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Reliable Multicast Error Recovery Algorithm in Ad-Hoc Networks

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Abstract: Mobile ad hoc network is an autonomous system of mobile nodes characterized by wireless links. The major challenge in ad hoc networks lies in adapting multicast communication to several environments, where mobility is unlimited and failures are frequent. Reliable multicast delivery requires a multicast message to be received by all mobile nodes in the communication group. The recovery mechanism requires feedback messages from each one of the receivers. In the tree-based recovery protocols, a group of nodes into recovery regions designate a forwarding node per region for retransmitting lost messages. In this study, local error recovery algorithm is applied within these relatively smaller regions, where the repaired packets are retransmitted only to the requested receivers in the local group. These receivers create a sub group from the local group which itself is a subgroup of the global multicast group. By applying local error recovery algorithm, the number of duplicated packets, due to packets retransmission, decreases which lead to improving the system performance. Simulation results demonstrate the scalability of the proposed algorithm in comparison to Source Tree Reliable Multicast (STRM) protocol. The algorithm achieved up to 2.33% improvement on the percentage of duplicated packets in stable mobility speed without incurring any further communication or intense computation overhead.

Keywords: Local error recovery, mobile ad hoc networks, reliable multicast, tree-based protocol

INTRODUCTION

A Mobile Ad hoc Network (MANET) (Sobeih *et al*., 2004; Bettstetter *et al*., 2003) is a wireless communication that allows its nodes to communicate with each other without the existence of an infrastructure. Therefore, nodes can act as routers to route the packets between the source and destination nodes which are outside the transmission range of each other.

In MANET, the nodes are constrained by the battery power and processing capabilities of the mobile devices. In addition, wireless connectivity between nodes are limited by transmission range, signal attenuation, interference and terrain. Nodes in MANET are varying in degrees of mobility (Alsaqour *et al*., 2011a). Nodes switch off or move into or out of the range of other nodes in MANET leads to changing the MANET topology frequently. Thus, MANET is characterized by dynamic topology, high error rates, low bandwidth and intermittent connectivity (Sadok *et al*., 2000; Sobeih *et al*., 2004; Alsaqour *et al*., 2011b; Yang and Wu, 2005).

Multicasting is a kind of information dissemination that transmits data packets to a group of receivers identified by a particular destination address (Tang and Gerla, 2001). Reliable multicast is essential for many applications in MANET to guarantee reliable data delivery to a large number of receivers simultaneously. When group communication is required, reliability is often a critical issue since missed packets cause tremendous negative consequences (Floyd *et al*., 1997).

In MANET, the membership of a host group is dynamic. Thus, the nodes are free to move in and out of the transmission ranges of the other nodes at any time. Also, the location or the number of members in a host group is unrestricted. A node can be a member of multiple groups at any time. Membership is not a precondition to sending packets to a multicast group. Reliable multicasting implies that all nodes in multicast group should get a packet that is transmitted to the group address. In a typical MANET environment, network nodes work in groups to fulfil a certain task.

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Reliable multicast transport protocols needs a recovery mechanism to cope with occasional losses, delay, congestion, errors, duplications and out-of-order delivery of packets. The recovery mechanism requires feedback messages from each of the receiver nodes. This is usually done by either using a positive Acknowledgment (ACK) to notify the source that a packet has been successfully received by the receiver node (s) or a Negative Acknowledgment (NAK) to notify the source when the receivers detect a lost packet. This possibly causes control-message implosion (Thiagaraja *et al*., 2002; Ken *et al*., 2002; Alahdal *et al*., 2008a; Paul *et al*., 1996), when an ACK/NAK is sent directly to source node from every receiver in a large group of receivers (Venkatesh *et al*., 2004), it spends nearly all of its time processing control messages. Also, the nodes that are incident to congested links might repeat NAKs and overload neighboring nodes (Özkasap *et al*., 2006; Alahdal *et al*., 2006; Wu and Stojmenovic, 2004).

The tree-based protocols are well-known protocols to provide high scalability, as well as reliability (Wu and Bonnet, 2004; Alahdal *et al*., 2008a; Ahi *et al*., 2006; Baek and Munene, 2007; Lane *et al*., 2007; Özkasap *et al*., 2006). They construct a logical tree at the transport layer for error recovery. This logical tree comprises three types of nodes: a sender node, repair nodes and receiver nodes. The sender node is the root of the logical multicast tree and controls the overall tree construction. Each repair node maintains in its buffer all the packets it has recently received and performs local error recovery for all its children nodes. As a result, tree-based protocols achieve scalability by distributing the retransmission workload among the repair nodes.

The STRM protocol (Alahdal *et al*., 2008a) provides reliable multicast by constructing a logical tree at the transport layer for error recovery. It allocates Forward Server nodes (FSs), from the sender one hop neighbors, in each local region and makes these FSs responsible for error recovery for all the other receivers in the same region. The selection of the FSs algorithm is presented and discussed in STRM protocol (Alahdal *et al*., 2008a). The FSs send their status to the sender node in the form of ACK packets at periodic intervals. Also, each receiver sends its status to its FS respectively at regular intervals. The FSs use these status messages to perform local retransmissions to the receiver nodes.

In this study, a local error recovery algorithm is proposed and applied over STRM protocol. By applying local error recovery algorithm, the number of duplicated packets; due to packets retransmission decreased and the system performance is improved.

LITERATURE REVIEW

A number of reliable multicast protocols have been proposed for MANETs (Sobeih *et al*., 2004; Tang and Gerla, 2001; Thiagaraja *et al*., 2002; Venkatesh *et al*., 2004; Özkasap *et al*., 2006). These protocols use different approaches to improve packet delivery of multicast routing protocols in MANETs. One approach is NAK suppression (Sobeih *et al*., 2004; Ken *et al*., 2002; Venkatesh *et al*., 2004). In this approach, the receiver is responsible for reliable delivery. Each receiver maintains receiving records and requests repairs via a NAK when errors occur. But the problem of this approach is the long end-to-end delay because the sender must wait for the next multicast packet to determine if the previous one is successfully delivered or not. Therefore, it is applied only when the sender has several packets to be sent. Another way to improve packet delivery is via hierarchical-receiver-oriented approach (Tang and Gerla, 2001; Thiagaraja *et al*., 2002; Wu and Bonnet, 2004; Özkasap *et al*., 2006). A tree for the reliable multicast session is made up of ordinary and special receivers which are called the forwarding regions (Sobeih *et al*., 2004). Commonly used reliable protocols include the Scalable Reliable Multicast (SRM) (Floyd *et al*., 1997) and the Reliable Multicast Transport Protocol (RMTP) (Paul *et al*., 1996). SRM is based on an application level framework; the same concept used in Reliable Multicast Protocol for ad Hoc (ReMHoc) where it is the application's responsibility to guarantee packet sequencing. ReMHoc (Sobeih *et al*., 2004) is a receiver-initiated NAK-based reliable multicast protocol. This protocol uses random timer-based feedback suppression to avoid NAK and retransmission implosion. It has also incorporated a 'heartbeat' timer, which is used to keep peer members updated on multicast packets. The *Repeat* and *Request* timers depend on the numbers of hops between nodes, which is not only in accurate in a mobile scenario but also causes additional overhead and more delays.

Some approaches which provide reliable multicasting in wireless MANETs include Active Reliable Multicast Protocol with Intermediate node Support (ARMPIS) (Wu and Bonnet, 2004) and Reliable On-Demand Multicast Routing Protocol (RODMRP) (Tang and Gerla, 2001). ARMPIS distributes multicast message cache and retransmission tasks among intermediate nodes to provide a scalable and reliable multicasting. On the other hand, RODMRP is an extension to the ODMRP (Lee *et al*., 1999), the protocol designed for multicast and unicast routing. In essence, RODMRP leverages the information propagated by ODMRP to determine which nodes directly downstream from the sender and forwarding nodes. Once this is determined, each outstanding data packet in the transmission window is unicasted to each downstream neighbour in the mesh in a round-robin fashion. This peculiar windowing mechanism has the potential for multicast sessions with long delays, because the entire session can be stalled by intermediate nodes that are overloaded or just slow to respond to its upstream sender.

Another solution for error recovery in mobile ad hoc environments is proposed by Ken *et al*. (2002) and afterward is enhanced by Venkatesh *et al*. (2004). The later makes uses of both source-oriented and local recovery mechanisms. The source-oriented component works the same as the one in the study done by ken *et al*. (2002) The local recovery is the main contribution of Venkatesh *et al*. (2004). Local recovery occurs immediately after the receiver detects a lost packet and this substantially impacts the overall performance of RALM. In particular the scheme works effectively when packet losses are caused by random errors, e.g., mobility and link errors. The missing packets drawback in local recovery happens faster than in source-oriented retransmission, which reduces the burden/congestion at source and alleviates potential feedback implosion problems. However, worst case scenarios exist for ReAct when local recovery frequently fails and source recovery is triggered all the time. When this happens, mostly possible in high mobility, longer delays and low throughput dominate the data delivery, leading to serious network performance degradation.

Stepwise probabilistic algorithm (Ahi *et al*., 2006) is based on epidemic algorithms to provide scalability and reliability. In this algorithm, each node periodically selects *f* random nodes from its partial view and sends them a digest including its recent message history. Digest of a node contains the state information for the last *d* messages the node has received so far and the identifiers of their bufferers. Upon receiving a digest, a node may determine the messages that it lacks and can request them from the bufferers indicated in the digest for retransmission. If a bufferer has crashed or cannot retransmit the message, the request can be forwarded to another bufferer. For determining the bufferers of a data message, the source sends buffering request messages to randomly selected *b* nodes in its partial view. Parameter *b* is the number of bufferers per message. For a data message, if b>1, then its bufferers are determined in parallel. Buffer Fullness (BF) ratio of a node is the ratio of the number of messages that are stored in the node's buffer to its long-term buffer capacity. Steps-to-Live (STL) value attached to a buffering request message indicates the maximum number of times that the request message can be forwarded among nodes. When a node receives a buffering request message for a particular data, it accepts the request with probability (1-BF). Otherwise, it forwards the message to a randomly selected node from its partial view with a probability equal to BF.

MATERIALS AND METHODS

This research was carried out during January 2009 to March 2012 between Faculty of Computer Science and Information Technology, Thamar University, Republic of Yemen and School of Computer Science, Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, Malaysia.

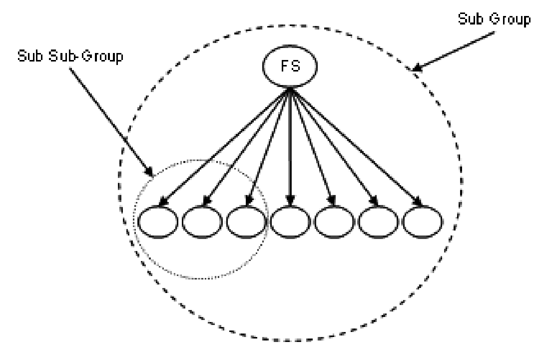

Fig. 1: Example of sub sub-casting tree

The local error recovery algorithm: The STRM protocol (Yang and Wu, 2005) is designed for multicast applications with only one sender using a tree-based hierarchical approach (Paul *et al*., 1996). The key idea behind hierarchical approach is to group receivers into local regions and to use special receivers called FS as representatives of local regions of receiver nodes.

The STRM allocates FS nodes in each local region and makes these FS nodes responsible for error recovery for all the other receivers in the same region. These FS nodes retransmit the lost packets to all group members that belong to its local region. Therefore, this retransmission causes duplication for members which have already received the same packet correctly. In order to avoid duplication for multicast data deliveries, this section proposes two algorithms for local error recovery. In general, the presented algorithms can be applied to tree-based multicast protocols. Furthermore, the dedicated support is provided for protocols which coordinate their group members using local group multicast whose leaders are connected with the sender node.

The Sub Sub-Casting (SSC) algorithm: The SSC algorithm illustrated in Fig. 1; is deployed for lost packet recovery, where the multicast tree is partitioned into local groups. This algorithm is based on the NAK packets received from the local receiver nodes to its FS nodes. In the individual FS node, the FS node acts as the local deliverers which provide a recovery service to the nodes of the local group. In this algorithm, each FS node is required to retransmit lost packets only to the affected receivers which have requested it.

The SSC is an algorithm, where the FS nodes are sent data packets and receive the ACK/NAK packets from its local group nodes. This local group acts as a sub-group of the original multicast group. In this local group, when the number of the affected receiver nodes that requesting for

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Algorithm Sub Sub-Casting (THRESHOLD, P)

Request_i = nodes that request the pkt P
if (Request_i ≥ THRESHOLD) {
  for all Request_i in FS_j; for all 1 ≤ j ≤ N^FS
    if (Request_i Status == 0) {// the pkt in the buffer
      multicast (Request_i(P))}
    endif}
endif}
else {
   for all Request_i in FS_j; for all 1 ≤ j ≤ N^FS
     if (Request_i Status == 0) {
       unicast (Request_i(P))}
     endif}}
```

Fig. 2: The Sub Sub-Casting (SSC) algorithm

a particular packet is greater than a specific threshold, the FS node multicasts the requested lost packet only to the affected receiver nodes which are located in its local group. This allows effected receiver nodes to recover from the same packet loss using only one retransmission from the FS node.

Multicasting the lost packet only to the receivers which request it will reduce the number of the duplicated packets. Thus, reducing the number of packets transmitted through the network and in turn increases the performance of the system. The FS node retransmits the lost packet by multicasting it to only the receivers which have requested it. Subsequently, this requires creating a dynamic (temporary) multicast group by the FS node whose receiver's members are only those which request the lost packet as shown in Fig. 1.

The dynamic and temporary multicast group to be created is a sub-group of the local group which is also a sub-group of the global multicast group. Accordingly, this group is a sub-group of another sub-group which can be denoted as sub sub-casting as shown in Fig. 1.

In order to build the sub sub-casting group, any receiver which detects any lost packet is required to send NAK packet to its FS node. The FS node registers the sequence number of the lost packets and the ID of the receiver node that request the lost packet in the retransmission queue. When the retransmission time comes, the FS node would be able to know which receiver has requested for the lost packet; if the number of the receiver is greater than or equal to the multicast threshold, a temporary multicast group, consisting of the receiver nodes which have requested for the lost packet, is created. In constrast, if the number of the receiver nodes requesting for the packet is smaller than the multicast threshold, the packet is unicast to each requesting receiver, as shown in the SSC algorithm in Fig. 2. The SSC algorithm cannot be implemented in the protocols, which use the NAK based with the NAK suppression because the idea of this algorithm is to reduce the number of receivers sending NAK packets to the sender node. Therefore, the SSC algorithm requires each receiver node

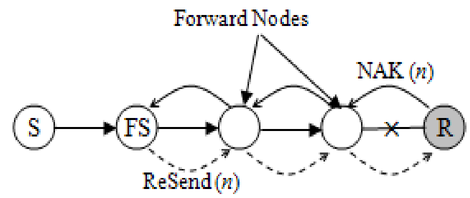

Fig. 3: The request and repair in the SSC algorithm

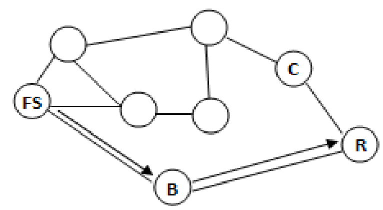

Fig. 4: Specific forward data path

to send a separate NAK packet to the FS nodes so that the FS node will identify all the receiver nodes which need the lost packet.

The next sub-section propose improvements to the SSC algorithm (SSC-I) which improves its performance in wireless local area networks and reliability in MANETs. The improved algorithm, SSC-I, is implemented to provide less delay compared to SSC algorithm.

The improved sub sub-casting algorithm: The SSC algorithm attempts to avoid duplication packets by creating a dynamic (temporary) multicast group by the FS nodes whose receiver's members are only those which requests the lost packet. The FS nodes retransmit the lost packets only to the sub group that new created. This solution is ineffective when the receiving node that requests a retransmission of the lost packet is distant from its FS node. Figure 3 illustrates this case; the forward nodes that located between the FS node and the requested node will receive the retransmitted packet again to forward it to the requested node, *R*.

The ACK packets in the Improved Sub Sub-Casting algorithm (SSC-I) are sent upstream to the FS nodes at regular intervals, but NAK packets are sent in an event-driven manner in order to reduce the end-to-end delay. Packet losses are identified through gaps in the sequence numbers of received packets. In the SSC-I algorithm, the affected node *R* required to send a retransmission request for each of the missing packet to recover from such packet losses. If the affected node *R* does not receive the lost packet before the interval of ACK time, it should generate a retransmission request to its FS node directly. The FS node in turn unicast the lost packet to the requesting receiver *R*.

As shown in Fig. 4, data paths are specific to each FS node. In order to efficiently recover from packet losses,

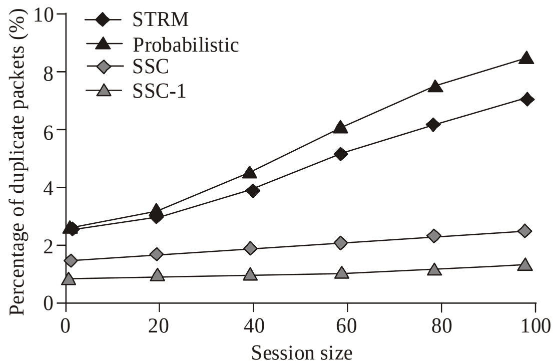

Fig. 5: Percentage of duplicate packets when the session size increases

node *R* should select the retransmission request of the lost packet from the node, which is upstream node on a specific FS's data path. According to Fig. 5, node *R* should request retransmissions of packets sent by the FS node from node *B*. Node *B* in turn forwards the lost packet to node *R* directly.

RESULTS AND DISCUSSION

A network with 100 nodes is considered. These nodes are randomly placed within a 700x700 m area, respectively. The network topology is configured adaptively depending on the node transmission range. Table 1 summarizes the variables used as input for the simulation. These values are taken from the based study of Alahdal *et al*. (2008a). The multicast delivery tree is rooted at the sender and spans over all other receiver nodes. The sender sent window of data packets to the receivers periodically, one window of data packet per 500 ms. The Final results were taken from the average of 10 simulation experiments for the same topology and input variables. We assume that the wireless links are symmetric and the packet transmissions error caused by node movements and wireless link error. The losses on the wireless link error are calculated as the packet error rate of approximately 3-10 at each wireless link. The buffer overflow in the receiver node is generated according to a uniform distribution U [0, 1]. Thus, the packet is considered to be lost if the uniform function returns a value less than 0.1. The packet transmission delay is approximately 10 ms on the link propagation delay, U [20-80] ms for queuing delay and 7 ms on the link connecting transit domains for each hop to the destination node.

Each node moves according to the random waypoint mobility model defined in (Bettstetter *et al*., 2003). Initially, the node stays in one location for a certain period of time (i.e., a pause time). Once this time expires, the node chooses a random destination in the 700x700 m simulation area and a speed that is uniformly distributed between 0 and 25 m/s with a step of 5 m/s. Once having reached the destination, the node pauses again for another pause time. Then it selects another random destination and speed and moves again. We use five different pause times in the simulation: 1, 5, 10, 15 and 20 s. These shorter pause times were used for higher mobility nodes. More details about the simulation model can be found in (Alahdal *et al*., 2008b). The evaluations were performed using a workstation with a Pentium 4-1.8 GHz CPU, 1 GB of RAM and MS Windows XP.

Table 1: Values of the simulation variables

Variables	Values
Number of nodes	100
Area	700x700 m
Transmission range	250 m
Number of receivers	1-80
Mobility model	random waypoint
Speed	0-25 m/s
Pause time	1, 5, 10, 15 and 20 s

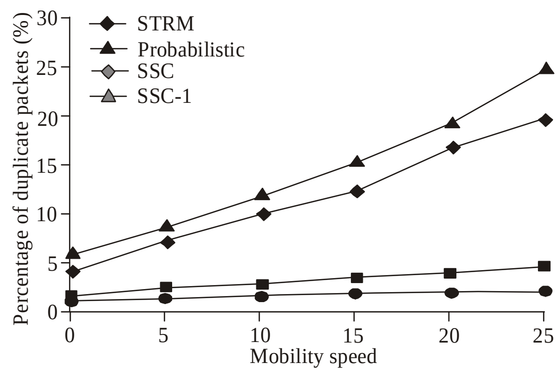

Fig. 6: Percentage of duplicate packets when the mobility speed increases

The experimental results of the local error recovery algorithms are compared with STRM protocol in (Alahdal *et al*., 2008a) and the Stepwise Probabilistic algorithm in (Ahi *et al*., 2006) in terms of duplication data packet metrics. The Stepwise Probabilistic buffering utilizes the selected FS nodes in STRM as long-term buffers and the STL value is set to be 10 hops, gossip interval is 200 msec equal to *Hello_Time* interval. The FIFO policy is implementing here for all algorithms when the node buffer is full.

Figure 5 and 6 shows the effect of the session size and mobility speed on the percentage of duplicate packets. Each member calculates the percentage of the duplicated and the retransmitted packets it has received. The result is averaged over all receivers in the group.

As shown in Fig. 5, SSC and SSC-I the sender node, *id* 0, is chosen to be the message sender. In the experiments, the number of nodes is 100 receiver nodes and the maximum movement speed of the nodes is 5 m/s. The Probabilistic algorithm utilizes the selected FS nodes in STRM as a long-term buffer and gives these nodes higher probability to buffer the data packets for retransmitted requested packets and the other nodes has the same low probability.

In Fig. 6, SSC and SSC-I show less percentage of duplicate packets comparing with STRM and Probabilistic when the session size increases. Also, the less percentage of duplicate packets can be observed for SSC and SSC-I when the mobility speed increase in Fig. 6. Probabilistic show increasing in the percentage of duplicate packets than others in both figures the reason is when the Probabilistic retransmit lost requested packets it multicast it to the entire receiver group this causes duplicate in the receiver which received the same packets in transmission time.

CONCLUSION

This study detailed the proposed SSC and SSC-I algorithms to enhance the local error recovery and decrease the number of duplicated packets in the STRM protocol. These algorithms combine NAKs and ordered ACKs to provide reliability in the multicast receivers. The algorithms enhance the error recovery by eliminating the duplication of retransmission repair packets in the local groups. In these algorithms, the requested packet is multicasted only to the receivers which request it. This causes the number of the duplicated packets, due to the retransmission of the lost packets, is less and this will increase the system performance. In addition, the results also prove that the SSC and SSC-I algorithms are scalable and can be used for a large number of receiving nodes in tree-based protocols, where the increments of the average delay time are smaller.

As a future study, since there is a large overhead in forward server nodes, their buffers should be managed in an efficient manner. We will use ordered ACK scheme to provide an efficient way to discard packets from forward server's buffers. In this scheme, each receiver needs to send a NAK to its FS every time they detect a packet loss. The nodes also will send an ACK packet to their FS. This packet will act as an implicit ACK for the previous packets that are received in the sending period. In addition, we mentioned before that when the number of the effected receiver nodes that requesting for a particular packet is greater than a specific threshold, the FS node multicasts the requested lost packet to only the effected receiver nodes located in its local group. Therefore, The optimal value for the Threshold currently under investigation in sub sub-casting algorithm.

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