International Conference on Advances in Communication and Computing Technologies (ICACACT) 2012
Proceedings published by International Journal of Computer Applications® (IJCA)

Energy Efficient Routing in Wireless Sensor Networks with a Dynamic Sink based Congestion Control Protocol

Medha Sanjay Asurlekar
Student M.E. second year
EXTC Department
Terna Engineering College,Navi Mumbai

R. D. Patane
Assistant Professor
EXTC Department
Terna Engineering College,Navi Mumbai

ABSTRACT
Congestion in wireless sensor network occurs mainly due to two reasons --when multiple nodes want to transmit data through the same channel at a time or when the routing node fails to forward the received data to the net routing node. Congestion in wireless sensor network cause packet loss and due to this packet loss throughput may be lowered and also, congestion leads to excessive energy consumption. Therefore congestion has to be controlled to prolong the sensor nodes lifetime, in terms of throughput and packet loss ratio along with the packet delay. This paper proposes an dynamic sink based congestion control protocol named dynamic sink based congestion control protocol (DSCCP) for wireless sensor networks. Congestion and data loss mainly occurs in the vicinity of the static sink. Dynamic sink is responsible for collecting data from the sensor nodes located in their vicinity ,thus avoiding data flow to a single data collection point, e.g. a static sink is the main cause of congestion , data loss and reduced lifetime of the sensor network. Also in proposed scheme we used the in-network storage model that is used to ensure data persistency under congestion on WSN. Through simulation we show the effectiveness of the given routing scheme in terms of congestion avoidance and increased lifetime of the WSN.

Keywords
congestion control, energy efficient routing, dynamic sink, wireless sensor networks

I. INTRODUCTION
A WSN consists of spatially distributed autonomous sensors to monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to main location. They are deployed in dense numbers to these fields, gathering information and transmitting it to the base station in constant intervals of time t. This results in a huge amount of data flow from different parts of the sensor network towards a sink, causing congestion at various locations along the routing path and especially in the vicinity of the sink. Congestion in wireless sensor network occurs mainly due to two reasons --when multiple nodes want to transmit data through the same channel at a time or when the routing node fails to forward the received data to the net routing node. Also, it is known that each sensor node can only be equipped with a limited amount of storage, so if at any given routing node the data collection rate dominates the data forwarding rate congestion starts to build up at this node. Due to congestion they are not able to send the packets so that packets are dropped and data loss occurs. Such type of congestion and data loss normally occurs at the nodes located in the vicinity of a static sink. Data loss at these nodes occurs due to the fact that at any given point of time a sink can only communicate with one or a limited number of sensor nodes

In traditional methods, centralized sink node is used to collect data from wide-spreading sensor nodes. As the number of sensor nodes concurrently reporting data increases, the unique sink node becomes bottleneck of the network. It causes congestion around sink node. In this paper, we assume that the sensor network is created with multiple sinks. So, the data traffic is dispersed among multiple sinks thus the chance of congestion is avoided.

However, a WSN has limited resources since it typically runs on battery power and usually has a very small in-network storage space. Thus, sensing devices must operate under severe resource constraints and one of the foremost goals is to minimize the energy consumption. To achieve energy efficiency, here part of the sensor nodes which guarantee the complete coverage of the monitored area kept in active state and remaining nodes kept in inactive or power saving mode.

So the sink implements a round robin like algorithm to grant equal opportunity to all the sensor nodes located in the vicinity of the sink for transferring data to the sink. Thus, during any given time interval only a subset of the sink's neighboring nodes can transfer data to the sink, while the remaining nodes wait for their turn. In the meanwhile waiting nodes keep on receiving data from their neighboring nodes. As a result, after some time in-network storage buffers at the waiting nodes fill up and further inflow of data leads to data loss. This type of congestion phenomenon that occurs because of many- to-one transmission is known as funneling effect.

In this paper we present an in-network storage model [1] based data routing protocol. The idea is to create a routing scheme for avoiding congestion, which is the major cause of data loss and increased energy consumption of the sensor field. We call the new protocol dynamic sink based congestion control protocol (DSCCP) routing protocol. In contrast to available congestion avoidance/control techniques the DSCCP routing protocol is based on utilizing the sink mobility along a fixed trajectory in a WSN that leads to congestion avoidance and increased lifetime of the sensor network.

The rest of the paper is organized as follows: Section II summarizes related work, Section III states the problem and the presents the network model, Section IV discusses the in-network storage model, Section V discusses the DSCCP routing protocol, Section VI summarizes the simulation based evaluation of the DSCCP routing protocol, Section

VII discusses the future scope, and section VIII concludes the paper.

II.RELATED WORK

Techniques developed so far to address he data congestion problem can be divided into two groups; congestion avoidance and congestion control. The former focuses on strategies to avoid congestion from happening and the latter one works to remove congestion when it occurs. From an implementation perspective these techniques can be categorized in the following three categories.

A. Congestion avoidance and control techniques

Chen et al. [2] divided the techniques developed to address the problem of data congestion in WSN into two groups: congestion avoidance and congestion control. The former focuses on strategies to avoid congestion from happening and the latter works on removing congestion when it has occurred. From an implementation perspective these techniques can be categorized into three groups: data aggregation techniques, multi hop/path routing techniques, and flow control techniques.

Data aggregation techniques focus on utilizing spatial or temporal correlation between sensed data to reduce its quantity and hence prevent congestion [3]. These techniques are especially useful in environment or remote area monitoring applications where the consecutive data readings by the sensor nodes do not vary much over the time. Aggregation schemes that exploit such type of correlation amongst the sensed data are called temporal aggregation schemes [4]. Other types of aggregation schemes are known as spatial aggregation schemes. Routing nodes (responsible for forwarding the data towards the sink) implementing spatial aggregation schemes try to find correlation amongst the data received from different sensor nodes in an effort to reduce data size and hence avoid congestion. Galluccio et al. [5] showed that the use of spatial aggregation can be very helpful for avoiding congestion in the vicinity of the sink.

Barton et al. [6] tried to improve the data aggregation rate by applying a cooperative communication technique, where multiple nodes in a network cooperate to send data to the sink. It was observed that best results were obtained if the distance between the source and the sink is large. However, their scheme requires cross layer design for routing, scheduling and communication protocols to achieve preeminent results. Gao et al. [7] presented a tree based data aggregation scheme that utilizes a probe and recall protocol to connect the sensor nodes that are sparsely located at hot regions in the sensor field.

Multi hop/path routing techniques utilize the dense deployment of the sensor nodes to remove congestion from WSNs. These techniques enable the routing nodes to find alternate routing paths to reach the desired destination in case of congestion at a routing link. The idea is that when a routing node senses increased data traffic and packets start to drop, it requests the neighboring nodes to become part of the routing scheme, thus creating a multi path routing topology to share the data traffic and eliminate congestion from the network [8]. Zhu et al. [9] studied the tradeoff between the network lifetime and the required data rate from the sensor field to the sink. Although they do not address the issue of congestion directly, their work can be used to estimate the overhead caused by multi-path routing.

Flow control techniques try to control the amount of data that is flowing on the routing path to avoid congestion using various strategies. For example, Wan et al. [10] implemented a back pressure mechanism to restrict data flow, Akan et al. [11] allow the receiver node to regulate the outflow of data from the sender node.

All the techniques belonging to this class restrict the flow of data which in general also results in data loss. In addition to above mentioned schemes Wang et al. [12] proposed a node priority based congestion control scheme for wireless sensor networks.

Their scheme is based on the assumption that the nodes located in a WSN have different bandwidth and wireless media control requirement for data transmission. Therefore, a node priority index can be generated on the basis of packet inter arrival time and service time at each node. With the help of this index, sensor nodes having heavy data traffic can be assigned more access to the transmission media than the nodes with less traffic. However, extra overhead is involved in this scheme for maintaining the priority index of the sensor nodes.

Chen et al. [2] presented a congestion avoidance scheme that is based on the idea that at any given point of time client nodes have complete information about the buffer status of their parent node. Therefore, in case of congestion the client node either reduces the data that it is forwarding to the parent node or switches to some other parent node.

Analysis of the given schemes has shown that although they avoid or remove congestion, but they fail to avoid data and energy loss during this process. For example, aggregation based techniques entirely depend on finding correlation between the sensed data. If the collected data is of diverse nature because of extraordinary activities of different types in the WSN, these techniques fail. Multi hop/path routing techniques tend to work well for controlling congestion and avoiding data losses, but they fail to avoid congestion in the vicinity of the sink. In case of flow control techniques data loss occurs when the back pressure reaches the leaf nodes. The leaf nodes become restricted and cannot forward the gathered data because of the back pressure mechanisms. On the other hand, sensor nodes require some space in the buffer to accommodate the newly collected data. Thus, in order to create room for storing the newly collected data, leaf nodes have to drop previously stored data which leads to data loss.

In summary, existing schemes tend to lead to data loss. In order to overcome this problem, an in-network storage model has been presented in [1]. Now will we discuss different types of sink mobility patterns and schemes for data routing to a mobile sink.

B. Data routing towards a mobile sink

Over the past few years the use of a mobile sink has increased in WSNs to achieve better performance, in particular for balanced utilization of the sensor field energy and to prolong the lifetime. The sink can follow three basic types of mobility patterns in a WSN: random mobility, predictable/fixed path mobility, and controlled mobility.

Random mobility: In this case the sink follows a random path in the sensor field and implements a pull strategy for data collection from the sensor nodes. Data can be requested from either one hop or k (where, k>1) hop neighbors of the sink. Chatzigiannakis et al. [13] used random sink mobility in their schemes. Their results showed that if increased data latency is permissible then random sink mobility can be used for increasing the lifetime of the sensor network. Moreover, if the sink carries out data collection from k hop neighbors instead of one hop neighbors, data latency can be sufficiently reduced. However, with random sink mobility it is not possible to guarantee data collection from all the sensor nodes positioned in a WSN.

Predictable/fixed path mobility: Luo et al. [14] have tried to find a mobility strategy for the sink that can lead to the most energy efficient utilization of the sensor field. Their results show that the longest lifetime for the sensor network can only be achieved if the mobility trajectory of the sink is along the periphery of the sensor field. Increased data latency and packet loss are major problems that arise due to the sink mobility in wireless sensor networks. Luo et al. [15] have addressed these problems by presenting a routing protocol that not only balances the energy dissipation of the nodes but also tries to reduce data latency and loss. Their scheme is based on discrete mobility of the sink where the sink pause time is greater than its mobility time in the sensor field. One potential drawback of their scheme is that whenever the sink moves, routing paths need to be updated. Moreover, when the sink pauses at any point along the boundary, then the scenario becomes equivalent to that of a static sink case that leads to increased data loss in the vicinity of the sink.

Controlled mobility: Use of controlled sink mobility is also analyzed in WSNs for increasing the lifetime. Jayaraman et al. [16] outlined a framework which utilizes context aware mobile pervasive devices for data collection from the sensor field. These context aware devices are supposed to be intelligent enough to retrieve their possible future location on the basis of data generated by the field and direction of mobility. This information is utilized for planning the data collection process. Controlled sink mobility based schemes are a good option if reduced data latency is required, but they are less cost effective than random/fixed path mobility.

The discussion showed that if data latency is permissible, then the best routing strategy that incurs minimum data loss due to sink mobility and also provides maximum lifetime of the sensor network with minimum cost is obtained if the sink follows a discrete mobility pattern along the boundary of the sensor field [14, 15].

III. PROBLEM STATEMENT AND THE NETWORK MODEL

This section presents the problem addressed in this paper and also outlines the underlying network model.

A. Problem statement

As discussed in Section I, the major reason for congestion in a static sink based WSN is many-to-one transmission that is depicted in Figure 1. These routing patterns degrade the performance of a WSN in two dimensions: (i) increased data loss due to congestion in the vicinity of the sink, and (ii) reduced lifetime of the sensor network because the nodes located in the vicinity of the sink run out of their energy much quicker than the rest of the sensor field. So it can be inferred that if the single data collection point is replaced with multiple data collection points then significant reductions in the congestion and the data loss can be obtained. However any solution based on the use of multiple static sinks is not cost effective; moreover, nodes located in the vicinity of the static sinks also consume their energy much earlier than the rest of the sensor field. Therefore in this paper we address the above mentioned issues, by presenting a routing protocol that is based on an in-network storage model and a dynamic sink.

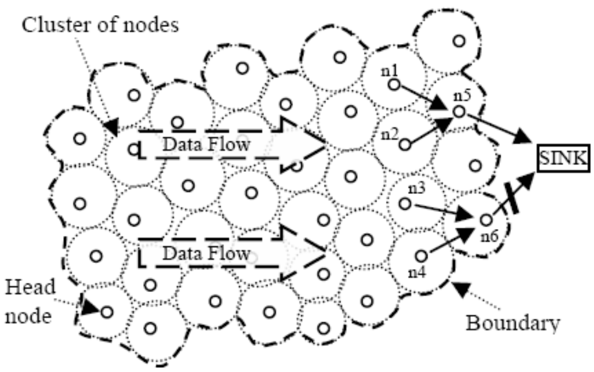

Figure 1. Sensor field with a static sink

B. Network model

We assume that the wireless sensor nodes are densely deployed in a remote field. Nodes will sense their environment and report readings to a sink in constant time intervals *t*. We consider the following properties about the network,

(i) nodes are grouped into small clusters and each cluster has a head node,

(ii) the head node is responsible for data gathering from the client node,

(iii) the head node will also perform the duty of a routing node by forwarding collected data towards the sink,

(iv) head nodes manage client nodes in the clusters by assigning them awake or sleep status depending on the node density,

(v) data collected by the sensor nodes is of diverse nature,

(vi) nodes will fail only when they run out of energy[17].

IV. IN-NETWORK STORAGE MODEL

This section reviews the in-network storage model that was developed to achieve data persistency in WSNs. The in-network storage model neither removes nor avoids congestion from happening, but it ensures data persistence under congestion and localizes its effects.

The in-network storage model is based on a clustered sensor field, where the cluster head node is responsible for energy efficient resource utilization and data routing towards the sink. It has been observed that under dense deployment of the sensor nodes only a subset of the nodes is needed to achieve complete coverage of the sensor field. Therefore, redundant sensor nodes are set to “sleep mode” by the cluster head nodes. This helps to increase the lifetime of the WSN and to avoid congestion by reducing the amount of data flowing along the routing paths towards the sink. The basic idea of the in-network storage is to utilize the redundant nodes (sleeping nodes) located in the vicinity of routing nodes (head node) as data buffers to avoid data loss from congestion in WSNs.

In order to better understand the idea, consider Figure 2(a) which shows a detailed view of a section of the sensor field shown in Figure 1, and Figure 2(b) which presents a detailed view of a cluster of nodes. It can be seen from Figure 2 that the nodes in a cluster are divided into two groups. One is the group of active sensor nodes which collect data from the field and the other is the group of sleeping sensor nodes. Since the head node is managing all the sensor nodes in a cluster, it maintains a list of all the cluster member nodes along with their current status as shown in Figure 2(b).

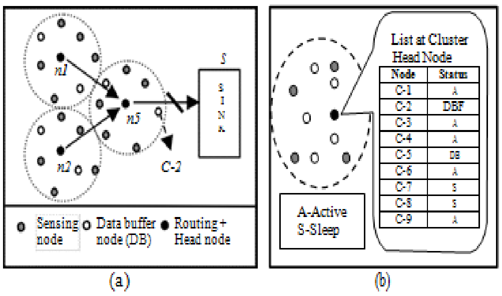

Figure 2. Clustered sensor field with data congestion at node N

Assume that the routing node n5 in Figure 2(a) fails to forward the collected data to the sink because of a temporary out-of-sight problem or because the sink is busy collecting data from other neighboring nodes. As a result, congestion starts to build at node n5. In order to avoid data loss and to localize the effect of congestion in the vicinity of the node where congestion has occurred, node n5 (which is also cluster head node) utilizes the in- network storage model and consults the list of client nodes shown in Figure 2(b). This list of neighbors provides information about the sensor nodes that can be used as data buffers. When the buffer at node n5 reaches a certain threshold limit, then n5 selects a buffer node (e.g., C-5 shown Figure 2(b)) and starts to redirect the arriving data from n1 and n2 to the data buffer node. When a data buffer node becomes full to its capacity then it sends a BUFFER FULL message to the cluster head node. Then the head node marks this node as DBF and selects another sleeping node as data buffer. As a result, data loss can be avoided and the affect of congestion remains localized. Later on, when the forward link gets clear, the data can be retrieved from the buffer nodes and forwarded towards the sink by n5.

V.DSCCP ROUTING PROTOCOL

To address the problems of congestion and energy efficiency in WSNs, we present the dynamic sink based congestion control routing protocol (DSCCP).

DSCCP is based on mobility of the sink along a fixed trajectory in the WSN. Data collector nodes are created utilizing the in-network storage model along the mobility trajectory of the sink; each MS is managed by the data collector node (Dc). The main responsibility of a data collector node is to receive and store the collected data from the sensor field to the mini- sink. The dynamic sink periodically visits each mini-sink in the sensor field for data retrieval. Thus data collector nodes in our scheme act as temporary storage devices that are filled by the data from the sensor node and flushed by the sink.

Now we will answer the following questions: What should be the trajectory of the sink? How can a routing node decides to which data collector node it should forward the data? How can a routing node decide to which mini-sink it should forward the data?

The DSCCP protocol does not impose any restriction on the shape of the mobility trajectory of the sink. However, it is known from [10, 11] that the most energy efficient routing is only possible if the mobility path of the sink is along the periphery of the sensor field. Therefore, without loss of generality, we select the periphery of the sensor field as the mobility trajectory of the sink.

How data collector nodes are created? During its first trip along the periphery of the sensor field the sink marks a subset of the nodes that it encounters as data collector nodes. These data collector nodes will perform two tasks: (i) set up a mini-sink utilizing in-network storage model, and (ii) inform the sensor nodes about the newly created mini-sink by broadcasting a message. The criterion for the selection of data collector nodes is based on distance measurement explained in the following,

The sink starts its mobility along the periphery of the sensor field from an arbitrary node located at the periphery of the sensor field called start node. If the start node is also a cluster head node then the sink assigns it the status of data collector node (Dc-1). Otherwise, the sink queries the start node about its cluster head node. On retrieval of the required information, the sink assigns the status of data collector node (Dc-1) to the obtained cluster head node. Now the sink starts its mobility along the periphery of the WSN The sink selects the second data collector node Dc-2 that is located at least h hops away from Dc-1 and is also the cluster head node. Similarly, the third data collector node Dc-3 is located at least h hops away from Dc-2, and so on. By the time the sink completes its first trip along the periphery of the sensor field a subset of the sensor nodes positioned along its mobility trajectory will have been converted into data collector nodes as shown in Figure 3.

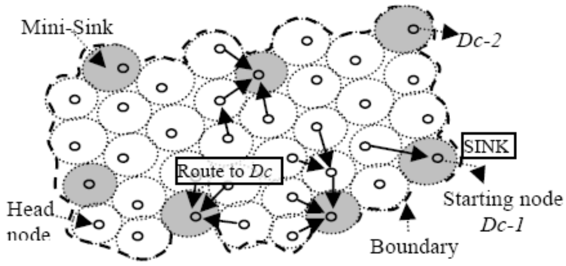

Fig 3. Sink following a fixed path around the sensor field

How are mini-sinks created? How can a routing node decide to which mini-sink it should forward the data? As mentioned before, when a node is assigned the status of data collector node by the sink then it broadcasts a message to inform the sensor nodes about the newly created mini-sink. The message contains two fields: the ID of the data collector node and the hop count that is initialized with 1. Each sensor node receiving this message performs the following check. If the available routing path to a data collector node is shorter than the newly reported route then discard the message; else update the previously stored route with the newly reported route. Increment the hop count by 1 in the received message and forward it. Thus, by the time the sink completes its first trip along the periphery of the WSN each node knows a shortest possible route to one of the data collector nodes as shown in Figure 4.

Each sensor node starts to broadcast the collected data to the nearest data collector node that receives and stores the data in one of the buffer nodes. The dynamic sink stops at each mini-sink and requests data transfer from the data collector node. The data collector node first of all reports the total number of bytes that it wants to transfer to the sink and then starts the data transfer. The halting time of the dynamic sink at a mini-sink is determined by the amount of data that is to be transferred from the mini-sink to the dynamic sink. This saves us from keeping track of the position of the sink that is required in many existing dynamic sink based routing protocols to avoid data loss.

Application of the DSCCP protocol to a sensor field results in an increased lifetime of the WSN because data from each node has to travel only a minimal number of hops to reach the closest mini-sink from where it is collected by the dynamic sink. Also, congestion and data losses can successfully be avoided because of the creation of multiple collection points instead of one static sink.

VI. SIMULATION BASED EVALUATION

This section presents a simulation based evaluation of the DSCCP routing protocol. We used the NS2 simulation tool to analyze the performance of the DSCCP protocol for congestion avoidance and energy efficient utilization of the sensor field.

NS (Network Simulator) is an object-oriented, discrete event driven network simulator developed at UC Berkeley. The ns simulator is used in large number of applications. We can show the behavior of wired, wireless, adhoc networks by using NS simulator.

Since the DSCCP routing protocol has introduced the idea of using a dynamic sink and an in-network storage model based mini-sinks instead of a static sink for congestion avoidance and energy preservation in a WSN. Therefore in this section we analyze and compare the benefit of using the DSCCP routing protocol over a static sink based scenario.

The radius of the sensor field is 300 meters and the communication range of each sensor node is set to 50 meters. All the sensor nodes are equipped with a limited battery of 0.5 joules. It is assumed that each message exchange (send/receive) costs a sensor node 50 nano joules of energy per bit .

Two networks are created with 24 nodes deployed randomly. In first network, single sink is placed centrally whereas in second network four mini sinks are created at the periphery of the field. The other simulation parameters such as routing protocol, simulation time, propagation model, radio range etc., are same for both networks.

Here performance is analyzed by means of energy and packet delivery ratio. In the first graph, we evaluate the number of lost packets due to congestion for two scenario dynamic sink and static sink. The number of packet loss in two scenario for different numbers of events is presented.

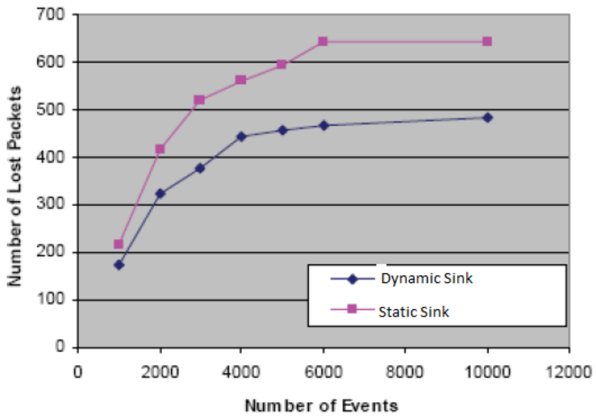

Figure 4. Number of Lost packets versus number of Events

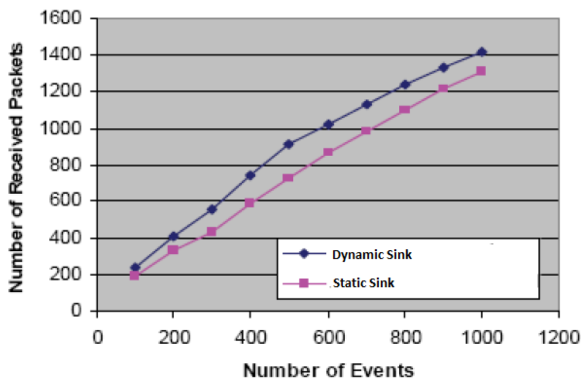

Figure 5. Number of Received packets verses number of Events

Number of packets received to sink in this algorithm is always more than static sink based protocol. It manages congestion; it tries to reduce packet loss in nodes which are located in paths between nodes and the sink. Lower packet loss leads to more success in delivering packets to sink.

Figure 6 presents the energy utilization of each routing node when the DSCCP routing protocol and a static sink based routing schemes were applied to the WSN, respectively. Analysis of Figure 6 shows that with the use of the DSCCP routing protocol the lifetime of the WSN becomes almost twice as compared to that of static sink.

Another drawback of a static sink based routing scheme is that nodes located in the vicinity of the sink dissipate their energy much earlier than the rest of the sensor field. As a result, the link between the sink and the sensor field gets broken and the deployed setup becomes useless even if the majority of the sensor nodes are still active. While the DSCCP routing protocol successfully avoids such scenarios by utilizing sink mobility.

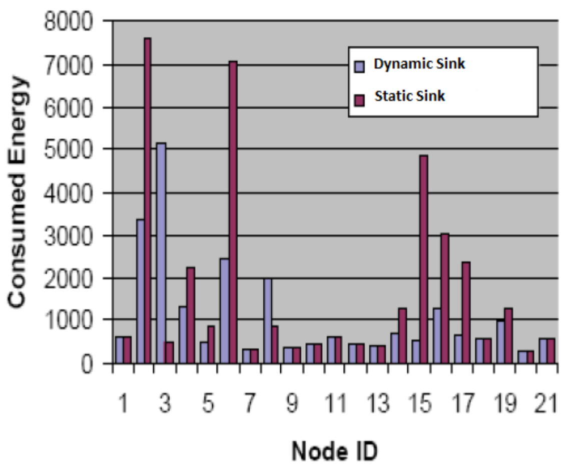

Figure 6 .Consumed Energy in Nodes

VII. FUTURE WORK

We used the parameters energy and packet loss for performance analysis. We will do with some other parameters to boost up our algorithm in future.

VIII. CONCLUSION

This paper presented an in-network storage model based routing scheme that exploits dense sensor node deployment and the mobility of the sink in a WSN to set up congestion free and energy efficient routing paths, leading to increased lifetime of the WSN. Since in the given model the sink performs the data collection by moving from one mini-sink to another, the presented model is best suited for delay tolerant sensor networks.

REFERENCES

[1] Majid I. Khan, Wilfried N. Gansterer, Guenter Haring, “In- network storage model for data persistence under congestion in wireless sensor network”. In Proceedings of the First International Conference on Complex, Intelligent and Software Intensive Systems (CISIS'07), 2007, pp. 221-228.

[2] Shigang Chen, Na Yang, “Congestion avoidance based on lightweight buffer management in sensor networks,” IEEETransactions on Parallel and Distributed Systems, Sept2006. vol. 17, no. 9, pp. 934-946.

[3] Fan, K., Liu, S., and Sinha, P. “Scalable data aggregation for dynamic events in sensor networks”. In Proceedings ofthe 4th international Conference on Embedded Networked Sensor Systems (Boulder, Colorado, USA, October 31 -November 03, 2006). SenSys '06. ACM Press, New York, NY, pp. 181-194.

[4] Sharaf, M. A., Beaver, J., Labrinidis, A., and Chrysanthis, P. K. “TiNA: a scheme for temporal coherency-aware in-network aggregation”. In Proceedings of the 3rd ACMinternational Workshop on Data Engineering For Wireless and Mobile Access. San Diego, CA, USA, September 19, 2003. MobiDe '03. ACM Press, New York, NY, pp. 69-76.

[5] Laura Galluccio, Andrew T. Campbell, Sergio Palazzo, “Concert: aggregation-based congestion control for sEnsoR networks”. In Proceedings of the 3rd international conference on Embedded networked sensor systems 2005, Conference On Embedded Networked Sensor Systems, San Diego, California, USA, pp. 274-275.

[6] Barton, R.J. Zheng, R. “Order-Optimal Data Aggregation in Wireless Sensor Networks Using Cooperative Time- Reversal Communication”. 40th Annual Conference on Information Sciences and Systems, 22-24 March 2006, Princeton, NJ, pp. 1050-1055.

[7] Gao, J., Guibas, L., Milosavljevic, N., and Hershberger, J. “Sparse data aggregation in sensor networks”. InProceedings of the 6th international Conference oninformation Processing in Sensor Networks (Cambridge, Massachusetts, USA, April 25 - 27, 2007). IPSN '07. ACM Press, New York, NY, pp. 430-439.

[8] Alberto Cerpa and Deborah Estrin. “ASCENT: AdaptiveSelf-Configuring sEnsor Networks Topologies”. In the IEEE Transactions on Mobile Computing Special Issue on Mission-Oriented Sensor Networks, July- September 2004, vol. 3, no. 3, pp. 272-285.

[9] Zhu, J., Hung, K., and Bensaou, B. “Tradeoff between network lifetime and fair rate allocation in wireless sensornetworks with multi-path routing”. In Proceedings of the9th ACM international Symposium on Modeling Analysis and Simulation of Wireless and Mobile Systems (Terromolinos, Spain, October 02 - 06, 2006). MSWiM'06. ACM Press, New York, NY, pp. 301-308.

[10] Wan, C., Eisenman, S. B., and Campbell, A. T. “CODA: congestion detection and avoidance in sensor networks”. In Proceedings of the 1st international Conference on Embedded Networked Sensor Systems (Los Angeles, California, USA, November 05 - 07, 2003). SenSys '03. ACM Press, New York, NY, pp. 266-279.

[11] Akan, Ö. B. and Akyildiz, I. F. “Event-to-sink reliable transport in wireless sensor networks.” IEEE/ACM Trans. Network 13, 5(Oct. 2005), pp. 1003-1016.

[12] Wang, C. Li, B. Sohraby, K. Daneshmand, M. Hu, Y., "Upstream congestion control in wireless sensor networksthrough cross-layer optimization," IEEE journal onselected areas in communications, vol. 25, no.4, 2007.

[13] Chatzigiannakis, I., Kinalis, A., and Nikoletseas, S. “Sink mobility protocols for data collection in wireless sensornetworks.” In Proceedings of the international Workshopon Mobility Management and Wireless Access(Terromolinos, Spain, October 02 - 02, 2006). MobiWac'06. ACM Press, New York, NY, 52-59.

[14] J. Luo and J.-P. Hubaux. “Joint mobility and routing for lifetime elongation in wireless sensor networks.” InProceedings of the 24th Annual Conference of the IEEE Communications Societies (INFOCOM’05), FL, USA.

[15] J. Luo, J. Panchard, M. Piorkowski, M. Grossglauser, andJ.-P. Hubaux. MobiRoute: Routing towards a

Mobile Sink for Improving Lifetime in Sensor Networks. InInternational Conference on Distributed Computing in Sensor Systems (DCOSS'06), San Francisco, CA, USA.

[16] Prem Prakash Jayaraman, Arkady Zaslavsky, JerkerDelsing. "Sensor data collection using heterogeneous mobile devices." ICPS'07: IEEE International Conference on Pervasive Services July 15-20, 2007, Istanbul, Turkey.

[17] Sun, K., Peng, P., Ning, P., and Wang, C. "SecureDistributed Cluster Formation in Wireless SensorNetworks". In Proceedings of the 22nd Annual Computer Security Applications Conference (December 11-15, 2006). ACSAC. IEEE Comp Society, WashingtonDC,pp.131-140.

[18] He, Y., Zhang, Y., Ji, Y., and Shen, X. "A new energy efficient approach by separating data collection and datareport in wireless sensor networks". In Proceeding of the2006 international Conference on Communications and Mobile Computing (Vancouver, British Columbia, Canada, July 03 - 06, 2006). IWCMC '06. ACM Press, New York, NY, 1165-117