Tree Based Energy Efficient and Congestion Aware Routing Protocol for Wireless Sensor Networks

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***Abstract*— Wireless Sensor Networks (WSNs) have inherent and unique characteristics. One of the most important issues is their energy constraint. Energy aware routing protocol is very important in WSN, but routing protocol which only considers energy has not efficient performance. Congestion management can affect routing protocol performance. Congestion occurrence in network nodes leads to increasing packet loss and energy consumption. Another parameter which affects routing protocol efficiency is performing fairness in nodes energy consumption. When fairness is not considered in routing process, network will be partitioned very soon and then the network performance will be decreased. In this paper a Hierarchical Tree based Energy efficient and Congestion aware Routing Protocol (HTECRP) is proposed. The proposed protocol is an energy efficient routing one which tries to manage congestion and perform fairness in network. Simulation results shown in this paper imply that the HTECRP has achieved its goals.**

Keywords-component; Congestion Aware Routing Protocol; Energy Efficiecy; Fairness; Tree base; Wireless Sensor Network

I. INTRODUCTION

Wireless Sensor Networks have been noticed and researched in recent years. These networks are composed of hundreds or thousands of sensor nodes which have many different types of sensors [1]. Using their sensors, nodes collect information about their environment such as light, temperature, humidity, motion and etc [2]. Sensor nodes should send their collected data to a determined node called Sink. The sink processes data and performs appropriate actions. Nodes using routing protocol determine a path for sending data to sink.

WSNs have inherent and unique characteristics compared with traditional networks [1, 2]. These networks have many limitations such as computing power, storage space, communication range and the most important of all, the energy. Nodes have limited primary energy sources and in most of applications they are not rechargeable [3]. Node's energy is consumed due to using sensors, processing information and communicating with other nodes. Communications are the main element in energy consumption. Routing protocol directly affects communications volume; therefore energy aware routing protocols are very effective in decreasing energy consumption [4].

Routing protocols which only consider energy as their parameter are not efficient. In addition to energy efficiency, using other parameters makes routing protocol more efficient. For different applications, different parameters should be considered. One of the most important parameter is congestion management. Congestion occurrence leads to increasing packet loss and network energy consumption. Congestion occurs for different reasons in networks. One of the main reasons is storage space constraint in relay network nodes. When a node receives packets more than its capacity, congestion is occurred, and then many packets will be dropped. Congestion occurred for almost similar reasons in wireless sensor networks. For example, when many nodes simultaneously decide to send packet using a shared medium, congestion will be occurred. Two main methods exist to manage congestion. Chen et al. [5] 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.

Efficiency in energy consumption is essential for routing protocol in WSNs. Different routing strategies such as multi path, geographical, flat and hierarchical exist for WSNs. Each mentioned strategies have own its unique characteristics. One of the considerable parameters, that affects the network energy consumption is fairness in nodes energy consumption. To perform fairness, nodes' energy should be used equally. If one part of a network is used more than other parts, its energy will drop sooner than others and then the network will be partitioned. If a network is partitioned, its energy consumption increases severely. Using different paths to send data to sink makes the fairness performance better. Using multi path protocols is adequate here.

Tree structure is used by routing protocols due to its suitable characteristics [7], "in press" [6]. Regarding as in wireless sensor networks structure, in most of applications we have one sink and too many sender nodes, and tree structure is very popular. In many protocols, by limiting routing tree such as determining most number of nodes' Childs or the most depth of tree, it is used in routing process.

In this paper, a hierarchical routing protocol which considers both energy and congestion as two main parameters in routing process is proposed. Our proposed protocol extends the routing approach in [8]. Simulation results show that HTECRP catch its goals. HTECRP consider two different traffics: high priority and low priority. Proposed protocol, uses best routes for high priority traffic and manages congestion, therefore we suggest HTECRP for transmitting real time traffic. The rest of the paper is organized as follows: Section II summarizes related work, in Section III, HTECRP is discussed, Section IV summarizes the simulation based evaluation of the HTECRP routing protocol, and Section V concludes the paper.

II. RELATED WORKS

This section summarizes the currently available Energy aware routing protocols and techniques for congestion avoidance and removal in a wireless sensor network. As mentioned before, energy consumption is the most important factor for routing algorithms of WSNs. Different energy aware routing algorithms have been designed for wireless sensor networks. In [9] optimal energy consumption is the most important objective.

Akkaya et al, propose [8] which is a well known algorithm for transmitting real time traffic in wireless sensor networks. It considers energy consumption in its routing procedure. It is a highly efficient and scalable protocol for sensor networks where the resources of each node are scarce. It is a Hierarchical routing algorithm. By determining real time data forwarding rate, it can support both real time and non real time traffics. Link cost function which is used by [8] is interesting.

Reactive Energy Decision Routing Protocol (REDRP) [10] is another routing algorithm for WSNs whose main goal is optimal energy consumption. This algorithm attempts to distribute traffic in the entire network fairly. Using this mechanism, it decreases total network energy consumption. REDRP is routing reactively, and uses residual node energy in routing procedure. It uses local information for routing, but nodes have a global ID which is unique for the entire network. This algorithm is divided into 4 steps. In the first step, the sink sends a control packet to all network nodes. The nodes estimate their distance to sink relatively by using this packet. The next step is route discovery. Routing is performed on demand in REDRP. This means that the routes are established reactively. After route establishment in route discovery step, data are forwarded to sink by using those routes. If a route is damaged, in route recovery step, it will be recovered or a new route will be established.

Different congestion control techniques have been proposed for wireless sensor networks [11, 12], in [11], CODA, an energy efficient congestion control scheme for sensor networks was proposed. CODA (COngestion Detection and Avoidance) comprises three mechanisms: (i) receiver-based congestion detection; (ii) open-loop hop-by-hop backpressure; and (iii) closed-loop multi-source regulation. CODA detects congestion based on queue length as well as wireless channel load at intermediate nodes. Furthermore it uses explicit congestion notification approach and also an AIMD rate adjustment technique.

In [13], two traffic types are considered: high priority and low priority. It selects a special area in network called conzone. The nodes placed in conzone only forward high priority traffic and other network nodes forward other traffics. Reference [13] proposes two algorithms: CAR and MCAR. CAR is a network-layer solution to provide differentiated service in congested sensor networks. CAR also prevents severe degradation of service to low priority data by utilizing uncongested parts of the network. MCAR is primarily a MAC-layer mechanism used in conjunction with routing to provide mobile and lightweight conzones to address sensor networks with mobile high priority data sources and/or bursty high priority traffic. MCAR Compared with CAR has a smaller overhead but degrades the performance of LP data more aggressively.

III. PROPOSED PROTOCOL

In hierarchical routing protocols, routing process is divided into two main different phases. In each phase, some functions of algorithm are performed HTECRP is composed of 3 phases: clustering, creating routing tree and data forwarding. In the rest of this section, these phases are discussed.

A. *Network clustering phase*

In this phase, network nodes are partitioned into different clusters. In proposed protocol clustering is done using clustering mechanism presented in [14]. Within the clustering phase, a cluster head should be elected for each cluster. At the end of this phase, information about each cluster's nodes should be delivered to cluster head.

B. *Creating routing tree phase*

In this phase, using information delivered to cluster node in the former phase. In a routing tree structure, for every cluster node a path to sink is determined. Cluster head knows position of all nodes located in its cluster, then in first step in this phase, cluster head evaluates link cost between every two nodes located in their communication range [8]. For determining link cost, proposed protocol uses formula.1.

$$\cos t_{ij} = \sum_{k=0}^{3} CF_{\mathrm{k}} = c_0 \times \left(dist_{ij}\right)^{\mathrm{L}} + c_1 + c_2 + c_3 \times f\left(e_{ij}\right)$$

Formula 1

- CF_0 (Communication Cost) = where c_0 is a weighting constant and the parameter L depends on the environment, and typically equals to 2. This factor reflects the cost of the wireless transmission power, which is directly proportional to the distance raised to some power L. The closer a node to the destination, the less its cost factor 0 *CF* and more attractive it is for routing.

- CF_1 (Energy stock) = this factor reflects the primary battery lifetime, which favors nodes with more energy. The more energy the node contains, the better it is for routing. Applicable in networks which have heterogeneous nodes.
- CF_2 (Sensing-state cost) = where c_2 is a constant added when the node j is in a sensing state. This factor does not favor selecting sensing-enabled nodes to serve as relays. It's preferred not to overload these nodes in order to keep functioning as long as possible.
- CF_3 (Error rate) = where f is a function of distance between nodes i and j and buffer size on node j (i.e. *dist ij / buffer _ size*). The links with high error rate will increase the cost function, thus will be avoided.

Cluster head using node's information, links cost and Dijkstra algorithm selects least cost route between every cluster node and sink. Using Dijkstra algorithm, route selected between every node and sink is optimum, therefore the set of all routes has a tree structure called routing tree. If a node uses selected least cost route for transmitting its traffic, network will consume least possible energy for its traffic. But, it is important to note here that, with respect to routing parameters discussed in section 1, the least cost route is not always the best route.

Wireless sensor networks are expensive networks. For decreasing costs, a network is used for more than one application. Each application have its own traffic, therefore in many cases, a sensor network should transmit different traffics with different priorities. The proposed protocol considers two traffic types: high priority and low priority traffic. Traffics based on their priority get network services. HTECRP after constructing routing tree improves it. High priority traffic volume and the ability to forward other node data are determined for each node. Based on mentioned parameters, most number of children for each node in routing tree to avoid congestion will be determined. A node's child is a node that selects former node as its next hop in its route to the sink. Usually a number in [3, 6] is determined as the most number of node's children. After determining most number of the node's children, routing tree is changed as much possible as no node has higher number of children than the most number of children. Cluster head has sufficient information about all the cluster routes, therefore it can find number of each node's children simply. The cluster head using mechanism will be discussed in the next paragraph, decreases number of the children of nodes which have children more than the most number of children.

Cluster head evaluates all of the cluster nodes and then chooses nodes that have children more than most number of children. For all of the selected nodes, it determines the following two parameters.

- least cost route between node and sink
- Number of children

Now among the children, the one which has a neighbor with fewer children than the most number of children and least cost route to sink will be selected. Then the selected child is improved and in future it will be the child of its qualified neighbor. In some situations, the child with appropriate conditions dose not exist, therefore exceptionally a node with children more than the most number of children is accepted.

After selecting the best route and determining the number of children for every node, cluster head creates a routing table for each cluster node. A special record in routing table is considered for the best selected route. For each of the node's neighbors which have shorter distance to sink, a record will be considered in routing table, too. Routing table has following fields: ID, residual energy, number of children, cost and average queue length. After constructing routing table, cluster head sends each node routing table to it.

C. *Data transmission phase*

At the end of the former phase, all the nodes have a routing table. As mentioned in phase B, the proposed routing protocol considers two traffic types: high priority and low priority. The main goal of this phase is to determine next hop for each arrival packet at each node. In the rest of this section routing process which is done in each node when it receives packets with different priorities is discussed.

When a node receives a high priority packet, does following steps:

1. If special record in its routing table is active, this record will be selected. Otherwise step 2 will be done.

2. Among the records which have average queue length lower than threshold β, the record with lowest cost field value will be selected. If all the records have average queue length more than threshold β, step 3 will be done.

3. Among the records, the one with the lowest cost field value will be selected.

After selecting the record, arrival packet will be sent to the node which is determined in record as next hop.

When a node receives a low priority packet, does the following steps:

1. Among the records which have average queue length lower than threshold β, the record with the biggest residual energy will be selected. If all of the records have average queue length more than threshold β, step 2 will be done.

2. Among the records, the one with biggest residual energy will be selected.

After selecting the record, the arrival packet will be sent to the node which is determined in record as the next hop. Threshold β numbered by multiply a number in [0, 1] to node queue capacity.

Nodes' routing table should be updated periodically; otherwise they can not play their role effectively. When a node residual energy becomes less than threshold α, it broadcast a message and informs its neighbors about its current condition. Neighbors receiving mentioned message, update the sender node's record in their routing table. Also the nodes should inform their neighbors about their average queue length. When a node queue length crosses threshold β (goes up or down the β), it should inform its neighbors. Threshold α numbered by multiply a number in [0, 1] to primary available energy.

IV. SIMULATION RESULTS AND PROTOCOL PERFORMANCE EVALUATION

The proposed protocol has many similarities to akkaya et al protocol [8]; in other word, HTECRP is an improvement to [8]. We simulate both HTECRP and [8], using C++ language in a UNIX operating system environment.

Most of hierarchical routing protocols are composed of two main parts. The first part is routing intra clusters and the second part is routing inter clusters. The first part's role is more important. HTECRP in part 1, acts like [8]; its improvements are in intra cluster routing. The number of cluster nodes in simulations is considered as to be between 29 and 99. The communication range is determined Based on number of nodes in cluster. We consider almost a 40*40 square for each cluster.

The main goal in HTECRP is congestion avoidance. HTECRP makes a routing tree with the most number of children for its nodes. When the number of children in a routing tree is limited, traffic volume which node receives is limited too. Therefore when an event is occurred, congestion occurrence probability will be decreased. Another parameter which affects HTECRP success in congestion management is the node's awareness about their neighbors average queue length. In this situation when nodes want to select the next hop for their data, they consider their neighbors average queue length as a parameter in decision making. Even when a node average queue length is shorter, its probability to be selected as next hop will be increased. In the first graph, we evaluate the number of lost packets due to congestion for two protocols. In fig.1 the number of packet loss in two protocols for different numbers of events is presented.

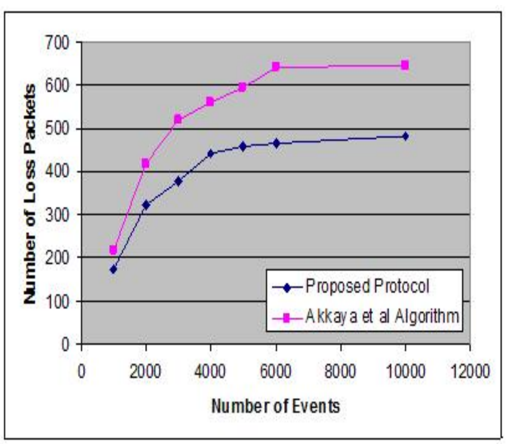

Figure 1. number of loss packets versus number of events

As is observable in fig.1 the number of packet loss when network uses HTECRP is less than another protocol. HTECRP manages congestion; therefore the result shown in fig.1 is obtained.

In figures 2 and 3 the number of received packets to cluster head is plotted versus the number of events. The number of nodes and events' place are different in two experiences. As shown in figures 2 and 3, in the same conditions, number of packets received to cluster head in HTECRP is always more than another protocol. HTECRP manages congestion; it tries to reduce packet loss in nodes which are located in routes. Lower packet loss leads to more success to deliver packets to cluster head. Both figures 2 and 3 show that HTECRP is more successful than another protocol.

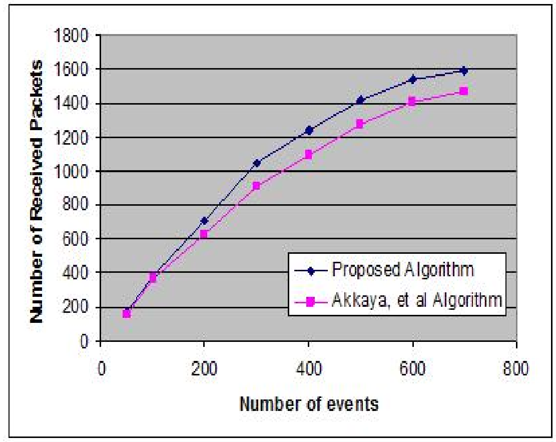

Figure 2. number of received packets to cluster head versus number of events

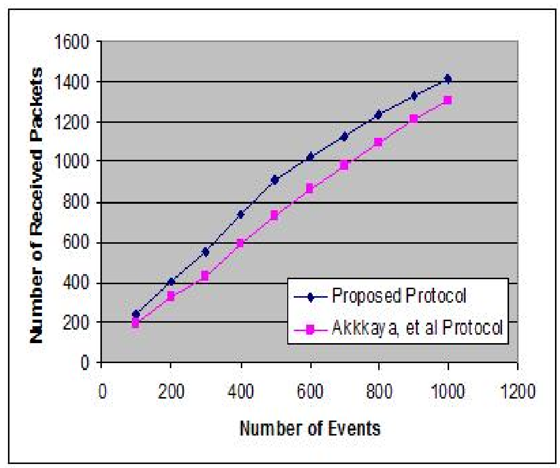

Figure 3. number of received packets to cluster head versus number of events

As mentioned in former sections, HTECRP considers two types of traffic. Network services traffics based on their priority. Both of the protocols try to deliver the best possible services to high priority traffic besides deliver suitable service to low priority traffic. In fig.4 the number of loss packets from each type of traffic for both protocols is plotted versus the number of events. TP1 is high priority traffic and TP2 is low priority traffic.

In fig.5 performing fairness in two protocols are compared. As mentioned in section 1, performing fairness is an important factor in wireless sensor networks routing protocols efficiency.

Imagine a protocol which sends all of the data from a best cost route, in this situation, the energy of nodes located in the best route are depleted very soon; however other cluster nodes have considerable residual energy. HTECRP tries to consume nodes energy as fairly as possible. Using residual energy parameter, HTECRP achieves its goal. In fig.5 Deviation parameter which is calculated using formula 2 is plotted versus number of events received to cluster head.

$$Deviation = (Node_i\ Energy - Average)^2 \quad : Formula\ 2$$

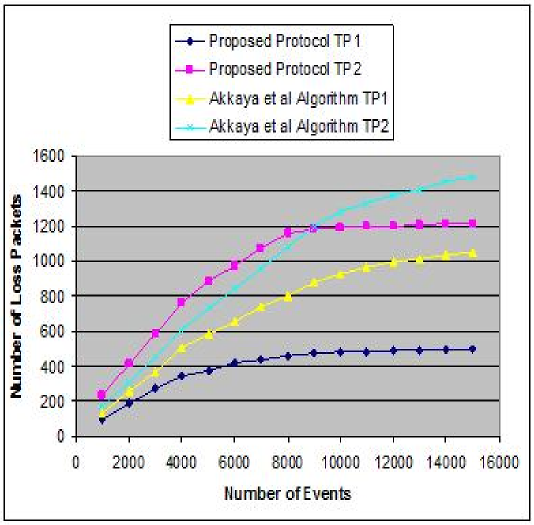

Figure 4. number of loss packets versus number of events for different types of traffic

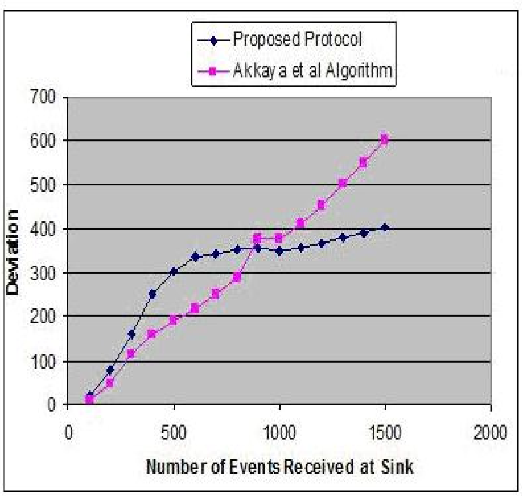

Figure 5. deviation versus number of events received at cluster head

As shown in fig.5, deviation parameter which depends on performing fairness has a better value for HTECRP rather than another protocol. Even a protocol performing fairness better, deviation parameter is valued less for it.

V. Conclusion and Future Works

In this paper, we presented a new hierarchical energy efficient routing protocol for sensor networks which considers congestion management. Routing protocol divides network into many clusters, then using Dijkstra algorithm constructs a routing tree for each cluster. In routing tree, most number of children for cluster nodes is determined. Proposed protocol using routing tree and node's neighbors average queue length as a parameter manages congestion. The effectiveness of the protocol is validated by simulation. Simulation results show that our protocol achieved its goals. Proposed protocol considers only intra cluster routing; we are currently extending the protocol to perform routing inter clusters.

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Reference

[1] M. Tubaishat, S. Madria, "Sensor Networks: An Overview.", IEEE POTENTIALS April/May, pp20-23, 2003

[2] I. F. Akyildiz, W. Su, W. Sankarasubramaniam, E. Cayirci, "A Survey On Sensor Networks.", IEEE Communication magazine, 2002, pp. 102-114.

[3] Hassanein, H.; Jing Luo, "Reliable Energy Aware Routing In Wireless Sensor Networks", Second IEEE Workshop on Dependability and Security in Sensor Networks and Systems, 2006. DSSNS 2006., 24-28 April 2006 Page(s):54 – 64

[4] Qiangfeng, Jiang, Manivannan, "Routing Protocols for Sensor Networks.", 1st IEEE Consumer Communications and Networking Conference, 2004. (2004) 93-98

[5] Shigang Chen, Na Yang, "Congestion avoidance based on lightweight buffer management in sensor networks," *IEEE Transactions on Parallel and Distributed Systems*, Sept 2006. vol. 17, no. 9, pp. 934-946.

[6] Z. Eskandari, M.H. Yaghmaee , A.H. Mohajerzadeh, "Energy Efficient Spanning Tree for Data Aggregation in Wireless Sensor Networks". SN 2008 Workshop at ICCCN 2008

[7] T. Niwat, T. Yoshito, S. Kaoru, "Tree-Based Data Dissemination in Wireless Ssnsor Networks", Proceedings of the IEICE General Conference (Institute of Electronics, Information and Communication Engineers), VOL.2005 ;PAGE.S.41-S.42(2005)

[8] K. Akkaya, M. Younis, "An Energy Aware QoS Routing Protocol for Wireless Sensor Networks.", ICDCS Workshop 2003, May 2003

[9] Vidhyapriya, R.; Vanathi, P.T., "Energy Aware Routing for Wireless Sensor Networks", Signal Processing, Communications and Networking, 2007. ICSCN '07. International Conference on 22-24 Feb. 2007 Page(s):545 – 550

[10] Y. H. Wang, C. P. Hsu, Y. C. Lin, C. S. Kuo, H. Y. Ho, "A Routing Method by Reactive Energy Decision in Wireless Sensor Networks.", 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07), IEEE 2007

[11] 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.

[12] M. I. Khan, W. N. Gansterer, G. Haring, "Congestion Avoidance and Energy Efficient Routing Protocol for Wireless Sensor Networks with a Mobile Sink", Journal of Networks, VOL. 2, NO. 6, December 2007, Page(s):42 – 49

[13] R. Kumar, et al, "Mitigating Performance Degradation in Congested Sensor Networks", IEEE Transactions on Mobile Computing, VOL. 7, NO. 6, June 2008, Page(s):682 – 697

[14] A. A. Abbasi, M. Younis, "A survey on clustering protocols for wireless sensor networks", Volume 30, Issues 14-15, 15 October 2007, Pages 2826-2841.