Journal of Engineering Science and Technology
Vol. 10, No.11 (2015) 1465 - 1476

INVESTIGATION OF ATTRIBUTE AIDED DATA AGGREGATION OVER DYNAMIC ROUTING IN WIRELESS SENSOR NETWORKS

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Abstract

Wireless Sensor Networks (WSNs) comprises several sensor nodes. The energy consumption is the major issue in WSNs. Data aggregation is a main method to conserve energy in WSN and minimizes the number of transmissions and then to save energy. This paper focuses on various data aggregation algorithms and protocols to collect and aggregate data in an efficient way so that life energy is increased. And, the varieties of algorithms are compared by of performance measures such as latency, data accuracy and life time. To make data aggregation more efficient a potential-based dynamic routing is elaborated to support an Attribute - aware Data Aggregation (ADA) strategy which is relied upon the idea of potential in physics and pheromone in an ant colony

Keywords: Wireless sensor networks, Data aggregation, Attribute aware, Data aggregation.

1. Introduction

Sensor networks are distributed systems, comprising hundreds / thousands of tiny, low-cost, low power sensor nodes and one or few powerful base stations [1]. Generally, sensors assess some physical phenomena and send their measurements to the base station by wireless communications [2]. The base station performs data processing functions and provides gateway services to other networks (e.g., the Internet). Sensor nodes are capable of sending messages only within a short communication range; therefore, it is assumed that the sensor builds a multi-hop network in which the nodes transmit messages on behalf of other nodes towards the base station and back to the nodes from the base station. Aggregator nodes

Nomenclatures

NS_2	Network Simulator (Version 2)
App1, 2, 3	Application 1, 2, 3

Abbreviations

ACA	Ant Colony Algorithm
ADA	Attribute - aware Data Aggregation
ANTRP	Average Number of Transmission per Received Packet
AR	Aggregation Ratio
CAG	Clustered Aggregation
CH	Cluster Head
CI	Computational Intelligence
CLUDDA	Clustered Diffusion with Dynamic Data Aggregation
CT	Cascading Timeout
DDS	Directed Dominating Set
EADAT	Energy Aware Data Aggregation Tree
LEACH-AP	LEACH Access Point
SPT	Shortest Path Tree
TDMA	Time Division Multiple Access
WCDS	Weakly Connected Dominating Set
WSN	Wireless Sensor Network

gather information from surrounding sensors, process the data collected locally, and transmit only a single, aggregated message towards the base station.

Data Aggregation

The ‘‘battery power” is the most restrictive factor in designing WSN protocols. Thus, to reduce the power consumption of WSN, several approaches have been proposed such as control packet elimination, radio scheduling, topology control, and most prominently data aggregation [3, 4]. Data aggregation protocols aim to merge and summarize data packets of numerous sensor nodes so that the amount of data transmission is minimized. An example data aggregation approach is illustrated in Fig. 1 where a group of sensor nodes gathers information from a target region.

When the base station queries the network, instead of sending each sensor node’s data to base station, one of the sensor nodes, called data aggregator, collects the information from its neighbouring nodes, aggregates them (e.g. Computes the average), and sends the aggregated data to the base station over a multi-hop path. As illustrated by the example, data aggregation reduces the number of data transmissions thereby improving the bandwidth and energy utilization in the network.

The existing data aggregation approaches can efficiently make packets more spatially and temporally convergent to enhance aggregation efficiency, most of them consider that there are homogeneous sensors and only one application in WSNs, and ignore considering whether the packets really carry redundant and correlated information or not. Actually, nodes are equipped with various sensors (i.e., Pressure, temperature, humidity, light intensity, etc.) and different applications can also run in the same WSN simultaneously [5]. It is not viable to perform simple aggregation operations on the packets from heterogeneous sensors even if all packets can be transmitted along the same reconstructed aggregation trees and timing control approaches can also ensure packets have a high probability to meet with each other.

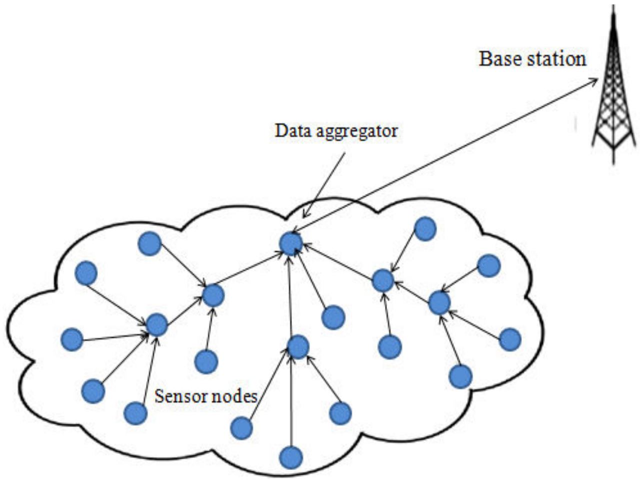

Fig. 1. Data aggregation in wireless sensor networks.

Many applications can be deployed in WSNs and various sensors are embedded in nodes, the packets generated by heterogeneous sensors or different applications have different attributes. The packets from different applications cannot be aggregated. Otherwise, most data aggregation schemes employ static routing protocols, which cannot dynamically or intentionally forward packets according to network state or packet types. The spatial isolation caused by the static routing protocol is unfavourable to data aggregation. They properly support data aggregation in the network with homogeneous sensors and a single application, but cannot conduct effective data aggregation when the data from heterogeneous sensors or various applications are forwarded along the same static path.

2. Related Work

Ming Fan et al. [6] preferred the data aggregation using an ant colony algorithm. Using direct transmission, sensor nodes that are far away from sink node, drain their power sources much faster. So the author introduces the Ant Colony Algorithm (ACA). It consumes less data delivery energy. Here assigning artificial ants to the source nodes to establish low latency paths between the source nodes and the sink node. Paths from different source nodes to a sink node from an aggregation tree rooted at the sink node. Data from different sources are opportunistic aggregated. If any node receives the data from a neighboring node, the node selects next node according to the random proportional rule of the ant colony algorithm. After a short time period the amount of pheromone on the aggregation node is meeting together for data aggregation. But Energy wise, opportunistic aggregation on a low latency tree is not optimal.

Umar Farooq [7] recommended the Computational intelligence based data aggregation. Data aggregation helps in improving the WSN protocols performance. Hierarchical networks or Clustering is vital for data aggregation, where the sensor nodes are divided into clustered and allocated different roles. So the Computational Intelligence (CI) based data aggregation is proposed. The paradigms of CI comprise reinforcement learning, Neuro-computing, fuzzy computing and evolutionary computing. CI combines the elements of evolution, fuzzy logic and learning, adaptation to solve complex problems. Paradigms of CI have found practical applications in areas such as robotics, product design, biometrics and intelligent control and sensor networks. Therefore the effective aggregation of information gathered from different sensors. The other CI paradigms are not appropriate and applied in the field of data aggregation.

Ding et al. [8] recommended the aggregation tree construction. Low power and in- network data processing makes data centric routing in Wireless Sensor Networks a challenging problem. The author proposed the Energy Aware Distributed heuristic to generate the aggregation tree which refers to as EADAT. It is based on neighboring broadcast scheduling and distributed competition among neighbors. So the aggregation tree can be used to facilitate data-centric routing. The dominant energy consumer is the radio transceiver. The only way to save energy is to completely turn off the radios of all leaf nodes. But all non-leaf sensors in the tree will be active. Applying this tree structure network lifetime can be extended. The performance of EADAT algorithm analyzed in terms of network lifetime, energy saving, data delivery ratio and the protocol overhead. In all scenarios EADAT performs very well compared to other approaches.

Chatterjea and Havinga [9] recommended the Dynamic Data aggregation. The author suggests methods to improve network efficiency by combining Directed Diffusion with clustering. It prevents flooding during interest propagation where every single node in a sensor network part in the transmission of interest messages. Clustered Diffusion with Dynamic Data Aggregation (CLUDDA) can also be split into two main phases: First one is interest propagation and another one is data propagation. In interest propagation a sink node Uni-Cast the message to its Cluster Head. The Cluster Head transmits the interest message to its children made up of regular, gateway nodes. Every node receiving an interest message responds with an appropriate data message. In data propagation phase, the data messages are forwarded from source to sink.

Nagaveni and Syed Khaja [10] suggested the Energy Aware data aggregation. Low Energy Adaptive Clustering Hierarchy (LEACH) is the first hierarchical cluster-based routing protocol for wireless sensor network that divides the nodes into clusters, each cluster contains a dedicated node with extra privileges called Cluster Head (CH) is responsible for creating and manipulating a TDMA (Time division multiple access) schedule and sending aggregated data from the nodes to the BS where this data is needed using CDMA (Code division multiple access). The remaining nodes are considered as cluster members. This protocol is divided into rounds; each round consists of two phases: set-up phase, steady state phase. Leach uses dynamic clustering, which results in extra overhead such as the head changes, an advertisement that reduces the energy consumption gain. As the nodes are rotated every time a new Cluster Head has to be formed, this consumes energy. So the author introduces the LEACH Access Point (LEACH-AP). The cluster contains access points which are having very high energy compared to Cluster Head. Instead of Cluster Head, using Access points, which are just like mini base stations. Each and every cluster has an access point. Every time there is no need to form new Cluster Head as there are no Cluster Heads.

Maraiya et al. [11] recommended the Architectural based data aggregation. With the help of data aggregation, we can reduce the energy consumption of nodes using by eliminating redundancy. The author proposes the architectural based efficient data aggregation. In centralized architecture, sensor nodes transmit data to one central node, called central processor fusion node. In this architecture central node has a responsibility of the whole network. In decentralized architecture, there is no single centralized node that makes decisions on behalf of all the sensor nodes. In hierarchical architecture all sensor nodes are partitioned into hierarchical level. Here the data from the individual sensor nodes pass through the different levels and at last it reaches the base station.

Pandey et al. [12] recommended the data aggregation. Data aggregation may be an effective technique in this context because it reduces the number of packets to be sent to sink by aggregating the similar packets. In this paper author introduces the various data aggregation algorithms. Data aggregation technique increases the lifetime of sensor networks by decreasing the number of packets to be sent to sink or base station. The data aggregation technique can be divided into different parts: structure based and structure free. Structure based data aggregation can be further divided into four parts flat networks based, cluster based, tree based and grid based.

Yoon and Shahabi [13] suggested Clustered AGgregation (CAG) algorithm that forms clusters of nodes sensing similar values within a given threshold (spatial correlation), and these clusters remain unchanged as long as the sensor values stay within a threshold over time (temporal correlation). With CAG, only one sensor reading per cluster is sent whereas with Tiny AGgregation (TAG) all the nodes in the network send the sensor readings. Thus, CAG provides energy efficient and approximate aggregation results with small and often negligible and bounded error. The CAG work in five directions: First, investigate the effectiveness of CAG that exploits the temporal as well as spatial correlations using both the measured and modelled data. Second, design CAG for two modes of operation (interactive and streaming) to enable CAG to be used in different environments and for different purposes. Interactive mode provides mechanisms for one-shot queries, whereas the streaming mode provides those for continuous queries. Third, propose a fixed range clustering method, which makes the performance of systems independent of the magnitude of the sensor readings and the network topology. Fourth, using Mica2 motes, perform a large-scale measurement of real environmental data (temperature and light, both indoor and outdoor) and the wireless radio reliability, which were used for both analytical modelling and simulation experiments. Fifth, model the spatially correlated data using the properties of real world measurements.

Ozdemir and Xiao [14] proposed the secure data aggregation. Due to hostile environments and unique properties of WSN, it is challenging task to protect sensitive information transmitted by WSNs. The traditional networks do not face the security problems. Therefore, security is an important issue for WSNs and there are many security considerations that should be investigated. Data confidentiality ensures that secrecy of sensitive data is never disclosed to unauthorized parties and it is the most important issue in mission critical applications. Data integrity guarantees that a message being transferred is never corrupted. Data freshness protects data aggregation schemes against replay attacks by ensuring that the transmitted data is recent. Source authentication enables a sensor node to ensure the identity of the peer node it is communicating with. Availability guarantees of network services against Denial-of-Service (DoS) attacks.

Markandeyulu and Prashanti [15] recommended the secure reference based data aggregation. The most existing aggregation algorithms and systems do not include any provisions for providing security, and consequently these systems are vulnerable to a large variety of attacks. In particular, the compromised nodes can be used to inject the false data that lead to incorrect the aggregates being computed at the base station. So the security requirements of wireless sensor networks can be satisfied using either symmetric key or asymmetric key cryptography. That is, data aggregators must decrypt every message they receive, aggregate the messages according to their corresponding aggregation function, and encrypt the aggregation result before forwarding it. These schemes require data aggregators to establish secret keys with their neighboring nodes. In order to provide end-to-end security, privacy homomorphism based secure data aggregation protocols have drawn considerable attention recently.

3. Method and Techniques (Designing ADA)

3.1. Potential field model

The entire network is viewed as a gravitational field. A packet is viewed as a drop of water; the packet is moving down to the bottommost along the bowl surface. The path is determined using the gravitational potential field.

3.2. Depth potential field

The depth of the node is defined as the number of hops that it is away from the sink. The depth potential field drives the packets move to the sink using shortest path, i.e., without any loops; hence it provides the basic routing function.

3.3. Pheromone potential field

A pheromone potential field is created to collect the packets with the same attribute together. In WSN the packets are treated as the ants. Ants are leaving some unstable pheromone information at every passed node. A path selected by other packets having more pheromone and can attract more packets and do it with the same attribute.

3.4. Hybrid potential field

Combine depth potential field and the pheromone potential field to form a hybrid potential field, it ensures the packets reach the sink at last. In network each node can obtain its depth through the routing update message. This message is sent by the sink periodically. The node which has the one hop distance away from the sink the depth value is considered as 1 which is sent by the sink periodically. In

WSN multiple sinks are presented for several purposes. In this nodes maintain the least depth value to the nearest sink or multiple depth values for multiple sinks. And combining the pheromone values from its direct neighbours, the node can take the routing decisions.

4. Results and Discussions

4.1. Average number of transmission per received packet (ANTRP)

ANTRP is defined as the ratio of the total number of transmissions to the total number of packets received by the sink. Without data aggregation, every packet generated at the node whose depth is d can reach the sink after at least d transmissions. An efficient data aggregation mechanism will reduce transmissions by aggregating packets at intermediate nodes. Thus, ANTRP is a proper metric to evaluate the efficiency of data aggregation schemes.

$$\text{ANTRP} = \frac{\text{Total Number of Transmissions}}{\text{Number of Packets Received}}$$

4.2. Aggregation ratio (AR)

AR is defined as the ratio of the total number of packets received by the sink to the difference between the total number of packets generated by applications and the number of dropped packets. If there are only packets with the same attribute and most packets are aggregated near events and then forwarded to the sink, the sink will receive a few packets. Conversely, the fact that more packets are received at the sink indicates that fewer aggregation operations are performed on networks.

Assume that an aggregation function can merge the packets with correlated information into one packet regardless of its actual operators. This assumption can be held for some common aggregation operators, such as MAX, MIN, SUM, AVG, STD, and VAR.

4.3. Shortest path tree (SPT)

Packets are forwarded to the sink along the shortest path. Aggregation is opportunistic and happens only if two packets with the same attribute encounter at the identified node as well as at the same instant.

4.4. Cascading timeout (CT)

CT is based on a routing tree in which nodes wait some time, according to the depth of the node before transmitting the packet.

4.5. Directed dominating set (DDS)

A special dominating set is constructed first and then a connected dominating set is constructed to connect dominates and the other nodes and the resultant tree can act as the aggregation tree.

4.6. Weakly connected dominating set (WCDS)

A directed tree over the sensor network nodes is constructed to compress the value of a node using the value of its parent.

Network Simulator (Version 2), generally known as NS_2. It is simply an event driven simulation tool that has proved useful in studying the dynamic nature of communication networks. Simulation of wireless network functions and protocols are done using NS_2. A WSN with 40 sensor nodes is randomly deployed in a rectangular region. The sink receives the aggregated result from the multiple sensors. The packets are randomly generated with average interval 30 ms All applications start at 100 s and end at 130 s. So the packet interval is 0.01 s, node transmission range is 250 ms.

Table 1 lists the parameters related to applications and *x, y* is the coordinate of the centre of the circle where the application happens and *r* is the radius of the circle. The ANTRP with different node density in different schemes is shown in Fig. 2, where it is observed that all the curves decline as the number of nodes increases. It is reasonable since the average number of neighbours of a node increases as nodes become denser, which is helpful to improve spatial convergence degree and then reduce ANTRP.

Table 1. Parameters of apps with different node density.

Application	*X in m*	*Y in m*	*R in m*	*Attribute*
App1	20	57	5	3
App1	30	50	5	2
App2	37	48	5	1

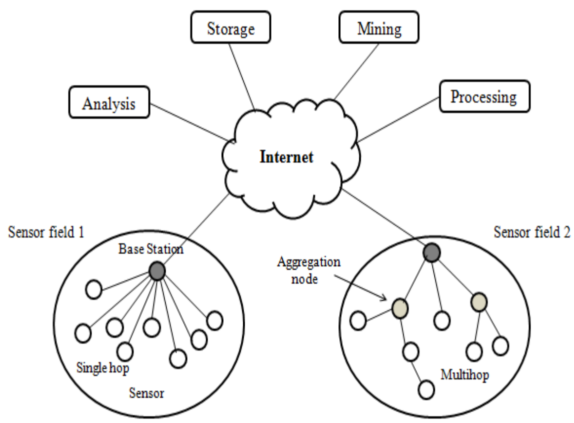

Fig. 2. Architecture of wireless sensor network.

Figure 3 shows the formation of different potential fields. Depth potential field and pheromone potential fields which are make the packet with the same attribute. A packet leaves some attribute dependent pheromone, when passing a node to attract the afterward packets with the same attribute. Figure 4 shows the how different packets are converted into the same attribute, which is based on potential based dynamic routing.

Figure 5 shows the process of data aggregation. The node maintains the timer for the packets with the same attribute in its queue. When the timer expires the equivalent aggregation is performed. The packets are collected from the multiple sensors (destinations) which are transmitted to the sink.

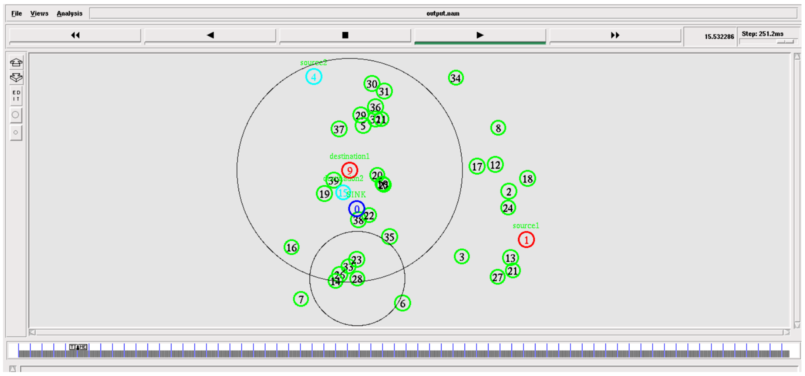

Fig. 3. Formation of potential fields.

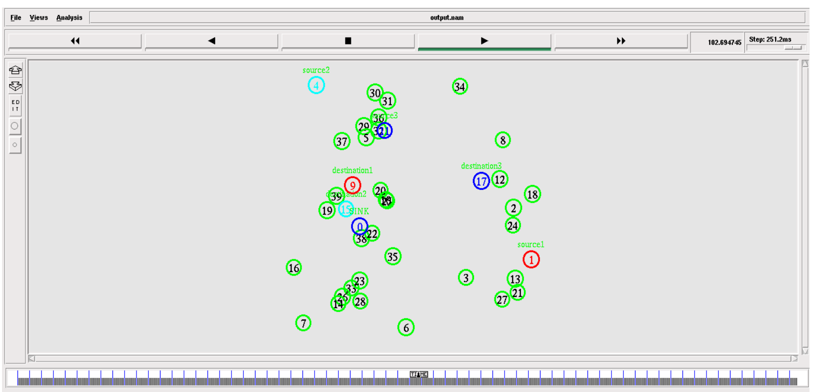

Fig. 4. Make packets with the same attribute and perform dynamic routing.

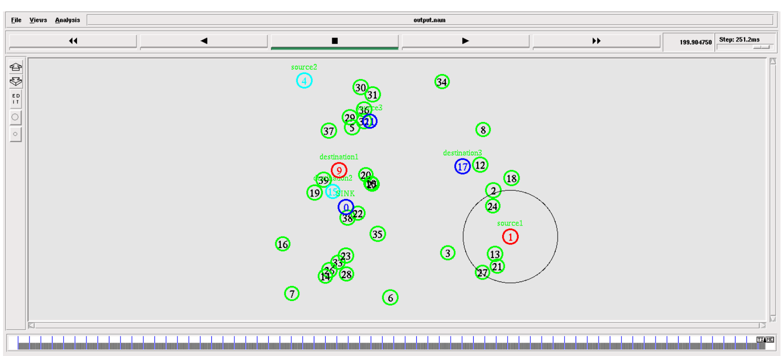

Fig. 5. Perform data aggregation.

Figure 6 shows the scalability result of different approaches. When the events are close to the sink, the number of packets received at the sink in ADA is less than CT by 20% and then SPT by 80%. Hence aggregation performed means the only minimum number of packets received by the sink.

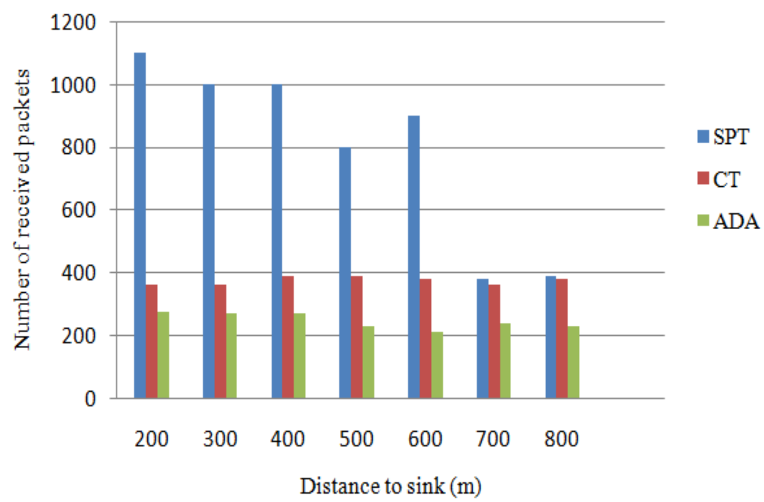

Fig. 6. Comparisons among ADA, CT and SPT.

SPT performs the worst since it does nothing to make packets spatially convergent and temporally convergent. In this paper also represented that the ADA outperforms the other schemes at any node density.

Figure 7 shows the Average Number of Transmissions per Received Packet. In this ADA scheme perform very well compared to other approaches.

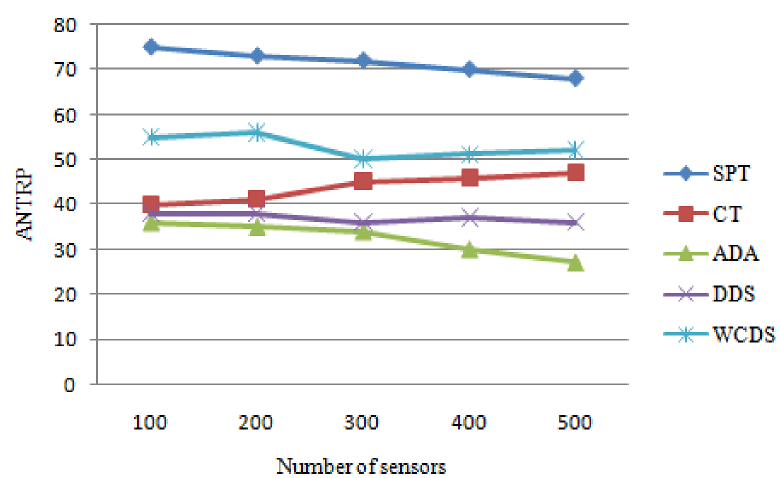

Fig. 7. Average numbers of transmissions per received packet.

Figure 8 illustrates the AR of different schemes in the same scenario. As the node density increases, all schemes perform better, and both ADA and DDS are major. It seems that ADA obtains more gains in Fig. 8 than that in Fig. 7. The reason is that ADA indeed improves spatial and temporal convergence remarkably and thus the number of the packets received by the sink is rather small. However, with respect to the average number of transmissions per received packet as shown in Fig. 7, the packets sometimes forwarded to the next hop with the same depth or even with a deeper depth to improve spatial convergence degree.

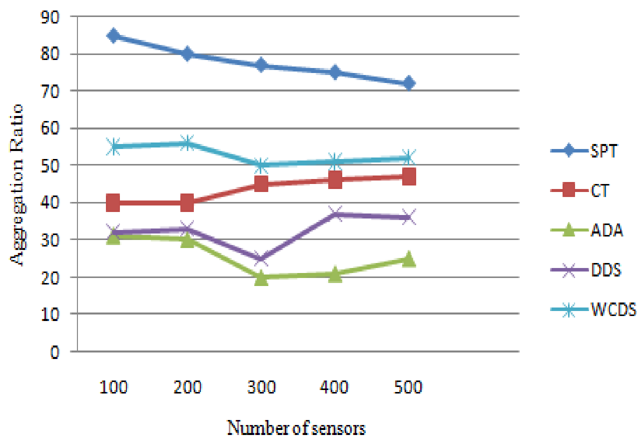

Fig. 8. Aggregation ratio.

5. Conclusion and Future Work

The data aggregation is an effective mechanism to save limited energy in WSNs. Data aggregation algorithms are to gather and aggregate data in an energy efficient manner. So that network lifetime is enhanced. In this paper, a survey of data aggregation algorithms and protocols are presented. All of them focus on optimizing important performance measures such as network lifetime, data latency, data accuracy, and energy consumption. Efficient organization, routing, and dynamic data-aggregation are the three main focus areas of data-aggregation algorithms.

In future, ensure packets reach the sink as well as be more spatially convergent; we linearly combine the depth potential field, the pheromone potential field and queue potential field to form energy based hybrid potential field. Dynamic scheduling which can be implemented using the currently available information without the necessity of predicting the future.

The future work should focus on eliminate redundancy, minimize the number of transmissions, and save energy.

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