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Efficient Multipath Routing Tree Based Energy Minimization in Wireless Sensor Networks

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Abstract: Wireless sensor networks consist of some nodes that have limited processing capability, small memory and low energy source. These nodes are deployed randomly and often densely in the environment. In monitoring applications, sensor nodes sense data from the environment periodically and then transmit them to a base station which is called sink node. Thereby, data transmission consumes node's energy based on transmission distance. In most wireless sensor networks, the energy source of the node is limited and can not be minimized. Here, researchers have proposed the Efficient Multipath Routing Tree based Energy Minimization (EMRTEM) for minimizing the energy consumption in WSNs. It consists of three phases. These phases are the Tree selection phase, multipath routing tree determination and Minimizing Average Energy Consumption Model. The proposed scheme which attains the balance route minimum cost, route redundancy and energy efficiency in WSNs. By simulation results, the proposed EMRTEM achieves better data delivery ratio, improved network lifetime, less end to delay and energy consumption in terms of mobility, time, throughput, packet interval and number of nodes than the existing scheme ADAPT.

Key words: WSN, EMRTEM, multipath routing, optimum energy path, network lifetime, end to end delay, energy consumption, throughput and delivery ratio

INTRODUCTION

Wireless Sensor Networks (WSNs): Wireless Sensor Networks (WSN's) have attracted a great deal of research attention due to their wide-range of potential applications. Applications of WSN include battlefield surveillance, biological detection, medical monitoring, home security and inventory tracking. This type of network consists of a group of nodes and each node has limited battery power.

There may be many possible routes available between two nodes over which data can flow. Assume that each node generated some information and this information needs to be delivered to a destination node. Any node in the network can easily transmit their data packet to a distance node if it has enough battery power. If any node is far from its neighbour node then large amount of transmission energy is required to transmit the data to distance node.

After every transmission, remaining energy of this node decreases and some a counts of data transmission this node will be eliminated from the network because of empty battery power and in similar situation there will be a condition that no node is available for data transmission and overall lifetime of network will decreases.

Design goals of Wireless Sensor Networks (WSNs): Based on the application, different architecture, goals and constraints have been considered for WSNs. As discussed by Chiwewe and Hancke (2012), the following design goals are given.

Energy efficiency: Sensor network is normally deployed in unattended environment and it is distributed in nature. With few of WSN application cases, its deployment is once and not be able to replace or monitor the nodes physically on regular basis, especially in the case of Military battle field and chemical industrial deployment. As sensor node is cost effective and less in size with very low computational and memory capability power along with its battery life, sensor node's life depends upon its battery. Most of the times as these nodes remain unattended and normally draining their batteries continuous on regular basis, it is too hard to replace these

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batteries. So, energy is the most important constraint for the WSN type's networks. In last decade a significant amount of research has been done in the field of WSN and most of the part was focusing about the energy concern. There are couple of different reasons for energy loss with the node including, un efficient routing, mixed traffic, run time change network topology, mobility, deployment of the nodes and distance from the sink. Dealing with real-time requires all the nodes live and in contact with the sink if any node from the loop is just died just because of energy reason then the complete real-time communication will be dropped. Past recent research shows more attention on this critical issue and about designing different energy efficient routing protocols with different energy efficient mechanism but even it still requires more significant attention.

Node deployment: Topology or node deployment is also a one reason to drain node energy of sensor network. Topology concept is entirely different from existing ad hoc networks with sensor network it is not possible to follow any existing standard of topology because this special characteristic network have very unique infrastructure. Topologies normally varies from application to application with sensor network but even each topology is changeable at run time as with sensor network connection path with sink established several times (when any active node dies resulting of power drain) again and again to avoid that up to a certain limit, densely nodes network deployment is suggested. In this situation network topology also changes it status randomly in all situations it affects routing activities.

Energy consumption without losing accuracy: Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime. In a multihop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

Fault tolerance: Fault tolerance can be defined as the ability of sensor network to sustain network functionalities in case of any un desired conditions occurred and may be few nodes not working properly. Sensor nodes may fail or be blocked due to lack of power have physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. This is the reliability or fault tolerance issue.

Quality of service: In some applications, data should be delivered within a certain period of time from the moment it is sensed otherwise the data will be useless. Therefore, bounded latency for data delivery is another condition for time-constrained applications. However, in many applications, conservation of energy which is directly related to network lifetime is considered relatively more important than the quality of data sent. As the energy gets depleted, the network may be required to reduce the quality of the results in order to reduce the energy dissipation in the nodes and hence, lengthen the total network lifetime. Hence, energy-aware routing protocols are required to capture this requirement.

Data aggregation/fusion: Data aggregation is the primary concern with sensor network as the infrastructure, topology energy source and operations are different than ad hoc networks. Nodes are normally deployed in densely way with defining any proper topology some of the time. All nodes broadcast the message to its neighboring nodes for tracing the right path to connect with sink. In this way, numbers of clusters build during the path tracing and each cluster trying to connect with sink, this way connection path becomes more than one to the sink. Data aggregation is necessary here otherwise there are chances to send multiple data through multiple path to the sink and again it becomes a great source of energy loss. Data aggregation possibly can be done by using one the most common techniques like suppression, maxima, average or minima. This technique also called as fusion technique which is time considering technique through which all nodes normally wait for a particular time to receive all the data from their neighbor nodes and then finally forward it to the sink.

Connectivity: Connectivity with sensor network is different in nature from wireless ad hoc network, the reason for it is the dense deployment of sensor nodes hence a maximum number of neighbor nodes are available around the node. The second reason is the broadcasting of messages for attempting the connection initially in all directions. Losing of connectivity is also a common fashion with sensor network because of power constraints and that connection losing activity affect routing activity.

Scalability: Scalability is highly required especially in sensor networks where there is no limit for nodes deployment. Normally nodes are deployed very densely method and the number of the nodes goes up to million in some special cases. Routing protocols should be designed in effective way that they should work with scalability with such a huge network.

LITERATURE REVIEW

Frey *et al.* (2008) proposed new multicast generalization with fast recovery mechanism to achieve a delivery of multicast message to improve energy efficiency and path to the destination messages. The proposed solution is based on Minimum Spanning Tree (MST) which requires information only on single hop neighbors. A message replication occurs when the MST spanning the current node and the set of destinations has multiple edges originated at the current node. Destinations spanned by these edges are grouped together and for each of these subsets the best neighbor is selected as the next hop. This selection is based on a cost over progress metric where the progress is approximated by subtracting the weight of the MST over a given neighbor and the subset of destinations to the weight of the MST over the current node and the subset of destinations.

Johansson *et al.* (2008) proposed a Localized Area-Spanning Tree (LAST) for wireless short-range sensor networks which comprises of selecting child nodes and target points. They consider a problem of building a forwarding tree for multicast and convergecast traffic in short-range wireless sensor networks. Interference awareness and energy efficiency are the major design objectives for WSN protocols in order to maximize the network lifetime. When creating the tree, the protocol jointly optimized the energy cost and the interference imposed by the structure.

Santhi and Venkatachalapathy (2012) explored a technique called an ant based multiple cluster tree routing for 802.15.4 sensor networks. In this approach, a node was randomly selected among the available nodes as the PAN coordinator. The PAN coordinator utilized the swarm intelligence based ant colony optimization technique to select the nodes within the transmission range for cluster formation which corresponds to the trees. In order to achieve the diverse topologies of different trees, a proper parent is selected based on the link quality index. Further, each node selects the tree with minimum cost as the main routing tree ADAPTable to fault free multimedia traffic. The QoS based routing was utilized for cluster based multi tree topology using ant agents.

Khayat (2012) developed a source-specific multicast protocol for wireless mesh network which has many application, in multimedia, radio and TV multicasting and distance learning. They have used core-based approach to construct Minimum Cost Tree (MCT) among member nodes and optimized this tree for multiple metrics by applying ant colony optimization metaphor. In this research, they have used weighted sum of two network metric; delay and number of non-forwarding node on new paths to calculate reinforcement value but researchers can extend these metric to include bandwidth, jitter or even security metrics.

Incel *et al.* (2012) constructed degree-constrained spanning trees and capacitated minimal spanning trees and show significant improvement in scheduling performance over different deployment densities. They addressed the fundamental limitations due to interference and half-duplex transceivers on the nodes and explored techniques to overcome the same. They found that while transmission power control helps in reducing the schedule length, multiple channels are more effective. They also observed that node-based (RBCA) and link-based (JFTSS) channel assignment schemes are more efficient in terms of eliminating interference as compared to assigning different channels on different branches of the tree (TMCP).

Ciciriello *et al.* (2007) proposed a scheme for routing data effficiently from multiple sources to multiple sinks. They first study the problem from a theoretical stand point by mapping it to the multi-commodity network design problem. This allows them to derive an optimal solution that albeit based on global knowledge and therefore impractical, provides us with a theoretical lower bound to evaluate decentralized solutions against. Then, researchers propose the own decentralized scheme, based on a periodic ADAPTation of the message routes aimed at minimizing the number of network links exploited. The resulting protocol is simple and easily implementable on WSN devices.

Capella *et al.* (2011) explored a proposed architecture with a new routing protocol to provide better scalability, reliability, deployment properties and energy minimization. They have shown the real feasibility of an ultra-low energy, long life cluster-based WSN applied to environments such as heritage monitoring contexts where it is necessary to guarantee long life and no operator intervention. Novel node sensors designed for monitoring wooden masterpieces and historical buildings, in order to perform an early detection of pests have been presented. These sensors have shown very satisfactory results in detection of termites and low power consumption.

Di Francesco *et al.* (2011) introduced an ADAPTive and cross-layer framework for reliable and energy-efficient data collection in WSNs based on the IEEE 802.15.4/ZigBee standards. The framework involves an energy-aware ADAPTation module that captures the application's reliability requirements and autonomously configures the MAC layer based on the network topology and the traffic conditions in order to minimize the power consumption. Specifically, researchers propose a low-complexity distributed algorithm called Adaptive Access Parameters Tuning (ADAPT) that can effectively meet the application-specific reliability under a wide range of operating conditions for both single-hop and multi-hop networking scenarios.

Watfa *et al.* (2008) developed a energy efficient approach to query processing by implementing new optimization techniques applied to in-network aggregation to ensure efficiency, competence and effectiveness. They have showed how aggregate queries are efficiently executed over wireless sensor networks in a distributed manner. They have proved that the in-network distributed approach performed better in terms of energy reduction and network lifetime than the naive and simple TinyDB approaches.

Yu *et al.* (2011) introduced the a knowledge-based inference approach using fuzzy Petri nets which is employed to select cluster heads and then the fuzzy reasoning mechanism is used to compute the degree of reliability in the route sprouting tree from cluster heads to the base station. Finally, the most reliable route among the cluster heads can be constructed. The algorithm is not only balanced the energy load of each node but also provided the global reliability for the whole network. The proposed algorithm effectively prolonged the network lifetime and reduces the energy consumption.

Dong *et al.* (2011) proposed energy efficient routing algorithm for WSN. In this algorithm, they have divided the sensor nodes into several scheduling sets and let them work alternatively. In this way, the sensors do not have to be active all the time which saves a lot of energy.

When choosing the next sensor to forward the information to, they considered both the distance from the base station to the sensor and its current energy level. So, the network power consumption will be distributed among the sensors. When the network does not have enough sensors that have sufficient energy to run, it generates new scheduling sets automatically.

Sahoo and Acharya (2011) proposed the energy efficient routing protocol in Wireless Sensor Network (WSN). Routing is a serious issue in WSN due to the use of computationally-constrained and resource constrained micro-sensors. Once the sensor nodes are deployed replacement is not feasible. Hence, energy efficiency is a key design issue to improve the life span of the network.

Since, the network consists of low-cost nodes with limited battery power, it is a challenging task to design an efficient routing scheme that can offer good performance in energy efficiency and long network lifetimes.

De Dieu *et al.* (2012) explored a new energy efficient secure path algorithm for wireless sensor networks to ensure the secure sensed data in a balanced energy network backbone. The proposed algorithm overcomes the limitations caused by the symmetric cryptographic algorithms for securing data in sensor networks. They have achieved the authenticity and integrity on the actual sensed data within the energy efficient infrastructure. The key contribution is to ensure secure transmission which results prolonging network lifetime via a suboptimal energy-efficient and Balancing Routing algorithm.

IMPLEMENTATION OF PROPOSED ALGORITHM

In the proposed algorithm Efficient Multipath Routing Tree based Energy Minimization (EMRTEM) in WSNs, there are 8 steps to achieve the minimal energy consumption through multipath routing tree. Here researchers added parent node, route node selection, finding multipath routing tree for message length queries and minimizing the average energy consumption. The alternative recovery approach is included in the proposed algorithm which offers the route redundancy to eliminate the need for route repair like node and link failure sessions (Fig. 1).

Step 1: Node which is having highest remaining energy is selected as a root node.

Step 2: Root node broadcasts the route control and data messages to neighbor nodes. These messages contain root ID.

Step 3: Neighbor nodes receive the messages and choose the parent node as its root node.

Step 4: If node k having child nodes which is lesser than the maximum child nodes (k.child node < n.max child node), the node k calculates the path energy and broadcast the message to all neighbors.

Step 5:

If node k sender's path energy average > parent's path energy average
THEN
Node k selects the sender as its new parent with minimum cost tree
ELSE
Node k does not select its parent with minimum cost tree

Minimum cost tree is defined as the tree in which all accumulative node cost of all nodes between the destination node

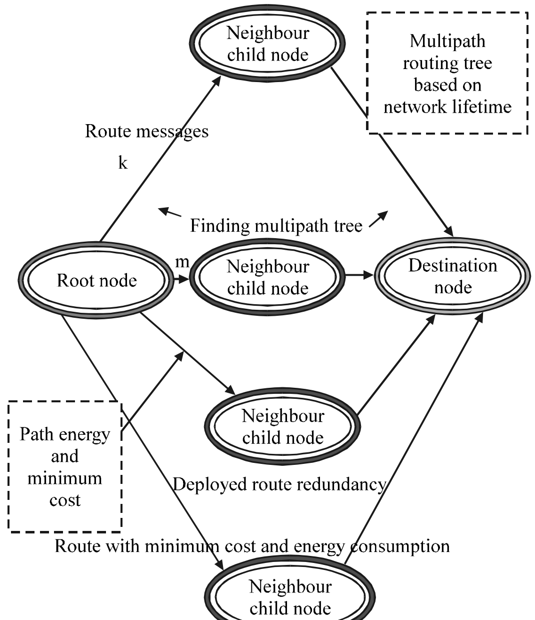

Fig. 1: Process flow of proposed approach

Step 6 (Determination of multipath routing tree): In this step, researchers are finding the multipath routing tree for longer message length aggregate queries. Here, researchers use the concept of minimum spanning tree approach to find multiple trees. Here, the transmission range of each sensor is identical. Consider the sensor network G consists of sensor nodes with initial energy IE at each node. It consists of potential number of stages M:

- Suppose the tree is used at stage A, the network lifetime is τ_A where: $\tau_A \leftarrow$MDST (G, IE/M)
- For i←B to M do, $\tau_i \leftarrow 0$ (Initial duration of stage i)
- For each v∈V do (Small child nodes belongs to Maximum Child nodes) compute the residual energy ΔE_i (v)
- $\tau^A_i \leftarrow$NMDST (G, IE/M+ΔE_i (v)) where, τ^A_i is the network lifetime developed by degree spanning tree using NMDST algorithm
- If $\tau_A < \tau^A_i$ (checking the degree constrained tree will result in a longer duration of stage i) then:

$$\tau_i \leftarrow \tau_i^A$$

else

$$\tau_i \leftarrow \tau_A$$

end if

end for

The network life time is delivered by the proposed algorithm is longer than but at least as long as one delivered by the algorithm for finding the multi routing tree.

Step 7 (Minimizing the energy consumption): Node Energy consumption (E_N) measures the average energy dissipated by the node in order to transmit a data packet from the source to the sink. It is calculated as:

$$E_N = \frac{\sum_{p=1}^{M}(e_{p,init} - e_{p,res})}{M\sum_{q=1}^{D} dataN_q}$$

Where:

M = The number of nodes

$e_{p,\,init}$ and $e_{p,\,res}$ = The initial energy and residual energy levels of node p, respectively

D = The number of destination nodes and data N_q is the number of data packets received by destination q

Let p_0, q_0 denotes the coordinates of the access point in sensor networks and p_i, q_i be the coordinates of the ith sensor nodes. The distance between the access point and the ith sensor node is given by:

$$d_i = \sqrt{(p_0 - p_i)^2 + (q_0 - q_i)^2}$$

If F is the set of sensor nodes, the energy consumed by the active sensor nodes:

$$E_{ti} = E_0 \sum_{i \in A} d_i^{\beta}$$

$$(p_0, q_0) = \text{avg} \min_{p,q} E_t$$

Where:

E_{ti} = The energy used by its sensor node

E_0 = The energy needed to transmit one unit of data

The average energy is minimized at $\partial E/\partial p$ at $p = p_0$ and $\partial E/\partial q$ at $q = q_0 = 0$ where the condition executes at:

$$\max_{i \in A} E_{ti} \rightarrow \min$$

Step 8 (Alternative route recovery phase): The node k replaces its old main tree with its alternative tree in the multiple routing tree to avoid node and link failures. The minimum cost and route redundancy is deployed to eliminate the need for route breakages.

PERFORMANCE ANALYSIS

Researchers use Network Simulator (NS3) to simulate the proposed algorithm. Network Simulator-3 (NS3) is used in this research for simulation. NS2 is one of the best simulation tools available for wireless sensor networks. Researchers can easily implement the designed protocols either by using the otcl coding or by writing the C++ Program. In either way, the tool helps to prove the theory analytically.

In the simulation, 250 mobile nodes move in a 1600×1600 m^2 region for 60 sec simulation time. All nodes have the same transmission range of 250 m. The simulation settings and parameters are summarized in Table 1.

Performance metrics: Researchers evaluate mainly the performance according to the following metrics.

End to end delay: The end to end delay is averaged over all surviving data packets from the sources to the destinations.

Packet delivery ratio: It is the ratio of packet received to packet sent successfully. This metric indicates both the loss ratio of the routing protocol and the effort required to receive data. In the ideal scenario the ratio should be equal to 1. If the ratio falls significantly below the ideal ratio, then it could be an indication of some faults in the protocol design. However, if the ratio is higher than the ideal ratio then it is an indication that the sink receives a data packet more than once. It is not desirable because reception of duplicate packets consumes the network's valuable resources. The relative number of duplicates received by the sink is also important because based on that number the sink can possibly take an appropriate action to reduce the redundancy.

Throughput: It is defined as the number of packets received successfully. Researchers compare the Proposed algorithm (EMRTEM) with ADAPT (Mario, 2011) in presence of energy consumption. Figure 2 shows the results of average residual energy for varying the time from 10-50. From the results, researchers can see that EMRTEM scheme has minimal energy consumption than the ADAPT scheme. Figure 3 shows the results of average residual energy for varying the packet interval from 10-50. From the results, researchers can see that EMRTEM scheme has minimal energy consumption than the ADAPT scheme. Figure 4 presents the network lifetime comparison for EMRTEM and ADAPT. It is clearly seen that number of epochs consumed by EMRTEM is high compared to ADAPT. Figure 5 presents the comparison of data delivery ratio. It is clearly shown that the data delivery ratio of EMRTEM is higher than the ADAPT scheme. Figure 6 shows the results of time vs. end to end delay. From the results, researchers can see that EMRTEM scheme has slightly lower delay than the ADAPT scheme because of authentication routines.

Table 1: Simulation settings and parameters of EMRTEM

Parameters	Values
No. of nodes	250
Area size	1600×1600
Mac	802.11
Radio range	250 m
Simulation time	60 sec
Traffic source	CBR
Packet size	512 bytes
Mobility model	Random way point
Transmitter amplifier	150 pJ/bit/m^2
Package rate	5 pkt sec^{-1}
Protocol	AODV

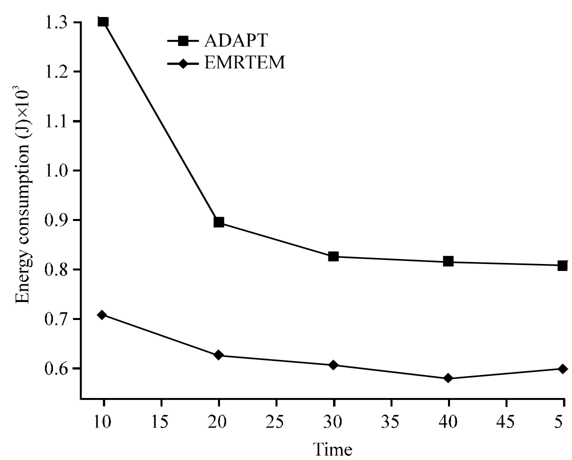

Fig. 2: Time vs. energy consumption

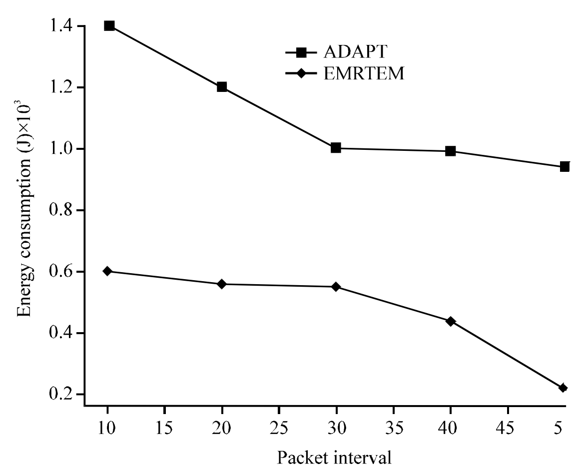

Fig. 3: Packet interval vs. energy consumption

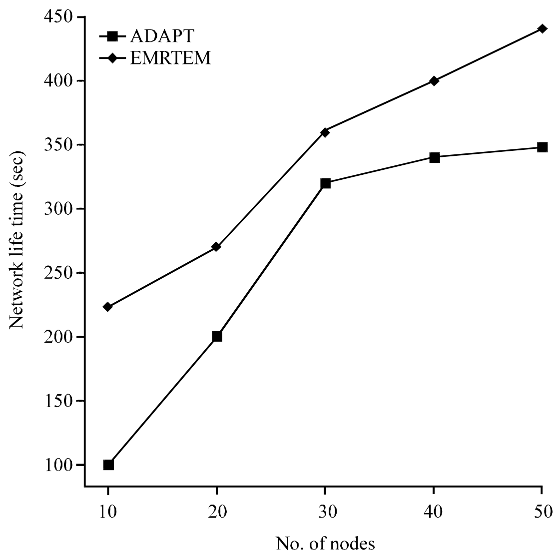

Fig. 4: Increasing the network lifetime

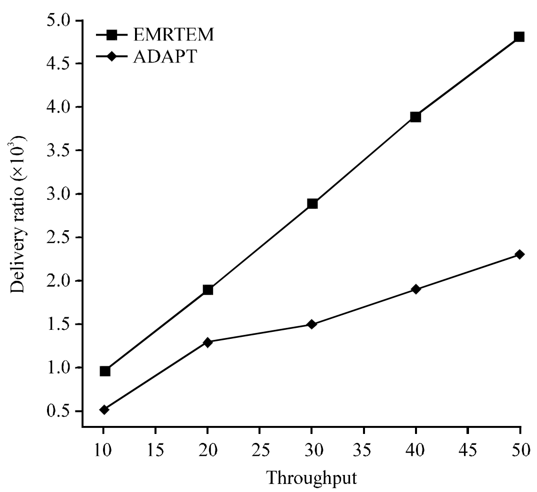

Fig. 5: Throughput vs. data delivery ratio

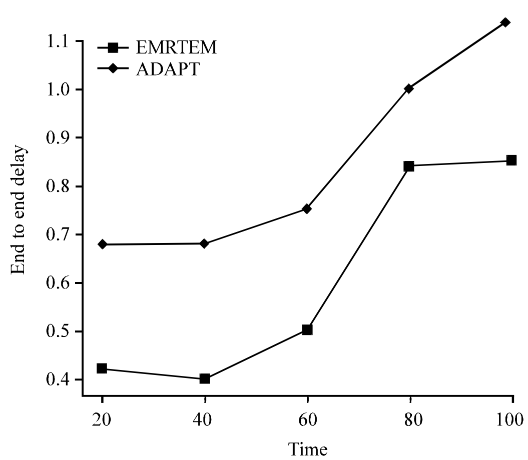

Fig. 6: Time vs. end to end delay

CONCLUSION

In WSNs, in this study, researchers have developed a New Multipath Routing Approach which attains Tree Selection Model, Determination of Multipath Routing Tree and Average Energy Consumption Model to make a correct balance between network life time, energy consumption and throughput, route redundancy, minimum cost to the sensor nodes. In the first phase of the scheme, Tree Selection Model is proposed. In second phase, construction of multipath routing tree is implemented. In third phase, average energy consumption is minimized. It uses following factors minimum cost, route redundancy to favour packet forwarding and reduce the effect of node and link failures by maintaining high residual energy consumption for each node. Researchers have demonstrated the node energy consumption of each node. By simulation results we have shown that the EMRTEM achieves good throughput, high network lifetime, low energy consumption, good delivery ratio while attaining low delay, energy consumption than the existing schemes ADAPT while varying the number of nodes, time, throughput and packet interval.

REFERENCES

Capella, J.V., A. Perles, A. Bonastre and J.J. Serrano, 2011. Historical building monitoring using an energy-efficient scalable wireless sensor network architecture. Sensors, 11: 10074-10093.

Chiwewe, T.M. and G.P. Hancke, 2012. A distributed topology control technique for low interference and energy efficiency in wireless sensor networks. IEEE Trans. Ind. Inform., 8: 11-19.

Ciciriello, P., L. Mottola and G.P. Picco, 2007. Efficient routing from multiple sources to multiple sinks in wireless sensor networks. Proceedings of the 4th European Conference on Wireless Sensor Networks, January 29-31, 2007, Delft, The Netherlands, pp: 34-50.

De Dieu, I.J., N. Assouma, M. Muhamad, W. Jin and S. Lee, 2012. Energy-efficient secure path algorithm for wireless sensor networks. Int. J. Distrib. Sensor Networks, Vol. 2012. 10.1155/2012/751784.

Di Francesco, M., G. Anastasi, M. Conti, S.K. Das and V. Neri, 2011. Reliability and energy-efficiency in IEEE 802.15.4/ZigBee sensor networks: An adaptive and cross-layer approach. IEEE J. Selected Areas Commun., 29: 1508-1524.

Dong, Y., H. Chang, Z. Zou and S. Tang, 2011. An energy conserving routing algorithm for wireless sensor networks. Int. J. Future Generation Commun. Networking, 4: 39-54.

Frey, H., F. Ingelrest and D. Simplot-Ryl, 2008. Localized minimum spanning tree based multicast routing with energy-efficient guaranteed delivery in Ad Hoc and sensor networks. Proceedings of the International Symposium on a World of Wireless, Mobile and Multimedia Networks, June 23-26, 2008, Newport Beach, CA, USA., pp: 1-8.

Incel, O.D., A. Ghosh, B. Krishnamachari and K. Chintalapudi, 2012. Fast data collection in tree-based wireless sensor networks. IEEE Trans. Mobile Comput., 11: 86-99.

Johansson, T., E. Osipov and L. Carr-Motyckova, 2008. Interference Aware Construction of Multi-and Convergecast Trees in Wireless Sensor Networks. In: Next Generation Teletraffic and Wired/Wireless Advanced Networking, Balandin, S., D. Moltchanov and Y. Koucheryavy (Eds.). Springer, USA., ISBN: 978-3-540-85499-9, pp: 72-87.

Khayat, M., 2012. ASSM: Agent based source specific multicast routing protocol for wireless mesh networks. Int. J. Inform. Electron. Eng., 2: 342-346.

Sahoo, S. and B.M. Acharya, 2011. Energy efficient routing protocol in wireless sensor network. Int. J. Eng. Sci. Technol., 3: 6084-6089.

Santhi, S.G. and K. Venkatachalapathy, 2012. Ant based multiple cluster tree routing for 802.15.4 sensor networks. Int. J. Comput. Appl., 48: 1-6.

Watfa, M., W. Daher and H. Al Azar, 2008. EEIA: Energy efficient indexed aggregation in smart wireless sensor networks. Word Acad. Sci. Eng. Technol., 3: 234-245.

Yu, Z., X. Fu, Y. Cai and M.C. Vuran, 2011. A reliable energy-efficient multi-level routing algorithm for wireless sensor networks using Fuzzy Petri Nets. Sensors, 11: 3381-3400.