recent proposals are summarised below.

Multicast ad hoc on demand distance vector (MAODV) routing protocol is derived from AODV [4, 5]. The multicast group leader broadcasts a group sequence number periodically to keep the routing information fresh. A node wishing to join a multicast group generates a route request. Replies from the leader or the members are forwarded to the requester, which selects the best of them in terms of highest sequence number and lowest hop count, and sends a multicast activation message to its next hop to enable that route. Nodes wishing to leave a group send a multicast activation message to their next hop with its prune flag set.

The on-demand multicast routing protocol (ODMRP) introduces the concept of a forwarding group [6, 7]. Sources periodically broadcast join query messages to invite new members and refresh existing membership information. When a node decides to join a session, it broadcasts a join reply. When a node on the path to the source receives a join reply, it sets its forwarding group flag. Periodic join requests initiated by the source must be answered by session members with join replies to remain in the group.

Bandwidth-efficient multicast routing (BEMR) finds the nearest forwarding group member for nodes broadcasting join requests [8]. Forwarding nodes receive some of these requests, choose the best hop route and send a reply along the selected path. The requester receives the replies, chooses the best hop alternative and sends a reserve packet along the same path. All nodes on this path become forwarding nodes.

Associativity-based ad hoc multicast (ABAM) builds a source-based multicast tree [9]. Association stability helps the source select routes to members which will probably last longer and need fewer reconfigurations. Valid receivers also reply with routes of highest association stability. Upon receiving the replies, the source builds the multicast tree, and sends a setup message to its receivers. To join a multicast tree, a node broadcasts a request, collects replies from group members, selects the best route, and sends a confirmation. To leave a tree, a notification is propagated upstream along the tree to a branching or receiving node.

Neighbour-supporting multicast protocol (NSMP) utilises node locality to reduce overhead [10]. A mesh is created by a source, which broadcasts a request. In order to maintain the connectivity of the mesh, the source periodically sends local requests, which are only relayed to mesh nodes and their immediate neighbours to limit flooding while keeping the most useful nodes informed. Nodes more than two hops away from the source cannot join the mesh with local requests. They have to flood member requests.

Differential destination multicast (DDM) lets source nodes manage membership and stores the forwarding state encoded in packet headers to achieve stateless multicasting [11, 12]. Join messages are unicast to the source, which tests admission requirements, adds the requester to the list, and acknowledges it. In order to purge stale members, the source sets a poll flag in data packets and forces its active receivers to resend join messages. Forwarding computation is based on destinations encoded in the headers. Each node checks the header for any DDM block or poll flag intended for it.

III. THE AD HOC QoS MULTICASTING PROTOCOL

Bandwidth reservation, bounded loss and delay, and the implementation of QoS classes are important for an efficient ad hoc QoS multicasting strategy. Addressing these issues, the structure of AQM is defined in the following sections. The design details include session initiation and destruction, membership management, and neighbourhood maintenance.

A. Session Initiation and Destruction

A session can be started by any node (MCN_INIT), which broadcasts a session initiation packet (SES_INIT) consisting of the identity number and the application type of the session. A table of active sessions (TBL_SESSION) is maintained at each node to keep the session definition. Using their session tables, nodes forward initiation packets of new sessions. A membership table (TBL_MEMBER) is used to denote the status of the predecessors (MCN_PRED) having informed the node on the existence of a multicast session, and the QoS level of the path from the session initiator up to that node via this predecessor. The initiation packet is forwarded as long as the QoS requirements are met. Before the packet is rebroadcast, each node updates its QoS fields with current conditions experienced by that node. The packet is dropped if QoS requirements cannot be met any more, avoiding flooding the network unnecessarily. If a node receives an initiation packet for a known session which improves the QoS conditions substantially, the tables are updated and the packet is also forwarded. Hop count information in the packets is used to prevent loop formation.

The session is closed by its initiator with a session destruction message (SES_DESTROY). Upon receiving it, all nodes clean their tables, whereas nodes forwarding multicast data also free their resources allocated to that session. A node receiving a session destruction packet forwards it if it has forwarded the corresponding initiation packet or is currently forwarding session data. Thus, receivers of a closed session are forced to leave the session.

B. Membership Management

A node directly joins a session if it is already forwarding data to other nodes in that session. Otherwise, it has to issue a join request. When a node broadcasts a join request packet (JOIN_REQ) containing the session information, upstream neighbours which are aware of the session take the request into consideration. The upstream flow of the request is guaranteed by comparing the hop count information of the packet with the distance to the server of the related session at each intermediate node. The predecessors of the requester propagate the request upstream as long as QoS can be satisfied. The QoS conditions are checked at each node to make sure that the current situation on resource availability allows the acceptance of a new session. Ad hoc networks are highly dynamic, and available resources may change considerably after the arrival of the QoS conditions with the session initiation packet. As explained in the following section, greeting messages are exchanged between neighbours to update nodes on the bandwidth usage in a neighbourhood. However, nodes do not send session status update messages to avoid excessive control traffic. Instead, QoS is announced once by the session initiation packet and is updated only on demand. Intermediate nodes maintain a temporary request table (TBL_REQUEST) to keep track of the requests and replies they have forwarded and prevent false or duplicate packet processing.

A forwarded request eventually reaches some nodes which are already members of that session and can directly send a reply (JOIN_REP). Members of a session are the initiator, the forwarders, and the receivers. Downstream nodes, having initiated or forwarded join requests, thus waiting for replies, aggregate the replies they receive and forward only the reply offering the best QoS conditions towards the requester. The originator of the join request selects the one with the best QoS conditions among possibly several replies it receives. It changes its status from predecessor to receiver (MCN_RCV) and sends a reserve message (JOIN_RES) to the selected node which has forwarded the reply.

Upon receiving the reserve packet, intermediate nodes check whether they are among the intended forwarders on the path from the selected replier towards the requester. If this is the case, they change their status from predecessor to forwarder (MCN_FWD), reserve resources, and update their membership tables to keep a list of successors for that session. Finally they forward the message upstream.

Eventually, the reserve message reaches the originator of the reply, which can be the session initiator with some or without any members, a forwarder with one or more successors, or a receiver. If the replier is the session initiator and this is its first member, it changes its status from initiator to server (MCN_SRV). If it is a receiver, it becomes a forwarder. In both cases, the replier records its successor in its member table and reserves resources to start sending multicast data. If the node is an active server or forwarder, it must have already reserved resources. It only adds the new member to its member table and continues sending the regular multicast data. At the end of each successful request-reply-reserve process, intermediate nodes have enough routing and membership data available to take part in the multicast data forwarding task.

A node needs to inform its forwarder on the multicast graph upon leaving a session. After receiving a quit notification (SES_LEAVE), the forwarding node deletes the leaving member from its member table. If this has been its only successor in that session, the forwarding node checks its own status regarding the session. If the node itself is also a receiver, it updates its status. Otherwise, it frees resources and notifies its forwarder of its own leave.

C. Neighbourhood Maintenance

Each node periodically broadcasts greeting messages (NBR_HELLO), informing its neighbours on its existence and bandwidth usage, which is determined by the QoS classes of the sessions being served or forwarded by that node. Each node keeps the information it receives with these messages in its neighbourhood table (TBL_NEIGHBOUR). This table is used to calculate the total bandwidth currently allocated to multicast sessions in the neighbourhood, which is the sum of all used capacities of the neighbouring nodes for that timeframe. Neighbourhood tables also help nodes with their decisions on packet forwarding. If a node does not receive any greeting messages from a neighbour for a while, it considers that neighbour lost. Lost neighbours are deleted from neighbourhood, session and membership tables.

Due to the broadcasting nature of the wireless medium, the available bandwidth of a node is the residual capacity in its neighbourhood. A node can only use the remaining capacity not used by itself and its immediate neighbours. This approach to residual bandwidth calculation has some flaws since it does not consider bandwidth usage beyond direct neighbours. Thus, it is susceptible to hidden terminal problems and therefore needs further research. Nevertheless, it provides a sufficient method to measure bandwidth availability within a neighbourhood.

IV. PERFORMANCE EVALUATION

Previous research efforts in the literature have essentially been evaluated through the use of several important ratios to give a notion about the internal efficiency of the protocol developed. These are data delivery ratio in terms of data bytes or packets sent, and control overhead in terms of control bytes or packets sent, all measured per data byte or packet delivered [13]. However, the evaluation of QoS performance in ad hoc networks requires additional metrics. The QoS-related multicasting decisions made by AQM prevent the network from being overloaded at the cost of more rejected join requests. Thus, the overload prevention grade and the join acceptance ratio are defined for multicast members to evaluate the node-level success rate of AQM [14]. However, it is also necessary to evaluate the efficiency of AQM in providing multicast sessions with QoS. Therefore, a new and session-level performance metric is required.

Rejection of join requests and excessive bandwidth usage by some nodes during a session also affects other members of that session. Therefore, it is necessary to observe the implications of these events on sessions as well. Thus, the session satisfaction grade $S_{Session}$ is defined as the weighted sum of these two components to evaluate the session-level success ratio of AQM, and formulated as follows:

$$S_{Session} = \gamma\left(1-\frac{l}{m}\right)+(1-\gamma)\left(1-\frac{j}{m}\right) \qquad (1)$$

In (1), l is the number of sessions with at least one overloaded member, j is the number of sessions with at least one rejected join request, and m is the total number of sessions. The first term is the ratio of sessions without any overloaded members, which can be interpreted as a session-level overload prevention factor, whereas the second term reflects the success of AQM with regard to sessions without any rejections. The purpose of γ, which can be varied between 0 and 1, is to adjust the relative weight of one term over the other according to the preferences of the ad hoc network. To explicitly stress the effect of overloaded sessions on AQM, γ is set to 0.99 in the evaluations. Other values are also possible to increase the weight of the sessions with rejected join requests and observe their effect.

Table 1
QoS Classes and Requirements.

QoS Class	Bandwidth Requirement	Delay Tolerance	Application Type
1	128 Kbps	10 ms	High-quality voice
2	256 Kbps	100 ms	CD-quality audio
3	3 Mbps	90 ms	SDTV-quality video
4	4 Mbps	10 ms	Video conference

Table 2
Simulation Parameters.

Parameter Description	Value
Area size	400 m x 400 m
Greeting message interval	10 s
Maximum available bandwidth	10 Mbps
Membership duration	600 s
Node distribution	Uniform
Session duration	1,200 s
Session generation / joining ratio	1 / 9
Simulation duration	8 h
Wireless transmission range	200 m

The simulations are conducted using OPNET Modeler 10.0 Educational Version and Wireless Module [15]. AQM nodes are modelled in three layers with application, session, and network managers. The application manager is responsible for selecting the class of application to run, and making decisions on session initiation/destruction or join/leave. A node can take part at only one application at a time as a server or receiver. However, it can participate in any number of sessions as a forwarder as long as QoS conditions allow. The session manager is responsible for declaring new sessions initiated by its application manager to other nodes, sending requests for sessions its application manager wishes to join, keeping lists of sessions, members and requests of other nodes, processing and forwarding their information messages, and taking part in their join processes when necessary. The network manager is responsible for packet arrival and delivery, and for broadcasting periodic greeting messages and receiving other nodes' greeting messages in order to process them to derive free bandwidth information.

Multiple simulations are run in a multicasting scenario with 4 QoS classes to represent a sample set of applications. Sessions belong to one of these classes defined in Table 1. The simulation parameters are given in Table 2. The usage scenarios consist of open-air occasions such as search and rescue efforts or visits to nature in an area with boundaries, where a wired network infrastructure is not available.

Figure 1 compares the session satisfaction grades of AQM to the non-QoS scheme in networks of class 1 applications. Due to the small amount of bandwidth required by the sessions, there is no significant difference between the results for small networks of up to 30 nodes. As the network size grows, however, QoS support protects more sessions from being overloaded. In a 50 node network, the grades are around 75% for AQM, and 50% for the non-QoS scheme.

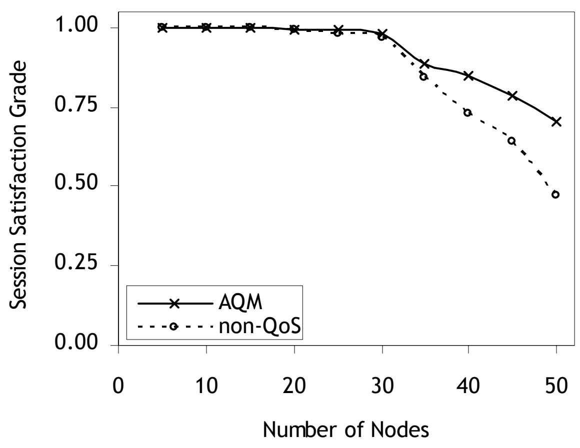

Fig. 1: AQM compared to the non-QoS scheme for class 1.

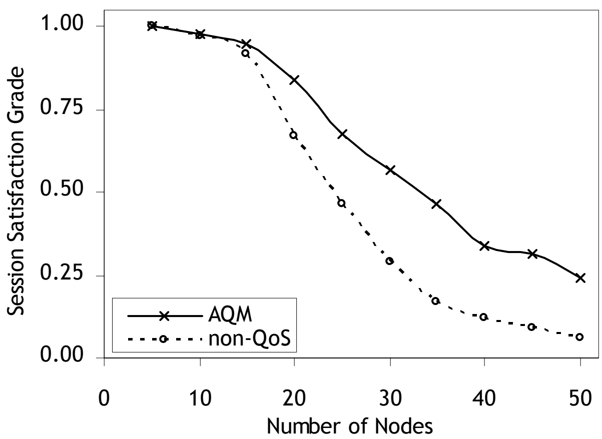

Fig. 2: AQM compared to the non-QoS scheme for class 2.

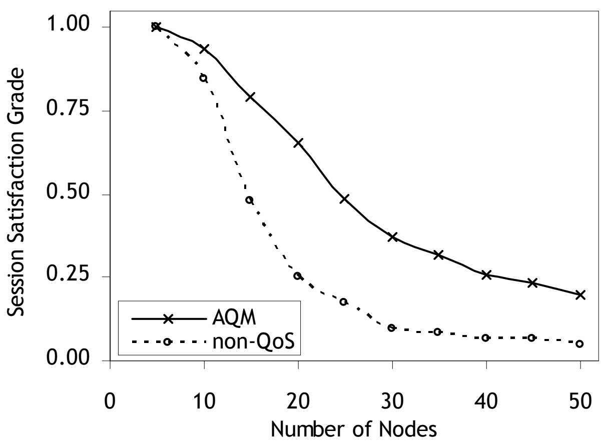

Fig. 3: AQM compared to the non-QoS scheme for class 3.

Figures 2 and 3 compare AQM to the non-QoS scheme for sessions of class 2 and 3, respectively. When QoS support is active, nodes do not make allocations exceeding the maximum bandwidth available in the neighbourhood. However, there are still overloaded sessions since some of their members become overloaded. Although none of these nodes by themselves allocate more bandwidth than available, the hidden terminal problem prevents them from making more accurate reservation decisions. Session satisfaction grades are around 50% in small networks of 25 to 30 nodes. As the network grows beyond 30 nodes, more members become overloaded. As a result of this, session satisfaction degrades and is around 25% for 40 to 50 nodes. When QoS support is deactivated, there are more overloaded sessions. Session satisfaction is around 25% for 30 nodes in class 2 networks. The rates drop drastically below 10% beyond 30 nodes, especially for QoS class 3 with higher bandwidth requirements.

V. CONCLUSION

The changing expectations of wireless users towards high quality, group-oriented, mobile multimedia communication forces today's networks to support ad hoc QoS multicasting. AQM improves multicasting efficiency through resource management on a neighbourhood basis. It has a simple and flat structure, avoiding complicated topologies such as hierarchical or clustered networks. However, it is possible to adapt AQM to a clustered network to scale with the network size. Intra-cluster multicast sessions can be handled by AQM, whereas inter-cluster communication can be managed by a higher-layer, hierarchical version of the same protocol, providing the network with QoS features. It is not a realistic assumption that a mobile network can afford a pure on-demand scheme if it has to support QoS. AQM proposes a hybrid method in terms of multicast routing with table-driven session management and on-demand verification of QoS information upon the initialisation of a join process.

AQM is compared to a non-QoS scheme with regard to session efficiency. By applying QoS restrictions to the ad hoc network, AQM achieves better satisfaction grades and improves the multicasting efficiency for sessions. Without a QoS scheme, users experience difficulties in getting the service they demand as the network population grows and bandwidth requirements increase. AQM proves that QoS is essential for and applicable to ad hoc multimedia networks.

Keeping the QoS data accurate and up-to-date is a major concern for a node in AQM, which involves handling of lost neighbours, on-demand data exchange, and interpretation of changes in a node's QoS status. Another related issue is the hidden terminal problem. To overcome it, an extension to the request-reply-reserve process is necessary, whereby each replying node consults its neighbourhood to see if there are any objections. However, within the scope of this work, efforts have been made to maintain AQM's integrity by addressing these issues in higher-layers.

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