A Reliable Secure Multicast Key Distribution Scheme for Mobile Adhoc Networks

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Abstract—Reliable secure multicast communication in mobile adhoc networks is challenging due to its inherent characteristics of infrastructure-less architecture with lack of central authority, high packet loss rates and limited resources such as bandwidth, time and power. Many emerging commercial and military applications require secure multicast communication in adhoc environments. Hence key management is the fundamental challenge in achieving reliable secure communication using multicast key distribution for mobile adhoc networks. Thus in designing a reliable multicast key distribution scheme, reliability and congestion control over throughput are essential components. This paper proposes and evaluates the performance of an enhanced optimized multicast cluster tree algorithm with destination sequenced distance vector routing protocol to provide reliable multicast key distribution. Simulation results in NS2 accurately predict the performance of proposed scheme in terms of key delivery ratio and packet loss rate under varying network conditions. This proposed scheme achieves reliability, while exhibiting low packet loss rate with high key delivery ratio compared with the existing scheme.

Keywords—Key Distribution, Mobile Adhoc Network, Multicast and Reliability.

I. INTRODUCTION

A MANET (MOBILE Adhoc Network) is a collection of autonomous mobile nodes that offers infrastructure-free communication over a shared wireless medium. It is formed spontaneously without any preplanning. Multicasting is a fundamental communication paradigm for group-oriented applications such as secure conferencing, visual broadcasts, military command and control, discussion forums, frequent stock updates, pay per view programs, and advertising.

The combination of an adhoc environment with multicast services introduces new challenges towards the security infrastructure to enable acceptance and wide deployment of multicast communication in mobile adhoc environment. [1, 2, 3].

In order to secure multicast communication, security services such as authentication, data integrity, access control and group confidentiality are required [4]. Among which group confidentiality is the most important service for several applications like military and fire brigades. These security services can be facilitated if group members share a common secret, which in turn makes key management a fundamental challenge in designing secure multicast and reliable group communication systems. The Key management includes creating, distributing and updating the keys then it constitutes a basic block for secure group communication applications [5, 6]. One of the primary objectives of any key management scheme is the secure distribution of keying material.

Most of the security services rely generally on encryption using Traffic Encryption Keys (TEKs) and re-encryption is using Key Encryption Keys (KEKs) [7]. Each member holds a key to encrypt and decrypt the multicast data. When a member joins and leaves a group, the key has to be updated and distributed to all group members in order to meet the above requirements. The process of updating the keys and distributing them to the group members is called rekeying operation [8]. Rekeying is required in secure multicast communication to ensure that a new member cannot decrypt the stored multicast data (before its joining) and prevents a leaving member from eavesdropping future multicast data.

A critical problem with any rekey technique in multicast key distribution is unreliability with high packet loss rates due to frequent node mobility. The rekey process should be done after each membership change, and if the membership changes are frequent, key distribution will require a large number of key exchanges per unit time in order to maintain both forward and backward secrecies. The number of TEK update messages in the case of frequent join and leave operations induces high packet loss rates and reduces key delivery ratio which makes unreliable.

To overcome this problem, several key distribution approaches propose a multicast clustering. [9, 10, 11] Clustering is dividing the group into several sub-groups. An entity called Local controller (LC) manages each subgroup, which is responsible for local key management within the cluster. Thus, after Join or Leave procedures, only members within the concerned cluster are affected by rekeying process, and the local membership dynamism of a cluster does not affect the other clusters of the group.

This paper proposes an enhanced algorithm which combines OMCT (Optimized Multicast Cluster Tree) with DSDV (Destination Sequenced Distance Vector) routing protocol for efficient multicast key distribution in mobile adhoc networks.

Several methods applied in this paper are as follows:

1) DSDV (Destination Sequenced Distance Vector) [12] routing protocol to maintain routing table periodically and event-triggered exchanges the routing table for electing the cluster head and distributing the keys when a node...
joins and leaves. It sends acknowledgement for each transmission in order to reduce the retransmission.

2) MAC 802.11 for providing communication between nodes.
3) Channel bandwidth for minimization of congestion that occurs during transmission.
4) Congestion control mechanism to control flooding message.

The main objective of the paper is design a reliable secure multicast key distribution with proposed enhanced OMCT clustering algorithm with DSDV for mobile adhoc network.

The simulation results in NS2 show that this proposed scheme achieves reliability, while exhibiting low packet loss rate with high key delivery ratio compared with the existing scheme under varying network conditions.

The remainder of this paper is structured as follows. Section II presents the related works about multicast key distribution. Section III describes the proposed enhanced algorithm of OMCT with DSDV for efficient multicast key distribution. Section IV presents the analysis of numerical and simulation results for the proposed scheme. Section V concludes the paper.

II. RELATED WORK

Several Clustering approaches [9, 10 and 11] for securing multicast key distribution in ad hoc networks have been proposed. They are basically classified into two main approaches. They are static clustering and dynamic clustering as shown in Fig. 1.

In Static clustering approach, the multicast group is initially divided into several subgroups. Each subgroup shares a local session key managed by Local Controller (LC). Example: IOLUS [13] and DEP [9] belong to the category.

Dynamic clustering approach aims to solve the “1 affect n” phenomenon. AKMP [10] and SAKM [14] belong to this approach and they are dedicated to wired networks. Enhanced BAAL [10] proposes dynamic clustering scheme for multicast key distribution in adhoc networks.

One approach to distribute group key on multicast environments based on clusters is the Optimized Multicast Cluster Tree (OMCT) [15, 16]. It is a dynamic clustering scheme for multicast key distribution dedicated to operate in ad hoc networks. Its main idea is to elect the LCs of the created clusters.

OMCT needs the geographical location information of all group members in the construction of the key distribution tree, which does not reflect the true connectivity between nodes. Based on the literature reviewed, OMCT is the efficient dynamic clustering approach for secure multicast distribution in mobile adhoc networks. However knowing the true connectivity between the nodes in mobile adhoc networks simplifies the key distribution phenomenon due to the node mobility. Hence the true node connectivity is taken into consideration for the cluster formation.

To overcome the above limitations another method called Optimized Multicast Cluster Tree with Multipoint Relays (OMCT with MPR) [17] is introduced which uses the information of Optimized Link State Routing Protocol (OLSR) to elect the LCs of the created clusters. OMCT with MPRs assumes that routing control messages have been exchanged before the key distribution. It does not acknowledge the transmission and hence results in unreliable key distribution due to high packet loss rate in mobile adhoc networks.

Destination Sequenced Distance Vector (DSDV) [12] is a table driven proactive routing protocol designed for mobile ad hoc networks. This protocol maintains routing table as a permanent storage. Routes are maintained through periodically and event triggered exchanges the routing table as the node join and leave. Route selection is based on optimization of distance vector. It avoids routing loops and each node has a unique sequence number which updates periodically. It is mainly used for intra cluster routing. It allows fast reaction to topology changes. It sends acknowledgement for each transmission in order to reduce the retransmission. Hence it reduces packet loss rate and increases high key delivery ratio in multicast key distribution which is the main issue of mobile adhoc networks. Therefore the existing OMCT algorithm is enhanced by integrating OMCT with DSDV routing protocol. The LCs are elected easily using periodic updates of node join and leave information. The Enhanced OMCT algorithm simulated with network simulator NS-allinone-2.33 and the performance is studied using the metrics namely packet loss rate and key delivery ratio in multicast key distribution.

III. ENHANCED OMCT WITH DSDV

The main idea of Enhanced OMCT is to use DSDV routing protocol to elect the local controllers of the created clusters. The principle of this clustering scheme is to start with the group source Group Controller (GC), to collect its 1-hop neighbors by DSDV, and to elect LCs which are group members have child nodes at the next level. The LC belongs to the unicast path between the source and the child group members.

At this step, the elected LCs covers the group members having 2-hops neighbors of the group source. This scheme iterates until LCs cover all the group members.

The multicast tree is thus constructed using enhanced OMCT with DSDV is shown in Fig. 2.
A. Enhanced OMCT with DSDV Algorithm

The Enhanced OMCT clustering approach is described as follows:

Algorithm 1 Enhanced OMCT_with_DSDV (Cluster head)
//STEP 1
ListLCs = Cluster Head
Listnodes = {1, 2, 3... c} //c is the number of cluster members
//STEP 2
for (i = 1 to List nodes)
doi
if (Listnodes ≠ φ)
if (i multicast group) && (i has group members Childs)
ListLCs = ListLCs ∪ {i};
// Add i to the local controllers list
Listnodes = Listnodes / {group members covered by i};
// Remove members covered by i of the members list
OMCT_with_DSDV (i); // Execute recursively the algorithm applied to i
end if
end if
end for
//STEP 3
if (Listnodes ≠ φ)
for (j = 1 to Listnodesnumber)
Compute the reachability factor of j: number of members in List nodes, in 1-hop from the node
end for
while (List nodes = i)
// Group of child nodes provide reachability factor
ListLCs = Listnodes ∪ {i}; // LC joins the new member lists
ListLCs ≠ Listnodes ∪ {i};
// Remove from the members list
end while
end if

B. Key Distribution Scheme

The proposed scheme is to achieve reliable multicast key distribution for mobile adhoc networks. In this proposed scheme, the source encrypts multicast data with the TEK, and then sends it to all the members of the group following the multicast tree. The TEK distribution is achieved in parallel, according to the following steps.

Initially, the entire group members receive from the source by unicast the session key $KEK_{csg_0}$ (key encryption key of the sub-group 0), encrypted with their respective public keys. New clusters will then be created dynamically.

The local controllers form a multicast group GLC (Group of Local Controllers), and share a key called $KEK_{ccl}$. Each local controller should join this group. The local controllers decrypt this message, extract the TEK, re encrypt it with their respective clusters keys and send it to all their local members. To send the TEK to all the group members, the source encrypts it with $KEK_{csg_0}$ and sends it to all the members of its sub-group as shown in Fig. 3.

In the example shown in Fig. 3, the group source GC 0 collects its 1-hop neighbors by DSDV, and elects node 1 and 7 as L Cs, which are group members and which have child group members as 2, 3, 4, 5, 6 and 8, 9, 10, 11, 12 respectively. According to the step 3 in the algorithm, if a new member 13 joins the group, based on the connectivity information using DSDV, this node is attached to a particular cluster 0. If the created clusters do not cover group members then the node is selected as local controller for the remaining group members. The major advantage of this solution is to minimize the overhead of decryption and re-encryption process for the local controllers. Hence local controller should only to decrypt and re-encrypt the TEK and not all the multicast flow which in turn makes the multicast key distribution as reliable one.

IV. ANALYSIS OF RESULTS

This proposed scheme focuses on the analysis of key distribution scheme. It also evaluates its performance in terms of key delivery ratio and packet loss rate under varying network conditions.

The numeric evaluation of the metrics is as follows.

1) Key Delivery Ratio (KDR): is defined as the number of received keys divided by number of sent keys. This
metrics allows evaluating the reliability of the protocol in term of key transmission from the source to the group members.

\[
KDR = \frac{\text{Number of received keys}}{\text{Number of sent keys}}
\]

2) Packet Loss Rate (PDR): is obtained as subtracting number of packets received at the destination from number of packets sent to destination. This metrics allows in evaluating the reliability of the protocol in term of packet loss rate in key transmission from the source to the group members.

\[
PDR = \frac{\text{No. of packets sent to destination}}{- \text{No. of packets received at the destination}}
\]

This section presents analysis of numerical results which are used to compare the performance of Enhanced OMCT with DSDV and OMCT with MPR in varying density of cluster and network surface. The results are obtained in three different network surfaces as 1000*1000, 1500*1500 and 2000*2000 and also with different density of group members as 7, 13 and 28.

The numeric results of both the parameters are given in Table I.

The proposed Enhanced OMCT is approach is also simulated under Linux Fedora, using the network simulator NS2 version ns-allinone-2.33.

The following are the parameters considered.

- The density of group members within the ad hoc network: group members number (7 - 13 - 28)
- Network surface (1000m*1000m, 1500m*1500m, 2000m *2000m).
- The mobility scenarios are generated by the automatic generator setdest provided by NS2
- The maximal speed of members is defined at 10km/h (2.77m/sec),
- The pause time is 20 seconds
- The simulation duration is 200 seconds.
- Physical/Mac layer: IEEE 802.11.
- Mobility model: random waypoint model [20] with pause time equal to 20 sec and with maximum nodes movement speed equal to 3 m/s.
- Routing protocol: DSDV
- Traffic: only unicast distribution keys traffic exists in the simulation. The source of the group sends the TEK to the LCs, which is forwarded to the local members.

The simulation results are tabulated and shown in Table II.

<table>
<thead>
<tr>
<th>Surface</th>
<th>No. of Nodes</th>
<th>Enhanced OMCT with DSDV</th>
<th>OMCT with MPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000*1000</td>
<td>7</td>
<td>5109 6091 982 90 7</td>
<td>3200 5700 2500 60 40</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>5464 5976 564 96 4</td>
<td>3221 5741 2520 60 40</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>5464 6028 564 96 4</td>
<td>3801 5602 1801 72 28</td>
</tr>
<tr>
<td>1500*1500</td>
<td>7</td>
<td>5305 5787 482 95 5</td>
<td>3245 5805 2560 63 37</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>5389 5951 562 96 4</td>
<td>3751 8002 4251 69 31</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>5650 6055 405 97 3</td>
<td>3915 5731 1816 72 28</td>
</tr>
<tr>
<td>2000*2000</td>
<td>7</td>
<td>5464 6026 562 96 4</td>
<td>3245 5746 2501 63 37</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>5452 6016 561 96 4</td>
<td>3954 4977 1023 70 30</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>5461 6023 562 96 4</td>
<td>3961 5187 1126 72 28</td>
</tr>
</tbody>
</table>
TABLE II
SIMULATION RESULTS

<table>
<thead>
<tr>
<th>Surface</th>
<th>Nodes</th>
<th>Key Delivery Ratio (%)</th>
<th>Packet Loss Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OMCT with DSDV</td>
<td>OMCT with MPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OMCT with DSDV</td>
<td>OMCT with MPR</td>
</tr>
<tr>
<td>1000</td>
<td>7</td>
<td>93</td>
<td>60</td>
</tr>
<tr>
<td>1000</td>
<td>13</td>
<td>96</td>
<td>60</td>
</tr>
<tr>
<td>1500</td>
<td>7</td>
<td>95</td>
<td>63</td>
</tr>
<tr>
<td>1500</td>
<td>13</td>
<td>96</td>
<td>69</td>
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<td>2000</td>
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<td>13</td>
<td>96</td>
<td>70</td>
</tr>
<tr>
<td>2000</td>
<td>28</td>
<td>96</td>
<td>72</td>
</tr>
</tbody>
</table>

From the above two comparison tables, it can be observed that Enhanced OMCT gives better performance and achieves reliability in terms of key delivery ratio and packet loss rate compared to the OMCT with MPR algorithm under varying network conditions.

The simulation results are also shown in Fig. 4a and Fig. 4b.

![Key delivery ratio in multicast key distributions](image)

![Packet loss rate in multicast key distributions](image)

V. CONCLUSION

Reliable Secure multicast communication is a significant requirement in emerging applications in adhoc environments like military or public emergency network applications. Membership dynamism is a major challenge in providing complete security in such networks. Some of the existing algorithms like OMCT address the critical problems using clustering approach. However, the major challenges in mobile adhoc networks include high packet loss rate which is not attempted in OMCT with MPR and hence results in unreliable key distribution. Therefore an attempt is made to improve the reliability by reducing packet loss rate and increasing key delivery ratio using an algorithm called Enhanced OMCT with DSDV. This algorithm uses DSDV routing protocol for electing LCs. The proposed Enhanced OMCT is tested and the entire experiments are conducted in a simulation environment using network simulator NS2. The results are formed to be desirable and the proposed method is reliable and more suitable for secure multicast key distribution dedicated to operate in MANETs.

REFERENCES


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