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A Synopsis of Energy Optimized Hybrid Data Aggregation Algorithm for WSN

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Abstract : Wireless sensor networks (WSNs) consist of numerous low-power sensor nodes with limited computing ability and storage capacity. Maximizing energy savings is a crucial research area in WSN. Data aggregation is the most appropriate way to resolve energy issues involves various scheduling algorithms. This paper proposes a combined framework for data aggregation that resolves many data aggregation issues. The hybrid tree construction algorithms proposed in the first part uses binary tree construction method to perform delay efficient data aggregation. The collision problem of the network has been resolved using a hybrid tree based distributed aggregation scheduling in second part. The hybrid cryptography algorithm proposed in third part provides the secure data aggregation. The final part of this proposed model concludes all the algorithms into a single solution in an energy efficient way. The performance analyses of the proposed frameworks are verified through mathematical models and simulation results. The proposed model is designed to support static as well as dynamic network environment in all monitoring applications.

Keywords : Collision avoidance; Data Aggregation; Delay efficiency; Energy efficiency; Security; Wireless sensor networks.

1. INTRODUCTION

Wireless sensor network is a new paradigm of telecommunication networks intended to allow efficient data collection and event control. WSNs are the deployment of tiny sensor nodes over an area to monitor the continuously varying physical phenomena like temperature, pressure, humidity and so on. WSN has a significant role in a variety of appliances and applications. A variety of disciplines use the WSNs for various applications like monitoring of specific features or targets especially in rescue and surveillance applications, medical, engineering and industrial applications and much more. Besides that they can be implemented in areas like underground, underwater or the normal landscape which makes it more reasonable.

Sensor nodes are normally deployed in an ad-hoc manner. They operate in a distributed way and coordinate with each other to fulfil a common task. Sensor nodes have reduced the computation and communication capabilities and are usually non rechargeable. Depending on the application, there are several kinds of reporting methods for WSNs, such as periodical reporting, reporting by request, and event-driven reporting. The advances in wireless sensor networks, while shows potential, have also posed challenges, such as resource limitations, dynamic environment and various application needs. These challenges and tradeoffs also include data aggregation issues like aggregation delay, collision, security, energy and so on. This proposed model analyses all the potential challenges in performing data aggregation in wireless sensor networks and proposes a framework which can deliver the secured data to the sink without delay and collision in an energy efficient manner for real time applications in wireless sensor networks.

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The rest of the paper is organized as follows. The second section of this paper gives the introduction about the data aggregation with problem statement and objective of the proposed model. The proposed hybrid data aggregation algorithm has been discussed in section III. The proposed methodology has been evaluated and the simulation results have been discussed in section IV. Finally section V draws conclusions concerning the study of resolving the data aggregation issues in WSN.

2. DATA AGGREGATION

The sensors normally sense the data from the environment and transmit them to the base station or sink node. The regularity of sending the data and the number of sensors that sends the data are depends on the particular application. Data Aggregation is outlined as the method of aggregating the data from multiple sensors to reduce the redundant transmission, processing the data about the sensed environment and then providing combined information to the base station. Data aggregation algorithm's goal is to gather and aggregate data in an energy efficient way to improve the network lifetime. In WSN there are many routing protocols that minimize the used energy, extending subsequently the lifespan of the WSN. Data aggregation needs a method for combining the sensed data into high quality information. It involves aggregation algorithms that collect the sensed data from multiple sensors and transmit the data to the base station for further processing. The various design issues of the data aggregation algorithm [5] is discussed here.

1. The individual sensor nodes have limited energy and storage capacity, they operate on inaccessible environments and employ a short-range transceiver for communications. These create huge constrains in the design and development of routing protocols [1].
2. Since the WSN nodes are having limited memory capacity, the well known sophisticated table driven aggregation algorithms may not be suitable for WSN environment.
3. The many-to-one data flow of WSN makes the WSN routing different from adhoc routing. Also, the effective energy utilization in communication is the main objective of WSN routing in contrast to the shortest route in adhoc network.
4. Sensor nodes are generally densely deployed to provide redundancy and fault tolerance. This leads to a situation of same event being observed by many nodes simultaneously and transmission overlap taking place.
5. Many WSN applications require high confidentiality and data accuracy on their aggregated data. Due to the limited computational efficiency of sensor nodes, providing security in data aggregation is a difficult task.
6. WSNs are prone to frequent topology changes due to hardware failures, communication failure, attack from the adversaries, battery life and so on. Consequently the data aggregation algorithm has to configure the network with the ability to reconfigure themselves and inherent fault tolerance.
7. Scalability is an important design criterion due to high number of nodes for sensor network applications. Moreover the addressing of nodes needs different mechanism for individual identification.

A. Problem Statement

1. Effective data collection from the sensor nodes using tree based data aggregation [6, 10] is an important research area. design of an effective data aggregation protocol should achieve the main goals such as (*i*) energy efficiency (*ii*) reducing aggregation delay (*iii*) avoiding collisions and (*iv*) security. Even though many existing data aggregation techniques have been proposed to achieve these goals, the combined solution that resolves many data aggregation issues in energy efficient way is not much discussed. The problems with existing solutions for data aggregation issues have been analyzed in terms of aggregation function, aggregation scheduling and routing scheme.

2. Tree based existing data aggregation models (*e.g.* [6] and [10]) are follow an ambiguous tree construction model which are application specific like Periodic reporting, Event driven and so on.
3. Even though cluster based data aggregation models (*e.g.* [7] and [9]) resolve aggregation delay and energy issues, the cluster head selection is more specific for all the existing models. And these cluster head selection algorithms leads to collision problems in dynamic environments.
4. The existing models which are good at resolving security issues in data aggregation (*e.g.* [9]) uses highly complicated algorithms which increases aggregation delay and energy utilization.
5. In some existing models (*e.g.* [1]) the energy related issues are resolved through renewable energy architectures which consumes more deployment costs and not suitable for more density networks.
6. Some existing energy efficient data aggregation algorithms (*e.g.* [8] and [11]) are more specific to the type of network (homogeneous, heterogeneous, and static) and not suitable for high density networks.

B. Motivation

Energy consumption is the most important factor that decides the life of a sensor network and sensor nodes being mostly driven by batteries. This necessitates energy optimization in the sensor nodes to increase the lifetime of the network. Even data aggregation algorithms resolve these energy related issues in WSN; the design and implementation of these algorithms into a real time environment is easier said than done. Even many data aggregation algorithms have been proposed to resolve these issues, an optimal solution which resolves all the problems have not been discussed much. Resolving the problems that are discussed in previous section with a combined unique solution may increase the real time implementation of WSN on various applications beyond the research. The motivation behind this proposed algorithm is to propose an energy efficient combined solution which resolves the maximum data aggregation issues in order to make the world more sensible with many WSN applications. Moreover the recent technologies like IoT, LiFi extend the WSN application needs and unveil new research opportunities in WSN.

C. Objectives of the proposed model

Efficient data aggregation scheme should collect as much information as possible from the network so that it can provide more secured information to the sink without any delay and collision. Discovery of an effective aggregation algorithm can be achieved by identifying the issues related to delay, collision, security and energy and developing algorithms to resolve those issues to improve the performance of the sensor network.

The main objective of this proposed model is to design a combined unique data aggregation framework which can collect information effectively from the network for real time WSN in energy efficient manner. This paper addresses issues involved in performing aggregation for real time applications and proposes a framework to reduce the maximum data aggregation issues while improving the lifetime of the network. The significant contributions of this research are made towards the design of a combined data aggregation framework for WSN which has the following objectives.

1. Investigating the impact of node mobility on various routing schemes and to identify the performance metrics that affect routing.
2. Reducing the data aggregation delay through an effective tree based distributed algorithm which is suitable for static as well as dynamic applications.
3. Avoiding collisions when aggregating data from more number of nodes in a sensor network.
4. Providing high accuracy and confidentiality for data through a secure data aggregation algorithm.
5. Improving the lifetime of the sensor network by reducing the communication and computational overhead of the algorithms.

6. Reducing the number of communications between nodes that improves the energy utilization.
7. Handling dynamic changes in tree structure, due to hidden node problem or change in link quality of the channel or residual energy of a node.

Analyzing and comparing the new protocol with the existing models using the simulators.

3. HYBRID DATA AGGREGATION FRAMEWORK

In the proposed work, an energy optimized hybrid data aggregation algorithm for wireless sensor network is proposed. This work is an effective integrated solution which resolves collision and delay issues to improve the energy efficiency and delivers the aggregated data to the sink in a secured way. This framework has four phases, (*i*) construction of data aggregation tree [2] (HTC) with the objective of reducing the data aggregation latency (*ii*) a collision aware data aggregation algorithm [3] (HCDA) has been proposed on the delay efficient data aggregation tree. (*iii*) security issues has been resolved through a Hybrid Secure Data Aggregation [4] (HSDA) which provides data integrity and confidentiality and (*iv*) finally all the three phases has been integrated and modified in HCED [5] to provide combined solution for data aggregation in an energy efficient way.

A. HTC: Hybrid Tree Construction for Delay aware Data Aggregation

This The first phase of the work presents two parts; the first part proposes a hybrid solution to reduce the data aggregation delay through a binary tree based data aggregation tree construction algorithm (algorithm 1 in [2]). This model uses a high residual energy node as root node. Each other nodes indentified their parent and child nodes among their neighbour nodes based on the distance and available energy. The least distance node will be assigned as left child node and the second least distance node will be assigned as right child node. When the distances are equal with two or more neighbour nodes, parent node prefers the high residual energy node as the child node (algorithm 2 in [2]). Correspondingly a two hop binary tree based data aggregation tree has been constructed towards the root node in the first part. The second part proposed a delay aware data aggregation algorithm (algorithm 3 in [2]) that employs on the hybrid data aggregation tree constructed in first part. A distributed aggregation scheduling has been proposed to reduce the aggregation latency. The least level left child nodes are sending their data to parent nodes in the first time slot. The right child nodes sending their data in second time slot. Likewise all the nodes sends their data to its parent nodes so that data reaches the root node. The proposed binary tree based tree construction model significantly reduces the aggregation latency due to its two hop data aggregation nature. Since the data aggregation delay has been reduced, considerable energy wastage has been avoided. The delay and energy performance of this proposed model has been evaluated and compared with existing models through simulation results.

B. HCDA: Collision Aware Energy Efficient Data Aggregation

The subsequent phase presents a collision free hybrid algorithm for data aggregation called HCDA [3] that reduces the energy wastages of the sensor nodes. The operation of HCDA is managed by two algorithms: i) Node Discovery Algorithm (algorithm 2 in [3]) (NDA): each node finds its neighbours and chooses their corresponding child nodes to form a two-hop collision free aggregation tree. ii) Hybrid Data Aggregation (algorithm 4 in [3]) (HDA): by applying HDA Algorithm on NDA aggregation tree, the sink node achieves the fast data aggregation in a collision free topology. The correctness of HCDA is formally proven and approximation and complexities have been analyzed. The evaluation and comparative analysis of HCDA thus described in this phase proves the contribution made in this part is better than the existing models in data aggregation. The performance analysis graphs proved that the use of this method is highly supportive when the number of nodes in the network is high.

C. HSDA: Hybrid communication for Secure Data Aggregation

The third phase of the work proposes a secure data aggregation algorithm [4] (HSDA) to provide energy efficient secure data aggregation in wireless sensor network. A hybrid encryption technique (algorithm 5 in [4]) which is presented in this phase is a mixture of symmetric and asymmetric encryption techniques. Homomorphism encryption will be performed by encrypting the raw data with public key. The proposed secure data aggregation algorithm (algorithm 2 in [4]) is a uses a public key as well as private key for encryption purpose. During the encryption process the public key (algorithm 3 in [4]) is generated by sink node and shared with all the other nodes through a broadcast. And the private key (algorithm 4 in [4]) is generated by all the nodes in the network but that is not shared with any other nodes. When decrypting (algorithm 6 in [4]) the data, the private keys of each node has been generated by sink node. Thus an unwanted communication has been avoided to share the private keys and data integrity also has been ensured by the sink node by generating the proper private keys. If the sink node is not able to decrypt the data using the private and public key, the data will be discarded as false data. Hence the authentication of data has been verified in the proposed model. This less complex hybrid algorithm reduces the computational overhead at each node so that the energy optimization has been improved. The simulation results of this proposed model proved the improvement in secure and energy efficient data aggregation compared than existing models.

D. HCED: Hybrid Communication for Energy Efficient Data Aggregation

To provide energy optimized integrated solution that resolves the major causes of energy dissipation like delay, collision and security, the concluding phase of the work presents a hybrid data aggregation algorithm [5] for energy optimization in wireless sensor networks which is referred as HCED. This HCED is a combination of distributed and centralized aggregation mechanism to perform simultaneous data aggregation from sensor nodes. This algorithm has three parts. First part proposes an energy efficient tree construction algorithm (algorithm 1 in [5]) based on the binary search tree model. It follows a two hop routing model for data aggregation to improve the delay efficiency.

The second phase proposed a delay aware hybrid data aggregation algorithm (algorithm 2 in [5]) that reduces the energy consumption by performing the collision free data aggregation. Finally a secured data aggregation has been achieved through a hybrid cryptography technique (algorithm 3 in [5]). The encryption algorithm (algorithm 4 in [5]) which is proposed in this phase reduces the computation overhead of the network than existing models. The data aggregation framework that is proposed in HCED algorithm reduces the energy wastage by resolving the delay, collision and security issues. Simulations results show that the hybrid algorithm based data aggregation can appreciably decreases the total energy consumption and improves the lifespan of the wireless sensor network.

4. RESULT ANALYSIS

In this paper, an abstract of various data aggregation schemes have been proposed and the performance of each model has been analyzed. The comparative analyses of each model with related existing models are also done in the respective publications [2, 3, 4, 5]. But the comparative analysis on all the proposed models has not been discussed. The comparative study of all the methodologies proposed in this paper has been discussed in this section.

The proposed aggregation algorithms have been simulated using mobile relay nodes present in the wireless sensor networks. Network simulator (NS-2) is used to evaluate the performance of the networks. In the simulation setups, 100 to 600 mobile nodes and 1 sink node are randomly placed in a rectangular area of 1500m X 300m to form a wireless sensor network. The nodes are made to move with a maximum velocity of 10m/s. By increasing the density of the network, the performance have been studied and compared. Each simulation runs for 900 seconds totally. The radio propagation range of the nodes is 250 meters and the data rate is 2Mbits/s. At the Mac layer the 802.11 protocol is used and at the physical layer the free space signal propagation model is used.

The performance of the proposed models has been evaluated in terms of all the data aggregation issues. The delay has been evaluated as time (in seconds) which is required to aggregate all the data. The effect of collision has been analyzed based on throughput of the network. The data security has been evaluated in terms of Authentication, Confidentiality and Integrity. And finally the energy efficiency of the sensor nodes has been evaluated based on computational and communicational overhead.

A. Delay analysis

The delay performances of the proposed models that are discussed in [2] are evaluated by comparing with each other. The delay related issues on data aggregation has been resolved in HTC model which is discussed in section 3. The delay performance of the proposed system has been evaluated in terms of seconds. Fig 1 describes the comparison of the entire proposed models on delay in static networks. The result analysis shows that, the combined solution HCED performs the data aggregation of 100 packets with the delay of 22.16 seconds which is 0.11% smaller than the delay produced by the HTC. When the number of packets is increased to 600, the HCED produces 0.44% lesser delay than HTC. Hence these comparison results on static networks concludes that using of HTC model for data aggregation will resulting the better performance on delay even it employed on various data aggregation schemes like HCDA and HCED.

The delay performance of the proposed models in dynamic networks has been evaluated and presented in Fig 2. For aggregating 300 packets from 100 nodes in dynamic network, HCED produced 2.23% high delay than static networks. When the number of nodes is 600 HCED gives 6.48% of delay than the static network. The comparative performance of the proposed HCED model in static and dynamic showed that the delay performance of HCED is considerably better than HTC, HCDA and HSDA.

B. Collision analysis

The collision problem in data aggregation leads data loss problem. The throughput of a network is directly related with collision issues. Since the throughput can be calculated as the ratio of successful packet delivery, the collision can be evaluated in terms of failure packets. The collision related issues has been resolved in HCDA that are discussed in [3]. HCDA is an improved solution of HTC which resolve collision as well as delay issues. The performance evaluation of the proposed models based on collision issues has been made based on the simulation results. Fig 3 shows the throughput performance of the proposed models in static networks. The simulation graph of static network proves that implementation HCDA on HTC model will produces 0.66% better throughput than HTC model when 100 nodes aggregating 300 packets. If 600 nodes are aggregating 300 packets, the HCDA produces 2% better throughput than HTC model.

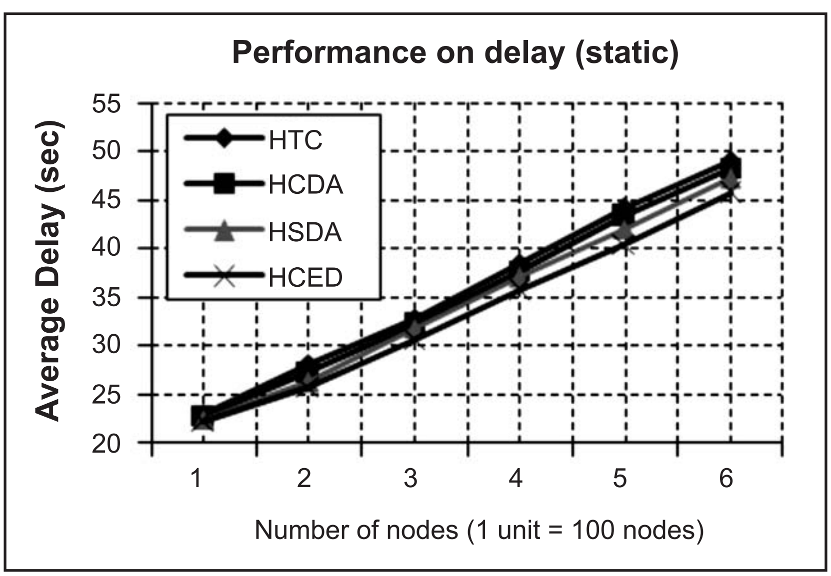

Figure 1: Delay performances in static network

The hybrid data aggregation scheme which is proposed in HCDA on a hybrid data aggregation tree is the main reason behind this successful improvement of HCDA in network throughput. The throughput performance of the proposed models in dynamic network has been evaluated and compared in Fig 4. The comparative results shows that HCED gets 0.67% less throughput in dynamic networks than static network for aggregating 300 packets from 100 nodes. When increase the density of the network to 600 nodes, HCED performs in 0.73% less throughput in dynamic networks. When compared to all the proposed models of this paper, the simulation results prove that the integrated solution HCED performs well in collision avoidance.

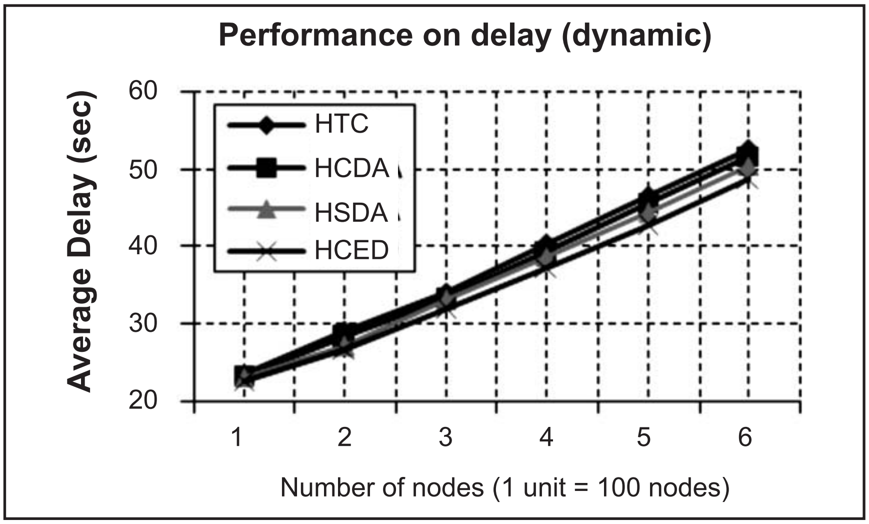

Figure 2: Delay performances in dynamic network

C. Energy analysis

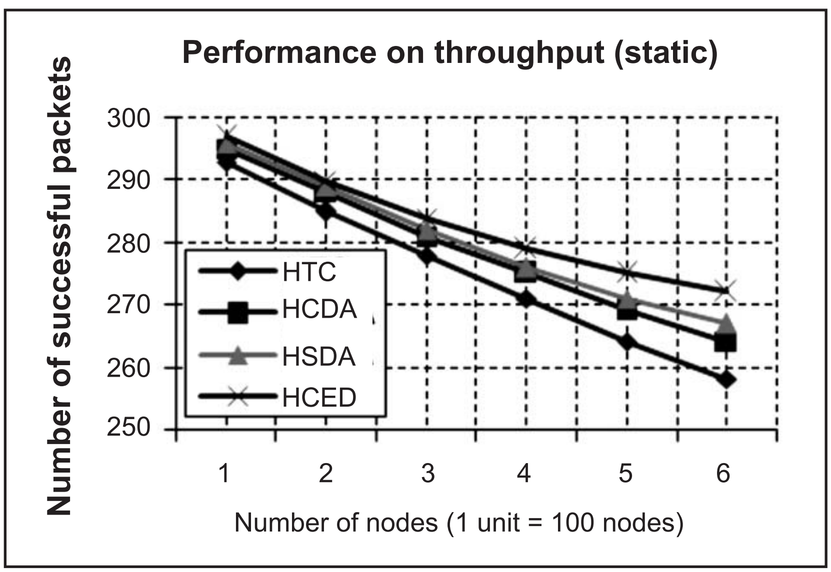

Figure 3: Throughput performances in static network

The energy utilization is a major evaluation criterion in wireless sensor network. Here all the proposed models have been evaluated in terms of energy and the comparative analysis was shown in Fig 5 and Fig 6. When the number of packets are 300, the average energy utilization of 100 nodes to aggregate all the 300 packets are mostly merge at the same level. But when increasing the number of nodes to 600, the combined solution HCED saves 1.24% more than HSDA and 0.66% more than HCDA in static networks. When simulate the same configuration in dynamic network, HCED produces 4.87% and 2.94% high energy consumption than static networks for 100 and 600 nodes respectively. This comparative simulation results on energy performance proves the significances of the HCED in terms of energy utilization in static as well as dynamic networks.

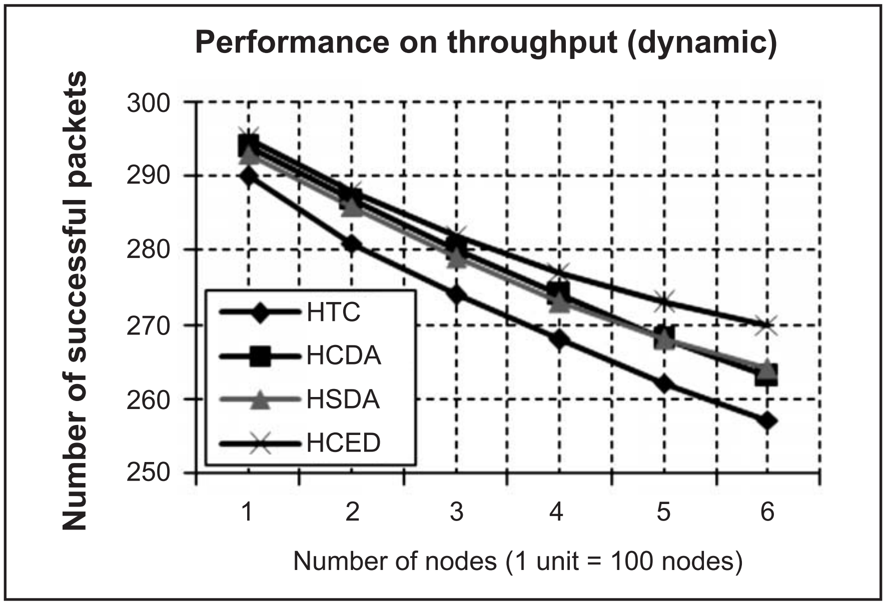

Figure 4: Throughput performances in dynamic network

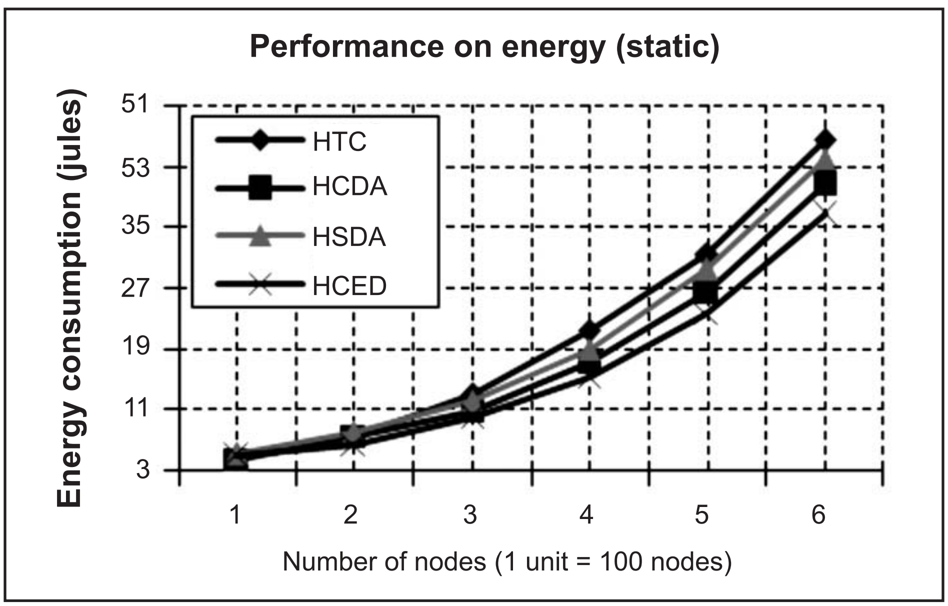

Figure 5: Energy performances in static network

At the conclusion, the hybrid aggregation model proposed in section III resolves delay issues and energy consumption of HTC model is also comparatively better than existing models. When resolving the collision issues using the hybrid data aggregation scheme on HTC, it further reduces the energy consumption. But when resolving the security issues using HSDA, then energy utilization little increased due to computational overheads. By reducing this computation overhead at HCED, it achieves better energy utilization than all the other models and existing systems.

5. CONCLUSION

The data aggregation algorithm which is presented in this work is a combined solution that resolves the maximum data aggregation issues in an energy efficient way. The hybrid tree algorithms proposed in this work reduces the data aggregation delay and performs fast data aggregation. The HCDA which is presented in the second part of this work avoids the collision problem in data aggregation and reduces the energy consumption. The third part HSDA ensures the security in data aggregation in an energy efficient way. Finally HCED presents a combined unique solution to resolve all the major data aggregation problems. All the parts of this research work is simulated and tested in multiple simulators. The improved performance of the proposed framework is verified through mathematical models and simulation results. The proposed model is designed to support event detection as well as periodic reporting applications. In addition to that, the proposed framework works well in static and dynamic environments.

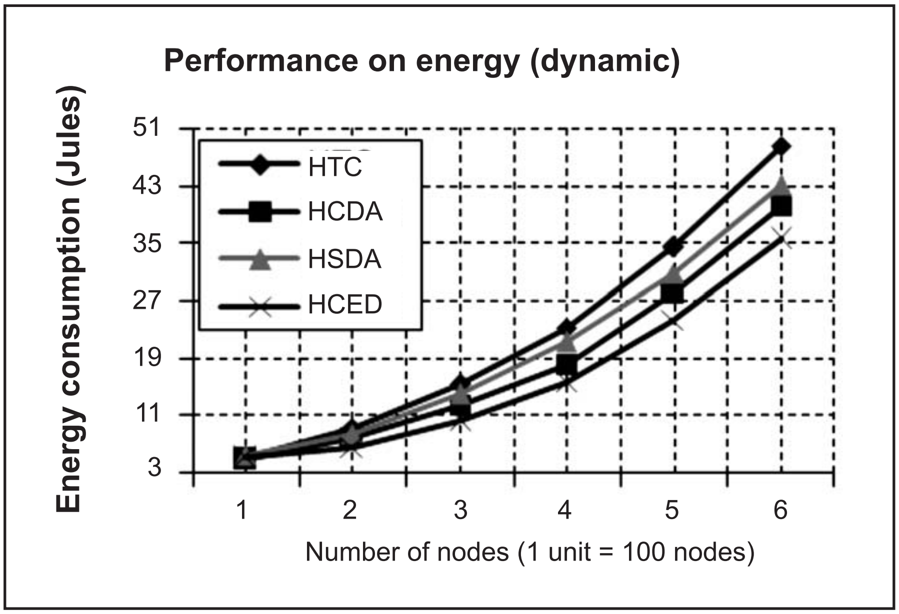

Figure 6: Energy performances in dynamic network

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