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Elliptic Curve for Secure Group Key Management in Distributed Network

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ABSTRACT
Group communication emphasis an important security criterion in the design of a distributed network. All the members of the group must agree to a common session key. The management of this session key refers to the group key management which is based on some group key agreement protocol. In this paper we propose a group key management method for secure group communication in a distributed network. Frequent change in group membership, and managing the key distribution for new members are the two main problems to be faced in group communication that too with minimal computation and communication overhead. Our system uses the concept of Elliptic curve Cryptography that provide same level of security as that of other cryptosysytems with reduced key size. This results in less re-keying and re-distribution operations, thus reducing computation and communication overheads respectively.

Keywords: *Computation cost, Communication cost, Distributed network, Elliptic Curve cryptography, Group communication, Key management, MANET, Security.*

I. INTRODUCTION

With the sudden growth in technology and network, group communication has become an increased concern in terms of security. A secure group communication can be defined as a situation where a set of users communicate with each other through messages in such a way that anyone outside the set will be unable to gather any information even if they can obstruct the message. Confidentiality, integrity and authentication are the basic security services provided by any trustworthy group communication system. Group key management lay the basis for these services. So it is very necessary to ensure these services for efficient group communication. Generally group key management protocol are classified into following three schemes:

1) Centralized: A centralized group key server take the responsibility of distributing and updating the group key to all the members in the network. But, a breakdown of key server will affect all the group application system. This is a major limitation of this scheme.
2) Decentralized: The groups are divided into different subgroups and a group key is shared between all group members. Every subgroup share a common subgroup key. Every group have a group key server (GK) which server all members in group and every subgroup have a subgroup key sever (SGK) which serve the subgroup members.
3) Distributed: In the distributed group management protocols, each individual member in the group is responsible for new group key generation and distribution. It is the most complex and difficult protocol. But, it is the best option for networks such as MANET.
4) Here we design an application of elliptic curve cryptography in a distributed network such as MANET. A MANET is a continuously self organizing and self configuring network. It is an application for distributed system with no particular infrastructure and base station. For confidentiality, members of the network exchange group keys for every membership change. This causes high computation overhead in the network. The key goal of this paper is to exchange these keys possibly in a MANET securely and efficiently with reduced computation overhead.

At times, several approaches have been proposed for distributed protocol to reduce the key size of group communication. Most of them were based on different types of Diffie-Hellman key agreement protocol. The main obstacle here is the large key size which will increase the computation overhead in the network.
In this paper, we propose a secure and authenticated group key management method in distributed network such as MANET using elliptic curve cryptography, to reduce the key size, re-keying computation and communication overhead compared to currently existing group key management approaches.

II. RELATED WORKS

Many works have been done in the field of group key management for secure communication. The papers enlisted from [4] to [14] discuss similar and typical approaches carried out in the field using different types of Diffie-Hellman key agreement protocols. The main drawback of these approaches is that, they either take high computation overhead or high communication cost or both.

Diffie-Hellman and Symmetric Algorithm (DHSA) [4] uses hierarchical approach to manage the keys logically. In this protocol, Diffie-Hellman key agreement and symmetric key are combined and assigned to the leaf nodes of the key tree and to intermediate nodes respectively. The drawbacks of this protocol are that key size is very large and modulo operation takes long computational time which makes the computation slow.

Paper describing secure group key agreement protocol using ECC (Elliptic Curve Cryptography) [8] is based on authenticated group key agreement protocol for wireless scenario. The protocol uses the concepts of elliptic curve cryptography to reduce the computation overheads and Asymmetric Encryption Standards(AES) to maintain efficiency. It consists of a set of users and a trustworthy server, where both of them contribute to create the group key. The performance and security analysis shows that the proposed protocol is secure and performs better in terms of computation cost. But as compared to the proposed system, the communication cost will be high due to larger key size, which accounts to the main drawback of this protocol.

Distributed group key agreement uses basically different variations of *n*-party Diffie-Hellman key agreement[9]. The main drawback of this system is that, the members must be synchronized to continuously calculate the parent's key from that of children. If any member is slow in re-keying computation, the packet will be delayed and the process will be postponed or disrupted. Also, there are dependencies among node keys which may break all ancestral keys in case of any compromise in key computation.

Tree based Group Diffie-Hellman (TGDH) [13] approach again emphasis the use of two-party Diffie Hellman key agreement protocol to a group. It also introduces the concept of hierarchical group key management. The members at the leaf node maintains the key tree. Each intermediate node represents the key shared by its child nodes that are computed with single Diffie-Hellman key agreement protocol. The protocol initializes again with every membership change which lead to computational delay due to large cost of modular exponentiation.

III. PROPOSED SYSTEM

Every network is designed in such a way that every time a user join or leave the network, it causes some changes to the members in the network. Here, we consider group of users in the network to make the join and leave of new members and existing members reliable and secure. Since we use ECC for key calculation the system ensure decreased re-keying overhead during member join and leave operation.

The main purpose of ECC here is not the key delivery, but is the calculation of group key for the associated members of the group. Therefore, the main features of ECC that define the system are.

- In the hierarchical structure, leaf keys correspond to the public keys of the ECC key pair and all intermediate node keys are symmetric keys
- A periodically updated list of public key and corresponding parent node binary code on every membership change.
- Equally trusted and responsible group members with same capability

An elliptic curve over finite field with parameters a, b and P where, P is a prime and a point G on the curve whose order is larger than n is used. n is the private key which is a random number between 1 and P-1 and therefore n x G is obtained as the public key, which can be used to share common keys within members of the groups. For example,

m_1 can share a key with m_2 by the common key $n_1 \mathrm{x}\ n_2 \mathrm{x}\ G$

ECC introduces two types of codes in it's key tree, binary code, used for member position discovery and decimal code, used for intermediate node key calculation. Figure 1 illustrates a key tree with 8 members, $\{m_1 \dots \dots m_8\}$, and its corresponding binary code. A list is maintained to find the public key of the member in the network with whom a new incoming user wants to establish a connection. The list consist of the binay codes of intermediate node just above the leaf nodes and their corresponding member's public key. The list is updated whenever there is a membership change and is informed to all the members through multicasting. Usually, the sibling member of affected branch is responsible to send the updated information to other members.

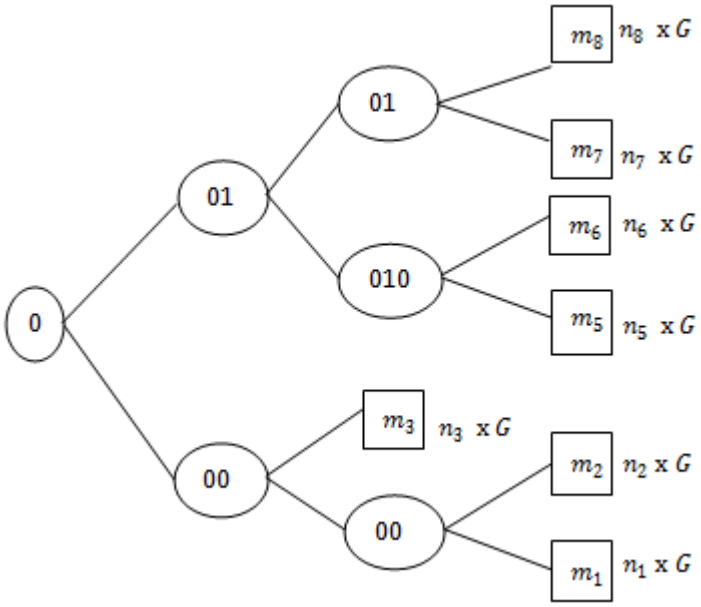


Figure 1 : Key tree for member position discovery

Table I shows the list of binary code and public key of corresponding members. As in the table, the public keys of m_1 is $n_1\ x\ G$ and that of m_2 is $n_2\ x\ G$ and their parent binary code is 000. Since m_3 doesn't have a sibling node, the list just shows the public key of m_3 that is, $n_3\ x\ G$ and the associated parent binary code, 00.

Table I. List of binary code and respective member's public key.

Binary Code of Parent	Child Public Key
000	n_1 x G, n_2 x G
00	n_3 x G
010	n_5x G, n_6x G
011	n_7x G, n_8x G

As mentioned before, other code is decimal which is used for intermediate node key calculation and is assigned to each intermediate node in the key tree. The intermediate node key is calculated by a one way hash function of the bitwise XOR of intermediate node code and the group key. It is defined in the following formula :

$$Key_{intermediate\_node} = f(Key_{group} \oplus Code_{intermediate\_node})$$

And the intermediate node code is calculated by the formula:

$$Code_{child\_node} = (Code_{parent_{node}} \parallel Random\ digit)$$

In the figure 2, the node code management is illustrated with 8 members $\{m_1 \ldots\ldots m_8\}$. For example, if the intermediate node code is *02* and generated random digit is *6*, the code of the child node will be *026*. Therefore, the number of digits in a code represent, the number of nodes in that set of path.

During the join operation, the group key is sent to the new member, which is being encrypted using the shared key by the new member's sibling node. The new members can calculate it by using a one way hash function on the previous key. If f is a hash function and K_G is the previous group key, then new key can be calculate as:

$$K_G^{'} = f(K_G)$$

$$K_{1,4} = f(K_G \oplus 02)\ \ K_{5,8} = f(K_G \oplus 04)$$

$$K_{1,2} = f(K_G \oplus 025)\ \ K_{5,6} = f(K_G \oplus 041)$$

$$K_{3,4} = f(K_G \oplus 028)\ \ K_{7,8} = f(K_G \oplus 046)$$

IV. DETAILED DESIGN

In the detailed design, we explain the join and leave operations of nodes to and from the network using the example figures 1 and 2 for join and 3 for leave operation. Members of the network commonly agree to a large

prime p and the primitive element G for each group. These values are selected during the initial stage of key tree establishment and are known publicly in the group.

During join operation of a new member to a group, he/she sends a hello message to discover the group members. Those members, who receive the signal, look up their corresponding list. The member who does not have a sibling member replies to the new node. But, if all the members have a sibling node, then the node with lowest parent binary ID replies to the node. The member then exchanges the public key generated using Elliptic Curve Cryptography. It is the sole responsibility of the member who replied to the new member to authenticate the incoming new member. Here, we assume the group members are equipped with some authentication methods. In advanced systems, an Elliptic Curve Digital Signature Algorithm can be used for this purpose.

Once the authentication is complete, the public key of new member and his/her corresponding parent binary code is updated in the list and this information is multicast to all other members. Now, the previous members and the new one can calculate the affected intermediate node keys by applying a given one way hash function to bitwise XOR of the intermediate node code and new group key.

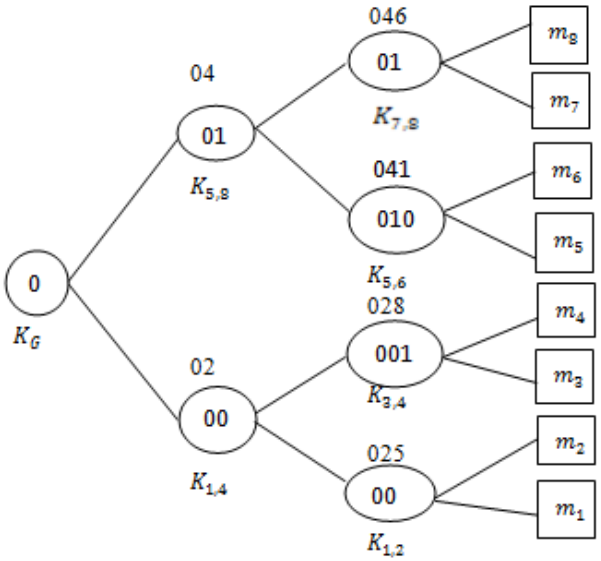


Figure 2: Intermediate node code and respective node key values

4.1. Join Operation

Fig. 1 and 2 explains the procedures taking place while a new member m_4 joins the multicast group of 7 members { $m_1, m_2, m_3, m_5, m_6, m_7, m_8$}

a. m_4 broadcast a hello message to all the members for member discovery.
b. The member who does not have a sibling node replies to the message. In our example, it is m_3.
c. m_3 shares the common key n_3 x n_4 x G with m_4
d. m_3 downgrades it's binary position from 00 to 001 and updates the member discovery table with its new parent binary code and public key of new member (Table II)
e. New intermediate node key is calculated by m_3 for it's new parent using :

$$Code\_K_{3,4} = (02 \parallel 8) = 028$$

f. m_3 then generates new group key as below:

$$K'_G = f(K_G)$$

g. m_3 then sends the new group key and node code to m_4 being encrypted using the common shared key between them.

$$m_3 \xrightarrow{unicast} (K'_G, 028)\, n_3 x\, n_4 x\, G$$

h. All other existing members renew the group key as described in step f.
i. The members in the affected set of path calculate the intermediate node key by applying one way hash function to the bitwise XOR of the intermediate node code and and new group key.

$$m_3, m_4 : K_{3,4} = f(K'_G \oplus 028)$$

$m_1, \ldots\ldots, m_4: K_{1,4} = f(K_G' \oplus 02)$

Table II. Completely updated list after member join operation.

Binary Code of Parent	Child Public Key
000	$n_1 \text{ x } G,\ n_2 \text{ x } G$
00	$n_3 \text{ x } G,\ n_4 \text{x} G$
010	$n_5 \text{x } G,\ n_6 \text{x } G$
011	$n_7 \text{x } G,\ n_8 \text{x } G$

Here just one key is delivered to new member which is an important feature for distributed group communication in wireless network. Since members dynamically join/leave the network in addition to their self mobility, simultaneous join operation may take place here. Therefore, the ECC procedures are designed in such a way that, the overload of join operation is minimized.

4.2. Leave Operation

When a member leaves the group, it's node is deleted from the key tree. The sibling node upgrades it's position to the parent node position. And the sibling node of leaving node is responsible for deleting the public key from the list and updating the information to other members in the group. After every leave operation some intermediate node code and the group key need to be updated.

Figure 3 explains the procedures while a member m_8 leaves the multicast group of 8 members $\{m_1, m_2, m_3, m_4, m_5, m_6, m_7, m_8\}$.

a. m_7 is promoted to it's parent position.

b. m_7 changes the parent binary code and updates the member discovery list by removing the public key of the leaving member from the list. It also informs other members in the group about the new update.

c. Now, the new group key K_G'' is generated by m_7 using symmetric algorithm.

d. m_7 checks the member discovery list and using elliptic curve key agreement, shares a key with one of the members in each sub group and then sends the new group key to the selected members.

$$m_7 \xrightarrow{unicast} m_5: (K_G'')n_5 \text{ x } n_7 \text{ x } G$$

$$m_7 \xrightarrow{unicast} m_5: (K_G'')n_5 \text{ x } n_7 \text{ x } G$$

e. $m_1$and m_5 will now multicast the new group key to all the members in their respective sub group as follows:

$$m_1 \xrightarrow{multicast} m_2, \ldots\ldots, m_4: (K_G'')K_{1,4}$$

$$m_5 \xrightarrow{multicast} m_6: (K_G'')K_{5,6}$$

f. Finally, the mebers in the affected path set computer thrie new intermediate node code as follows:

$$m_5, m_6, m_7: K_{5,7} = f(K_G'' \oplus 04)$$

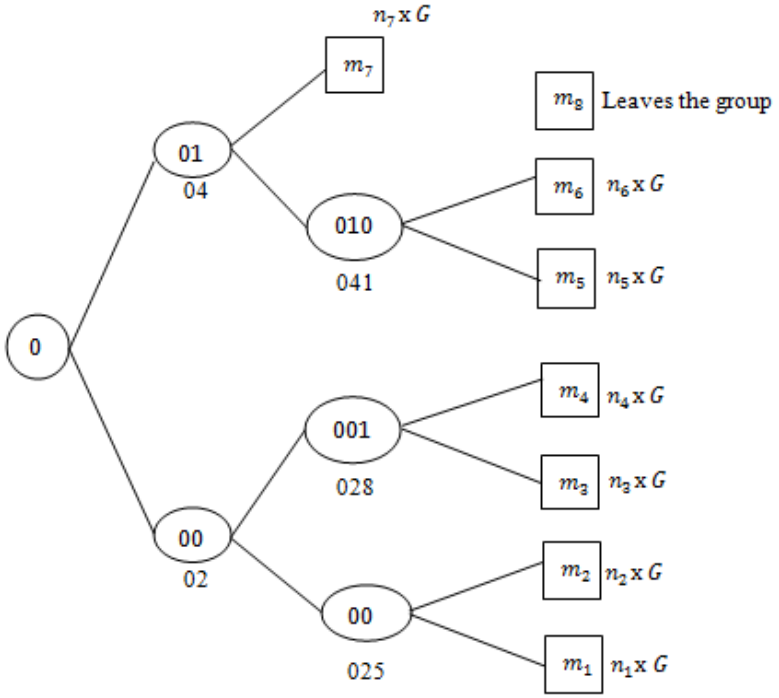


Figure 3 : Leave operation on ECC

Table III represents the updated member discovery list after a member leaves the group. This ensure backward secrecy by deleting the leaving nodes public key from the list.

Table III : Updated list after member leave operation

Binary Code of Parent	Child Public Key
000	$n_1 x G$, $n_2 x G$
00	$n_3 x G$, $n_4 x G$
010	$n_5 x G$, $n_6 x G$
011	$n_7 x G$

V. IMPLEMENTATION AND RESULTS

The proposed concept is implemented for Mobile Ad-Hoc Network using Network Simulator 2(NS2). To provide a realistic mobile environment, Ns2 is configured as follows: The proposed scheme is simulated by taking 50 nodes in a 1670m X 970m topology area. All of the nodes are mobile with no base station or particular infrastructure. In this mobility model, all the nodes moves with a constant speed chosen between a minimum and maximum speed. The system is implemented with Ad-hoc On Demand Multipath Distance Vector routing protocol . Table IV shows the chosen simulation parameters.

Table IV: Simulation Parameters

Parameters	Value
Channel Type	Channel/WirelessChannel
Radio-propagation model	Propagation/TwoRayGround
network interface type	Phy/WirelessPhy
MAC type	Mac/802_11
Interface queue type	CMUPriQueue
Antenna model	Antenna/OmniAntenna
Max packet in interface queue	300
Number of mobile nodes	50
routing protocol	AOMDV
Topology type	Flatgrid
Topology size	1670 x 970
Initial energy in Joules	100

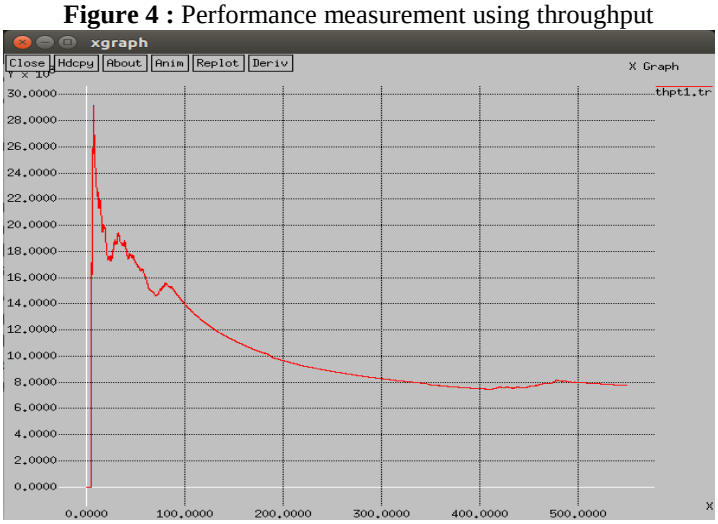
5.1. Simulation and Analysis

In any network there are possible chances of intruders, which may affect the network performance and security. To analyse the performance of implemented network, we considered the following two metrices:

5.1.1. Throughput

Throughput can be defined as the actual rate at which data is transferred from a node to another. It is the ratio of total bytes received by time.

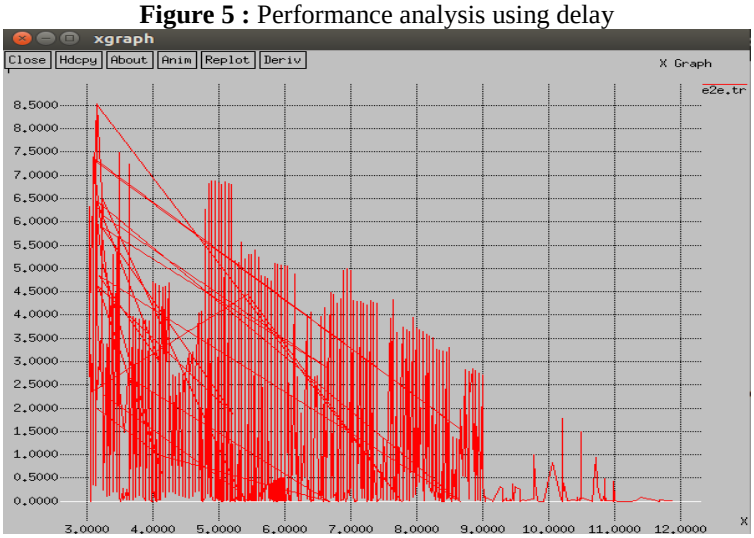
Figure 4 : Performance measurement using throughput



5.1.2. End-to End Delay

End-to-end delay can be defined as the time taken by a packet to reach the appropriate destination from the source. It is the difference between end time and start time.

Figure 5 : Performance analysis using delay



VI. CONCLUSION

In this paper, we have tried to develop a system for a distributed network such as MANET. This protocol is based on logical key hierarchy because in this group members are arranged in hierarchical manner. The protocol uses symmetric cryptosystem for intermediate nodes and asymmetric cryptosystem for leaf nodes. For asymmetric key, Elliptic Curve Cryptography key agreement is introduced. Elliptic Curve Cryptography provides much stronger security with smaller key size.

So we conclude this proposal by highlighting the contributions that, by using elliptic curves in the system, we considerably reduced the key size, thus reducing the re-keying and re-distribution cost which further reduced the computation and communication costs respectively. Analysis of performance improvement is another

contribution that can be drawn from the simulation results by measuring the throughput and end-to-end delay of the network. The network have been simulated with NS2 and while simulating with AOMDV, throughput and end-to-end delay have improved drastically.

The future work of the system can be extended to the concept of providing individual authentication to all the users in the network. Since elliptic curve cryptography is used in the proposed protocol, Elliptic Curve digital Signature algorithm(ECDSA) can be used for this purpose. It can be ensured that, providing such an authentication facility will provide more secure system in the future.

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