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ELLIPTICAL CURVE CRYPTOGRAPHY ALGORITHM FOR SECURE MOBILE ADHOC NETWORK

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ABSTRACT

Reducing network traffic and achieving high security are the most significant task of the Mobile Ad-hoc network (MANET). The beacon-less kNN query processing methods are utilized for reducing traffic and maintaining high accuracy of the query result in MANET. The explosion method and spiral method are adopted in this approach. However, the k-nearest neighbor (kNN) query processing in wired networks and wireless sensor networks cannot be applied in MANET due to the movement of mobile nodes and moderate network security. Hence, to overcome the drawbacks of the kNN query processing technique, this paper proposes the Elliptical Curve Cryptography Algorithm to improve the security in the Mobile Adhoc Network. Clustering approach also provides a mechanism to assign node duty cycles, such that a minimal set of nodes are active to maintain the network connectivity. The proposed approach includes topology discovery, dynamic cluster maintenance and cluster path switching, to enhance the energy efficiency of the network. The data security is monitored and maintained using the Elliptical Curve Cryptography Algorithm. The Quality of Service is enhanced, to improve the network performance. Experimental results show that the proposed algorithm can reduce the delay and achieve high security, when compared with the existing methods.

Key Words—*Elliptical Curve Cryptography Algorithm, Heuristic Algorithm, kNN Query Processing, Mobile Ad-hoc Network, Security and Top-disc Algorithm.*

1. INTRODUCTION

Mobile Ad-hoc Networks (MANET) are self-configuring and self-organizing multi-hop wireless networks with the dynamically changing network structure. In a MANET, the nodes communicate with each other, through the wireless links that either directly or relying on other nodes as routers. Operation of the MANET does not depend on the preexisting infrastructure or base stations. Network nodes in the MANETs can move freely and randomly. In MANETs, it is very important to reduce traffic as much as possible due to limitations of network bandwidth and battery of the mobile nodes. The integrity of the network is damaged, due to the vulnerability of the network to the intruders and attacks. Providing security against the intruder is a challenging task in the MANET.

The query processing technique is usually applied to the smallest datasets. But, when the datasets are large, it is highly impossible for the traditionalquery processing technique to retrieve the required data within the specified time. Thenearest neighbor techniques playa vital role in these situations. The nearest neighbor (NN) technique is very simple, highly efficient and effective, robust to noisy training data, improvedquery time and memory requirements, etc. The disadvantages of the NN technique are computational complexity,memory limitation and high execution cost.The k-nearest neighbor (kNN) lies in the first category in which whole data are classified into training data and sample data point. Distance is evaluated from all training points to sample point and the point with lowest distance is called nearest neighbor. This technique is very easy to implement, but the value of k affects the result in some cases. The NN training data set can be structured using various techniques, to improve over memory limitations of kNN. The kNN query processing methods reduce traffic and maintain high accuracy of the query result in MANET. The main drawbacks of the kNN query processing method are moderate security and low Quality of Service (QoS) parameters. The computational cost of the kNN method is high, for the large datasets. Hence, in order to overcome these drawbacks, this paper proposes an Elliptical Curve Cryptography (ECC)

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Algorithm for securing Mobile Adhoc Network (MANET).

The Elliptic Curve Cryptography (ECC) algorithm is used to provide security to the data that is sent between the nodes. ECC is a public key encryption technique based on the elliptic curve theory, for generating efficient cryptographic keys.In the public key cryptography process, each user or the device participating in the communication has a public key and a private key, such that the set of operations associated with the keys performs the cryptographic operations. The public key is usually distributed to all users involved in the communication, but the private key is known by the particular user. Some public key algorithm requires a set of predefined constants known by the devices involved in the communication. The public key cryptography is considerably slower than the private key cryptography, since there is no shared secret between the communicating parties in the public key cryptographic process. The mathematical operations of the ECC algorithm are defined over the elliptic curve as $y^2= x^3+ ax + b$. Each value of 'a' and 'b' defines a different elliptic curve. All the points (x, y) satisfies the above mentioned equation and a point at the infinity lies on the elliptic curve. The public key is a point lying in the elliptic curve and the private key is a random number. To obtain the public key, the private key is multiplied with the generator point 'G' in the elliptic curve. The generator point and the curve parameters 'a' and 'b', together with few more constants constitute the domain parameter of ECC.

The rest of the paper is organized as follows: Section II describes the conventional kNN Query processing methods. The proposed Elliptical Curve Cryptography (ECC) Algorithm for enhancing the security in the MANET is explained in the Section III. Section IV illustrates the performance evaluation results of the proposed approach and section V describes the conclusion and future work.

2. KNN QUERY PROCESSING METHODS

Y.Komai et al [1] proposed beacon-less kNN query processing methods to maintain high accuracy of the query result and reduce traffic in mobile ad-hoc network (MANET). The query-issuing node forwards a kNN query to the nearest node located proximate to the query point, using geo-routing process. The explosion method and spiral method are adopted in this process. In the explosion method, the nearest node floods the query to the nodes located within the specific circle region, such that each node that received the query replies the information on itself. In the spiral method, forwarding of query from the nearest node to the nodes is done in a spiral manner, such that the node that surely collects the kNN result and transmits the collected result to the query-issuing node. From the experimental results, it is clearly understood that the proposed approach can achieve high accuracy of the query result and reduce traffic in the MANET, when compared with the existing methods. T. P. Nghiem et al [2] proposed a pure mobile peer-to-peer (P2P) query processing scheme that primarily focuses on the exploration and validation algorithm for the kNN queries. The proposed scheme can reduce the energy consumption more than six times, when compared with the centralized and hybrid systems, with the help of data sharing from the peers in a reasonable mean latency of the network processing time with high density of moving objects.

T. Hara and S. Nishio[3] addressed data allocation for efficient query processing in mobile sensor network (MSN). Effective allocation of sensor data on mobile nodes and efficient processing of top-k and k-nearest neighbor (kNN) queries on the allocated data are also shown in the paper. Then, the quantification method of the impacts of mobility on the availability and dissemination of data in the MSNs are also described. Y.Han et al [4] proposed a novel KNN query algorithm based on the grid division routing in the skewness distribution setting, such that itinerary is formed on the basis of connectivity of adjacent grid cells centers. The proposed technique achieves better query accuracy and reduces energy consumption, due to the concurrent execution of query in the subregions. Moreover, the problem of the void region is addressed well, based on the proximity of the neighbor grid cells. Experimental result shows that the proposed technique achieves better performance in terms of data redundancy, query accuracy and energy efficiency.

Increase in the usage of the location-based service leads to many issues of the resource allocation and decision support. Resolving the Group k-Nearest Neighbour (GkNN) queries is a critical issue. T. P. Nghiem et al [5] proposed and evaluated a novel P2P algorithm focusing on Group k-Nearest Neighbour (GkNN) queries, including two different categories such as static

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objects and mobile query objects. The proposed algorithm is evaluated along with the real and artificial datasets. The practical possibility of the P2P approach is clearly demonstrated in the simulation results, for solving GkNN queries for mobile networks. W. Xie et al [6] proposed a novel search boundary estimation method and presented two algorithms to disseminate the message to the robots of interest and aggregate their data. Multiple Auction Aggregation (MAA) algorithm is proposed to achieve best bidding from each robot, based on the auction protocol. Partial Depth First Search (PDFS) algorithm traverses all the robots of interest with a query message to collect data using depth first search. The traditional itinerary-based KNN (IKNN) query processing method is optimized and compared it with the proposed algorithms. The experimental results clearly indicate that the overall performance of the MAA algorithm outweighs the traditional IKNN method. The development of the special in-network processing called as spatial query processing, for Wireless Sensor Network (WSN) is urged by the recent evolution in the sensor node location technology. R. I. Da Silva et al [7] proposed an in-network spatial query processing mechanism that assumes the nodes without any knowledge about their neighbors. The proposed mechanism can process the spatial queries without the need of periodic beacon transmissions to update the neighbor table or synchronization. Hence, the proposed mechanism yields better performance over different types of the duty cycle algorithms.

M. Lalli and V. Palanisamy[8] suggested a completely unique intrusion detection model for MANET, and Conformal Prediction K-Nearest Neighbor (CP-KNN) algorithmic rule for classification of review knowledge to detect anomaly. The non-conformity score worth is utilized to reduce the classification period for multi-level iteration. The robustness and anomaly detection performance of the proposed technique is improved, to avoid the abnormal activity. Y. Xiao et al [9] studied a Path-based Constrained Nearest Neighbor (PCNN) query including additional constraints on the non-spatial attribute values of data objects, during a continuous NN search along a path. An efficient PCNN query method is proposed to transform a continuous nearest neighbor (NN) search into the static NN queries at the discrete intersection nodes. The peer-to-peer sharing is leveraged further to improve the proposed approach. The experiment results demonstrate the effectiveness of the proposed approachs.G. Chatzimilioudis et al [10] studied the problem of efficiently processing a Continuous All k-Nearest Neighbor (CAkNN) query in a cellular or WiFi network. A proximity algorithm is introduced to answer the CAkNN queries in $O(n(k+\lambda))$ time, where ‘n’ denotes the number of users and λ, a network-specific parameter ($\lambda << n$). Proximity performs efficiently in terms of the high mobility and skewed distribution of users. The Proximity is evaluated using the mobility traces from two sources. Thus it is concluded that the proposed approach performs faster than the existing work.

F. Borutta et al [11] addressed the reverse *k* nearest neighbor (R*k*NN) queries in networks and presented an algorithm that solves the monochromatic time-dependent R*k*NN problem efficiently for a specific point in time. This algorithm uses a pruning technique to reduce the necessary network expansion. Finally, the proposed approachs for monochromatic queries are compared to a simple baseline approach by using time-dependent road networks of different sizes, various densities for the points of interests and various values for *k*. The results show that the proposed algorithms are faster than a straightforward alternative.J. Zhu et al [12] proposed a probabilistic threshold group reverse k nearest neighbor query (PT-GRkNN), for obtaining satisfied results for uncertain sensor network data. The proposed technique exploits the geometric filter and probability filter to reduce the search region. The final query results are obtained using the refine phase. From the experimental results, it is clearly evident that the efficiency of the proposed approachis higher than the existing methods.

L. Shou et al [13] introduced a novel cost model to search multi-dimensional data in the mobile P2P environment and proposed a novel mobile P2P search framework called as MIME. In addition, a novel expanding method is utilized to adjust the performance of kNN queries in the MIME. An update algorithm makes the dynamic updates to the overlay, and a cache mechanism reduces the data migration load during the dynamic updates. The proposed techniques are effective, when compared to the conventional system.Y. Komai et al [14] proposed the Filling Area (FA) method for processing a *k*NN query in mobile ad-hoc network (MANET). To achieve a small search area, the data items remain at the nodes located near the locations associated with the items, such that the nodes cache the data items. When a node issues a query, the

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neighboring nodes send back their copies including the query result.C.M. Liu and C.C. Lai[15] proposed a distributed CkNN search algorithm (DCkNN) on the wireless sensor network (WSN) based on the Voronoi diagram. The proposed approach is validated through intensive experiments and its results. But the security of the network is moderate and the Quality of Service (QoS) parameter is low, while adopting the kNN query processing methods. Hence, to overcome these shortcomings, this paper proposes the Elliptical Curve Cryptography algorithm to improve the network security.

3. ELLIPTICAL CURVE CRYPTOGRAPHY ALGORITHM

This paper proposes the Elliptical Curve Cryptography Algorithm to improve the security in the Mobile Adhoc Network. The data security is monitored and maintained using the Elliptical Curve Cryptography. The Quality of Service is enhanced, to improve the network performance. Fig.1 shows the flow diagram of the proposed approach.Elliptic curve cryptography (ECC) is a powerful approach to the public-key cryptography applications, on the basis of the algebraic structure of elliptic curves over finite fields. An elliptic curve over a field F is a nonsingular cubic curve in two variables, f(x,y) =0 with a rational point (which may be a point at infinity). The field F is usually taken to be the complex numbers, reals, rationals, and algebraic extensions of rationals, p-adic numbers, or a finitefield. Elliptic curves groups for cryptography are examined with the underlying fields of F_p.For current cryptographic purposes, an elliptic curve is a plane curve over a finite field consisting of points satisfying the equation,

$$y^2=x^3+ax+b \quad (1)$$

The generation of a public key and private key is an important part of this approach. The sender encrypts the message with the public key of the receiver, and the receiver decrypts the message with the private key.

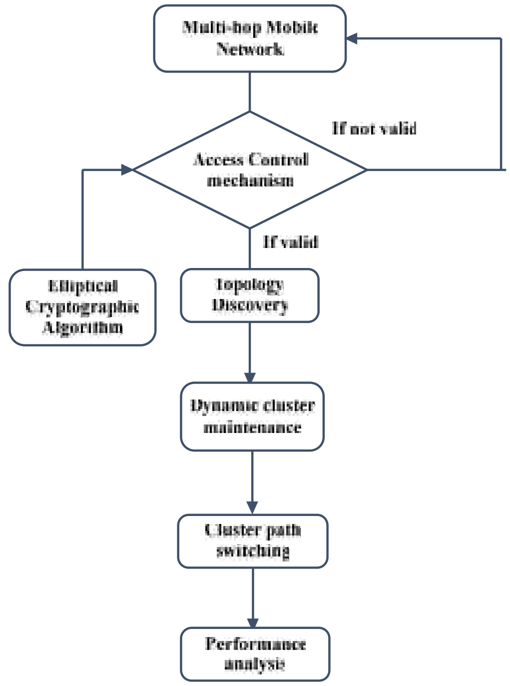

Figure.1 Flow diagram of the proposed approach

A random number k is selected within a range ‘n’. Then, the public key is generated using the equation,

$$QA=k*P \quad (2)$$

Where, QA is the public key, k is the private key and P is a point on the curve.

Signature Generation Algorithm

Step 1. Select a random k from [1, n-1]
Step 2. Compute kP=(x1,y1) and r=x1mod n. if r=0 Goto step 1
Step 3. Compute e =H(m), where H is a hash function, m is the message.
Step 4. Compute s=k-1 (e+dA r) mod n. If s=0 go to step 1. (r, s) is Alice’s signature of message m.

BOB function:
Signature verification

Step 1. Verify that r, s are in the interval [1, n-1]
Step 2. Compute e=H(m), where H is a hash function, m is the message.
Step 3. Compute w=s-1 mod n
Step 4. Compute u1=ew mod n and u2=rw mod n.
Step 5. Compute X=u1P+u2QA=(x1,y1)
Step 6. Compute v=x1 mod n
Step 7. Accept the signature if and only if v=r

Proof:

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If a signature (r,s) on a message m was authentic, then s=k-1(e+dAr) mod n. It can be rewritten as:
k ≡ s-1(e+dAr) ≡ s-1e+s-1rdA≡we+wrdA≡u1+u2dA (mod n)
Thus X=u1P+u2QA = (u1+u2dA)P=kP. So v=r is required.

3.1 Topology Discovery

A new path cost metric is deployed, based on the hop count to the sink node, distance between two neighbor nodes and residual energy of sensor nodes, for enabling path selection and improving the energy efficiency. Topology discovery is used to provide the structure to the network. In general, the random topologies are employed. The location of the sensor is identified by the concurrent values.The topology is constructed based on the Top-Disc algorithm using our own path cost metric. For the Route Discovery process, the request is sent by the source to the destination. The acknowledgement received by the source from the destination is utilized in the topology discovery process.

3.1.1 Top-disc algorithm

In the trivial approaches, all nodes respond back to the topology discovery queries. But, the Top-Disc algorithm differs from the trivial approaches in its response mechanism. Only a subset of nodes is selected to respond back to the topology discovery queries. The combination of the neighborhood lists of the selected subset of nodes forms the approximate topology of the network. The selection of the subset is performed, such that each node in the network is either a part of the subset or a neighbor of a node in the subset. Thus the subset is a dominating set for the network and should have a minimum cardinality for optimal consumption of the resources.

3.1.2 The coloring algorithm

A coloring algorithm that finds an approximate solution to the above problem in a distributed manner is described. Three colors are used to select the responding set. The nodes that receive a topology discovery request packet and remain alive to respond are considered as discovered nodes.

- White: Yet undiscovered node or node that has not received any topology discovery packet.
- Black: Cluster head node that replies to the topology discovery request along with its neighborhood set.
- Gray: Node that is covered by atleast one black node, i.e. it is the neighbor of a black node.

The node that broadcasts the topology discovery request is colored with black color. All the white nodes become gray nodes, when a packet is received from a black node.

3.1.3 Top-disc response mechanism

The first phase of the algorithm sets up the node colors. The initiating node becomes the root of the black node where the parent black nodes are located atmost two hops away. Each node has the following information at the end of this period:

- A gray node knows its neighboring black node.
- Each node knows its parent black node, which is the last black node from which the topology discovery is forwarded to reach it.
- Each black node knows the default node to which it should forward the packets to reach the parent black node. This node is essentially the node from which it received the topology discovery request.
- All nodes have their neighborhood information.

When a node becomes black, it sets a timer to reply to the topology discovery request. Each black node waits for this time period during which it receivesresponses from its childblack nodes.Thedistinguished nodes form clusters including nodes in their neighborhood. These clusters are arranged in a tree structure called TreC, rooted at the monitoring node. The TreC represents a logical organization of the nodes and provides a framework for managing sensor networks. Using only local information between adjacent clusters, information flows from nodes in one cluster to nodes in a cluster at a different level in the TreC. The clustering technique is adopted for grouping the network nodes into a number of overlapping clusters. Clustering enables a hierarchical routing in which the paths are recorded between the clusters instead of between the nodes. Cluster head (CH) election is performed for selecting a node within the cluster as a leader node. The information including a list of nodes in the cluster and path to every node, related to the cluster is maintained in the cluster head. In the clustering procedure, a representative of each subdomain is elected as a cluster head(CH)and a node serving as intermediate for inter-cluster communication is called as a gateway. The remaining members are called ordinary nodes. The boundaries of the cluster are defined by the transmission area of its CH. The clustering alsoprovides a mechanism to assign node duty cycles, such that a minimal set of nodes are active to maintainthe network connectivity.

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The cluster heads incur only minimal extra overhead of setting up the structure and maintaining local information about its neighborhood.

Heuristic Algorithm based on Revised Push forward Insertion

Input: Topology graph T, source node set S_N, deadline set D_L, remaining time of packets $T_{rem}$and sink node s
Output: A set of routes $S_R$with the minimum cost
Step1: Set candidate list C=0 and S_R=0
Step2: Calculate the minimum path cost of all source nodes $s_n \in S$ to the sink s using the Dijkstra's algorithm
Step3: Put all nodes in the source set $S_N$into the candidate list C
Step4: Find the node N_{new}having a maximum path cost to the sink from C and assign the global variable G_m=N_{new}
Step5: **while** $C \neq 0$ **do**
Step6: Remove the node N_{new} from C
Step7: Assign the remaining time of packet T_{rem} generated by the node based on the packet type
Step8: **for all** node $s_n \in C$ **do**
Step9: Compute the incremental delay
Step10: Compute the insertion cost as
$$INSCOST(N_{new}, s_n) + INSCOST(s_n, s)$$
Step11: If the insertion cost is the lowest, and the total delay $D_{total} \leq D_L$ pick $s_n$as N_{new}
Step 12: **for all** remaining time **do**
Step 13:**end for**
Step 14: **end for**
Step 15: **if** No candidate $N_{new}$is found **then**
Step 15: Put the currently found route into S_R
Step 17: Start a new route construction procedure
Step 18: Clear
Step 19: **end if**
Step 20: **end while**
Step 21: Return $S_R$as the output

The Centralized Heuristic Algorithm

Input: The list of routes L from RPFI
Output: A list of optimized routes O_R
1: Initialize Tabu move list L_M=0 and candidate list L_C={L}
2: **while** Total number of steps is less than T: **do**
3: Perform γ-interchange LSD based intensification on each route in L_C
4: **if** A better route is found: **then**
5: Record the partial solution into L
6: **else**
7: Perform γ-interchange LSD based diversification on each route in L_C
8: **end if**
9: **end while**
10: Output the best solution found so far in R

The proposed approach utilizes the stateless clusters in which all normal sensors in the cluster retain only the previous hop and corresponding sink. Hence, the cluster maintenance is simplified considerably. At the end of the Top-Disc topology discovery process, the network is divided into 'n' clusters, such that each cluster is represented by one node called as the cluster head. The cluster head can reach all the sensor nodes in the cluster directly, since they are all located within its communication range. The network tolerance and network monitoring are increased by using this concept. The cluster path switching mechanism is adopted, when the energy level of the sensors in the original main path has dropped below a certain level. This enables uniform distribution of energy consumption among the sensor nodes, to increase the energy efficiency of the network.

4.PERFORMANCE EVALUATION RESULTS

This section describes about the comparison of the performance of the proposed Elliptical Curve Cryptography (ECC) Algorithm and existing kNN query processing technique. The performance evaluation of the proposed ECC algorithm is performed based on the performance metrics such as bandwidth, delay and delivery ratio.The results are plotted using the X-graph, and visual interpretation of the network is shown in the Network Animator (NAM) window.

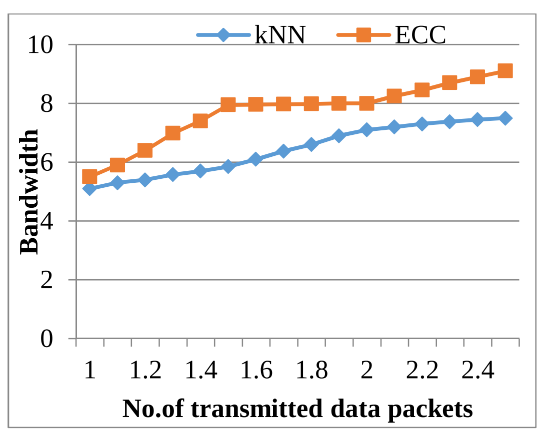

Figure 2 : No.of transmitted data packets vs Bandwidth

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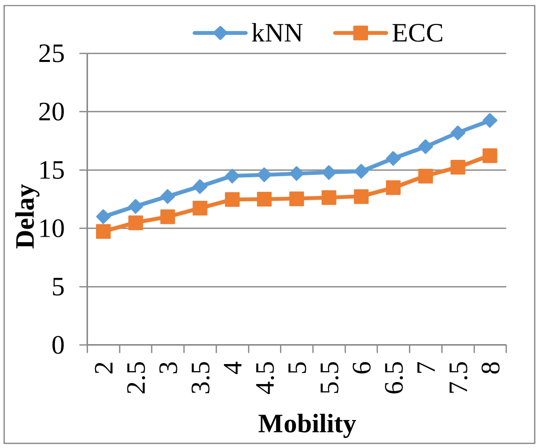
Fig.2 shows the graph illustrating the relationship between the number of data packets transmitted in the network and bandwidth of the proposed approach and existing kNN method. The bandwidth achieved by the proposed approach is 9.100 Mpbs and existing method is 7.500 Mpbs. This implies that the proposed approach achieves improved bandwidth, in comparison with the existing method.



Fiure.3: Mobility vs delay

Fig.3 shows the graph depicting the relationship between the mobility and delay of the proposed approach and existing method. The delay produced by the existing method is 19.500s and the delay produced by the proposed approach is 16.100s. This denotes that the proposed approach achieves lower delay than the existing method.

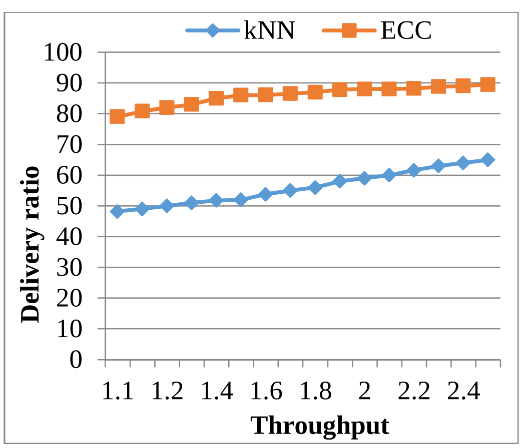


Figure.4: Throughput vs delivery ratio

Fig.4 shows the graph describing the throughput Fig.4 shows the graph describing the throughput and delivery ratio of the network, for the proposed approach and existing method. The delivery ratio of the proposed approach is 89.5 and the delivery ratio of the existing method is 65.3. When compared with the existing method, the proposed approach performs well in terms of the delivery ratio. Hence, it is clearly understood that the proposed approach is efficient in terms of the bandwidth, delay and delivery ratio, when compared with the existing method.

5. CONCLUSION AND FUTURE WORK

This paper proposes the Elliptical Curve Cryptography Algorithm to improve the security in the Mobile Adhoc Network (MANET). The encryption and decryption process is performed by the Elliptical method. The segmented Secret Key method is adopted for robust authentication in the network. The data security is monitored and maintained using the Elliptical Curve Cryptography. The proposed approach includes topology discovery, dynamic cluster maintenance and cluster path switching, to enhance the energy efficiency of the network.The clustering alsoprovides a mechanism to assign node duty cycles, such that a minimal set of nodes are active to maintainthe network connectivity.Experimental results show that the proposed algorithm can reduce the delay and achieve high security, in comparison with the existing methods. The bandwidth and throughput of the proposed algorithm are higher than the existing techniques. However, the ECC technique is complicated and tricky to implement securely.Energy navigation is also possible in the future work, for reducing the energy consumption. The Quality of Service is enhanced, to improve the network performance. To increase the lifetime of the network,Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol is concentrated.To provide strong security in the network, the modify secrete key creation in the network is also modified.Proceeding the comparative analysis with the general reactive protocols like dynamic source routing(DSR) and Destination Sequenced Distance Vector(DSDV) is proposed in the future work.

REFERENCES

[1] Y. Komai, Y. Sasaki, T. Hara, and S. Nishio, "(K) NN Query Processing Methods in Mobile Ad Hoc Networks," *IEEE Transactions on Mobile Computing*, , vol. 13, 2014, pp. 1090-1103.

[2] T. P. Nghiem, A. B. Waluyo, and D. Taniar, "A pure peer-to-peer approach for kNN query

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

processing in mobile ad hoc networks," *Personal and ubiquitous computing*, vol. 17, 2013, pp. 973-985.

[3] T. Hara and S. Nishio, "Data Allocation Techniques for Mobile Sensor Networks," in *28th International Conference on Advanced Information Networking and Applications Workshops (WAINA), 2014*, 2014, pp. 209-214.

[4] Y. Han, J. Tang, Z. Zhou, M. Xiao, L. Sun, and Q. Wang, "Novel itinerary-based KNN query algorithm leveraging grid division routing in wireless sensor networks of skewness distribution," *Personal and Ubiquitous Computing*, vol. 18, 2014, pp. 1989-2001.

[5] T. P. Nghiem, D. Green, and D. Taniar, "Peer-to-Peer Group k-Nearest Neighbours in Mobile Ad-Hoc Networks," in *International Conference on Parallel and Distributed Systems (ICPADS), 2013*, 2013, pp. 166-173.

[6] W. Xie, X. Li, V. Narasimhan, and A. Nayak, "K Nearest Neighbour Query Processing in Wireless Sensor and Robot Networks," in *Ad-hoc, Mobile, and Wireless Networks*, ed: Springer, 2014, pp. 251-264.

[7] R. I. Da Silva, D. F. MacEdo, and J. M. S. Nogueira, "Duty cycle aware spatial query processing in wireless sensor networks," *Computer Communications*, vol. 36, 2013, pp. 149-161.

[8] M. Lalli and V. Palanisamy, "ANovel INTRUSION DETECTION MODEL FOR MOBILE AD-HOC NETWORKS USING CP-KNN," *International Journal of Computer Networks & Communications*, vol. 6, 2014.

[9] Y. Xiao, Y. Shen, T. Jiang, and H. Wang, "Path-Based Constrained Nearest Neighbor Search in a Road Network," in *Database and Expert Systems Applications*, 2012, pp. 492-501.

[10] G. Chatzimilioudis, D. Zeinalipour-Yazti, W.-C. Lee, and M. D. Dikaiakos, "Continuous all k-nearest-neighbor querying in smartphone networks," in *IEEE 13th International Conference on Mobile Data Management (MDM), 2012*, 2012, pp. 79-88.

[11] F. Borutta, M. A. Nascimento, J. Niedermayer, and P. Kröger, "Monochromatic RkNN queries in time-dependent road networks," in *Proceedings of the Third ACM SIGSPATIAL International Workshop on Mobile Geographic Information Systems*, 2014, pp. 26-33.

[12] J. Zhu, B. Kan, Y. Liu, T. Wang, L. Pan, and D. Liu, "A Probabilistic Group Reverse k-Nearest-Neighbor Query in Sensor Networks," in *Advanced Technologies in Ad Hoc and Sensor Networks*, ed: Springer, 2014, pp. 121-130.

[13] L. Shou, X. Zhang, P. Wang, G. Chen, and J. Dong, "Supporting multi-dimensional queries in mobile P2P network," *Information Sciences*, vol. 181, 2011, pp. 2841-2857.

[14] Y. Komai, Y. Sasaki, T. Hara, and S. Nishio, "Processing k Nearest Neighbor Queries for Location-Dependent Data in MANETs," in *Database and Expert Systems Applications*, 2013, pp. 213-227.

[15] C.-M. Liu and C.-C. Lai, "Distributed Continuous k Nearest Neighbors Search over Moving Objects on Wireless Sensor Networks," *International Journal of Distributed Sensor Networks*, vol. 2013.