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QOS PROVISION FOR CONTROLLING ENERGY CONSUMPTION IN AD-HOC WIRELESS SENSOR NETWORKS

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Abstract. *In this paper, a new quality of service (QoS) approach is proposed to control the consumed energy in ad-hoc wireless sensor network (WSN). The main reason is to reduce the node's energy through discovering the best optimum route that meets QoS requirements; QoS technique is used to find the optimum methodology for nodes packets transmission and energy consumption. The primary goals of the research are to discover the best techniques to 1) minimize the total consumed energy in the ad-hoc wireless sensor network, and 2) maximize the ad-hoc wireless sensor network lifetime. The simulations of the problem will be formulated with the use of integer linear programming.*
Keywords: Energy consumption, Ad-hoc wireless sensor network, QoS provisions, QoS routing, Multicast incremental power (MIP), Network topology

1. **Introduction.** The ad-hoc wireless sensor network is categorized as a decentralized network; it is ad-hoc due to the fact that it is lack of a base station, as there is not a pre-architecture infrastructure to depend on. The ad-hoc wireless sensor network technology is used widely in various industries through developed applications. These technologies grew to become accessible as the sensor became smaller, sophisticated and cheaper. It consists of many independent nodes that are connected with each other to form a wireless ad-hoc network. Sensors are being used in this network for monitoring physical conditions. In the ad-hoc multi-hop networks, any connection between two nodes no longer exist inside transmission range, and the packets need to be relayed via using the route of the intermediate nodes [1]. Each node acts as a host and a router as well. There are four fundamental elements in a sensor network, which are illustrated as the following.

- **Radio:** It is a wireless cognitive allotted network of radio sensor nodes that has the ability to sense an event signal and collaboratively communicate their readings over dynamically spectrum bands in a multi-hop approach.
- **Battery:** They are battery-powered devices, given that it is commonly tough or not possible to run main resources to their deployment site.
- **Microcontroller:** It performs duties, processes records, and controls other components' capability in the sensor node.
- **Sensor Interface:** They are hardware devices that are mainly used to capture records from the environment and produce a measurable change response in physical conditions.

Our Contribution. The main target of our contribution is to provide the ability to the network to control the threshold value, to 1) consume the used energy in the whole network and 2) maximize the lifetime of the whole network. This was achieved in our

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experiment through adding a new threshold constraint that can control the consumed energy of the transmitted data. The variance in the energy matrix should be reduced; the main reason of this constraint is to use the minimum energy transmission for each node through the nodes that have not consumed its full energy. This paper is organized as the following, Section 2 is an illustration for previously related works for energy consumption in wireless sensor networks, Section 3 is the problem statement, Section 4 is the proposed QoS method alongside with our new added constraint, then the results of the ad-hoc WSN performance regarding this solution, Section 5 discusses the effectiveness of our methodology with other previously studied techniques and then Section 6 is a conclusion for the idea and the proposed study for the whole paper.

2. **Related Work.** Many related works have studied the topology control for wireless ad-hoc sensor networks with many different techniques such as fuzzy logic, multiple-input and multiple-output (MIMO) and swarm optimization. Firstly, the relationship between the throughput and transmission range in topology control was studied; to permit transmitting energy adjustment to decrease interference, there is a need for developing an analytical model to obtain high throughput. In [2], it was stated in the experiment that there is no focal point in each work for minimizing the consumed energy. There had been earlier topology control works that aim to decrease nodes' interference and attach high throughput via adjusting every node's transmitting electricity of an analytic model. Table 1 below is a comprehensive study about previous studies with various techniques to consume energy in wireless sensor networks in general.

Table 1. Study on energy consumption challenges in wireless sensor networks

Ref No.	Main challenge	Technique
Cui et al. [3]	Analyze best transmission strategy for minimizing energy	MIMO technique
Torres [4]	Mica2 motes using GSP for routing and a CSMA	Gossip-based sleep
Nandi and Roy [5]	Multi-layer medium access control (ML-MAC) scheme	Swarm optimization
Girgiri et al. [6]	Consume energy using a sensor's transmitter radio model	LEACH protocol
Toldov et al. [7]	The relation between interference & energy consumption	X-MAC RDC protocol
Okopa et al. [8]	Analytical model of delay & average energy consumption	M/G/1 queue model
Alhumud and Zohdy [9]	Reduce the energy consumption and increase the network lifetime in multiple numbers of greenhouses	CRSN sensing protocol

3. **Problem Statement.** Any ad-hoc wireless sensor network consists of a group of transceivers. The entire communications between the transceivers are primarily based on the radio broadcast. There is existence for the transmission energy. Transmission relies on many factors such as the transceiver distance, the antenna's sender route, and collision. In [10] it was stated that the nodes are corresponding "one to one" in transceivers. The (x, y) points exist directly in the design if only the transmission strength (x) has the lowest sending energy threshold. The main topology control goal is to assign the transceivers' needed energy. As a result, it is expected that the output design would match the targeted properties. To this point, the main motivation behind analyzing the problems of topology control is to reach the best usage from each node's energy. Additionally, using every

node's minimum energy to achieve a given task will minimize the MAC to the closest signals, the primary topology control purpose is to identify the energy of transmission to nodes; as a result, the output of the undirected design has a unique feature to the minimized energy which used to be assigned to the node.

4. Optimization Model Formulation.

The ad-hoc WSN is formed from many connected nodes via links. Links depend on the node's resources (e.g., memory, transmission energy, and computing energy), the behavioral properties and the connection properties [11]. Thoughtlessly, there is a possibility for a disconnection to occur in the network at any time, the operational network needs to be having the capability to overcome these dynamic risks in an efficient, scalable and secure method. Mostly, the nodes in ad-hoc WSNs are competing for accessing the shared medium. Because of this competition, collision interference will occur. To resolve this problem there is an enhancement for the immunity of the usage of the co-operative wireless communications. It solves the interference through having the destination node combining self-interference and other nodes interference in order to enhance the preferred signal decoding. The major QoS goal is to make the network conduct deterministically, as a result, the records delivering via this network in a better way and making use of the resources in a better way [12].

4.1. Parameters.

QoS parameters. Battery existence time, bandwidth, network availability, communication groups, contingency services.

Network parameters. The battery, delay jitter, buffering space, process strength, the bandwidth.

4.2. Routing protocols classification (QoS).

Because of the low range of every transmitter effectiveness, multi-hop paths are used through distant nodes to communicate with other nodes. As a result, obtaining a high availability performance in an environment where the change of the network occurs dynamically, there is a declaration on giving the shortest route between every two nodes. However, all the solutions deal only with traffic.

Eventually, given network graph O and the traffic demands between node pairs, the traffic needs to be routed away that achieves the purpose of the experiment by reducing the consumed energy in the whole network. In the system, the maximum load node that is referred to by using $L_{\max}$, x needs to be minimized. The components of this problem are represented by using the set of equations as presented in Formulae (1)-(5) [13].

4.3. Solution design.

$$Min\ L_{\max} \tag{1}$$

$$L_{\max} \geq 0 \tag{2}$$

$$\sum_i f_{i,j}^{s,d} - \sum_i f_{j,i}^{s,d} = \begin{cases} 1 & \text{if } s = i \\ -1 & \text{if } d = i \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$\sum_{(s,d)} \sum_j f_{i,j}^{s,d} + \sum_{(s,d)} \sum_j f_{j,i}^{s,d} \leq L_{\max} \tag{4}$$

$$f_{i,j}^{s,d} \geq 0, \quad \forall i, j \in V, (s,d) \tag{5}$$

$$\text{Note that: } \forall (s,d), f_{i,j}^{s,d} = 0$$

4.3.1. *Solution parameters.* P, maximum allowed transmission power. B, node bandwidth. λ_s, the node (s,d) traffic demand. V, a set of nodes with each node's location. Δ_s, the maximum hop count.

4.3.2. *Variables.*

- $x_{i,j}$, Boolean variables, $x_{i,j} = 1$ if there is a link from node i to node j; otherwise, $x_{i,j} = 0$.
- $x_{i,j}^{s,d}$, Boolean variables, $x_{i,j}^{s,d} = 1$ if the route from s to d goes through the link (i, j); otherwise, $x_{i,j}^{s,d} = 0$
- P_i, transmission power for node i.
- $R_{\max}$, the maximum power utilization of all nodes.

4.3.3. *Constraints.*

- **Topology Constraints**

Function 6: Reduce the maximum transmission energy.

$$Min\, E_{\max} \tag{6}$$

Function 7: Ensure the availability of two direct links for each edge.

$$x_{i,j} = x_{j,i} \quad \forall i, j \in V \tag{7}$$

Function 8: Ensure the broadcast ability for the nodes when the node transmits all the nodes in the transmission range will receive from this node.

$$x_{i,j} \leq x_{i,j'} \text{ if } d_{i,j'} \leq d_{i,j} \quad \forall i, j, j' \in V \tag{8}$$

- **Transmitting Power Constraints**

Function 9: Identify the maximum transmission energy for all nodes.

$$e \geq e_{\max} \geq d_{i,j}^{a} x_{i,j} \quad \forall i < j,\ i, j \in V \tag{9}$$

Function 10: Ensure that there is no exceeding from the hop-count to the pre-specified bound.

$$\sum_{(i,j)} x_{i,j}^{s,d} \leq \Delta_{s,d} \quad \forall (s, d) \tag{10}$$

- **Bandwidth Constraints**

Function 11: The total signals and transmission at a node do not exceed the bandwidth capacity of this node.

$$x_{i,j}^{s,d} \leq x_{i,j} \quad \forall i, j \in V \tag{11}$$

Function 12: Ensure the route validity for each node-pair; as the traffics are not split table $x_{i,j}$ represents the entire traffics of (s, d) going through the link (i, j) if it is in the route from s to d.

$$\sum_{j} x_{i,j}^{s,d} - \sum_{j} x_{j,i}^{s,d} = \begin{cases} 1 & \text{if } s = i \\ -1 & \text{if } d = i \\ 0 & \text{otherwise} \end{cases} \tag{12}$$

- **Binary Route Constraint**

$$x_{i,j} = 0 \text{ or } 1, \quad x_{i,j}^{s,d} = 0 \text{ or } 1 \tag{13}$$

4.3.4. *Threshold constraint.*

$$E_i \leq E_{average} + Threshold \quad \forall 1 \leq i \leq n \tag{14}$$

5. **Experimental Section.** The simulation design was made in a 180 × 180 two-dimensional regions. The number of assumed nodes was 15; every node in this topology is having its own range as well as its neighbors' nodes that can intersect with their range. The model was designed as an integer linear programming using Matlab, it is also ready to deal with any number of nodes and the only difference will be with the compilation time complexity using the previously mentioned Equations (1)-(14). The nodes' coordinates were uniformly distributed inside the region and the transmitting energy value function is set to 2. For each node, a random poisson function with the mean value $\lambda = 1$ to generate a number k, that represents the requests numbers from this node. The destination requests are picked randomly via other nodes.

5.1. **Topologies vs traffic load.** The optimum threshold was the main problem to test in this experiment, so there was a need to run the model simulation to assign the relation between the threshold – with different λ_m values – and the variance that was represented in both Figures 1 and 2; to prove that the topology control problem is an optimization problem. Figure 1 shows the minimum variance for threshold more than or equal to 100 for $\lambda_m = 37.5$.

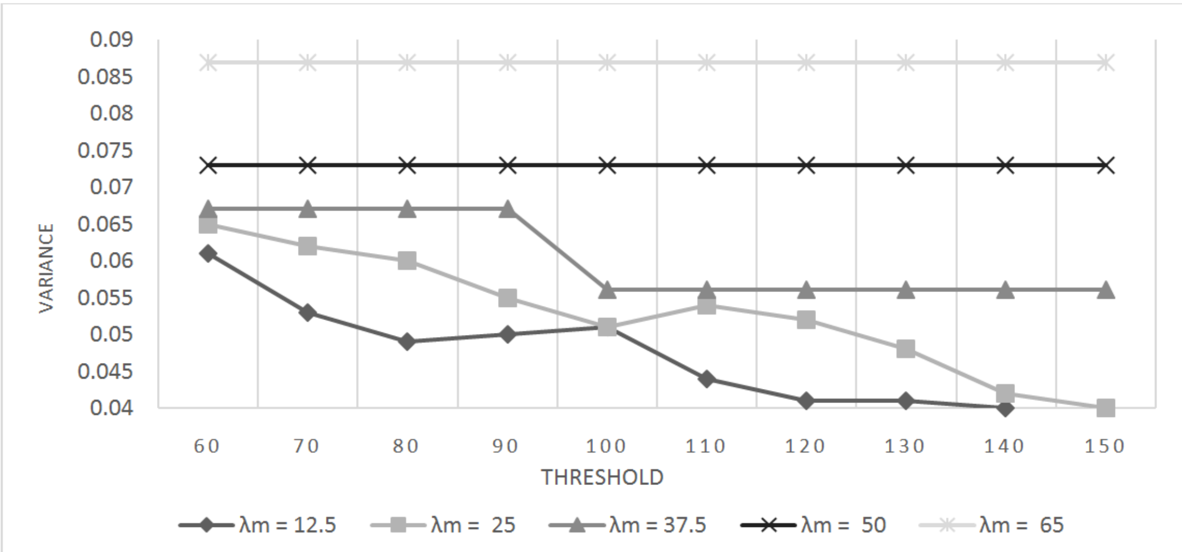

FIGURE 1. Variance vs threshold values with different λ_m values

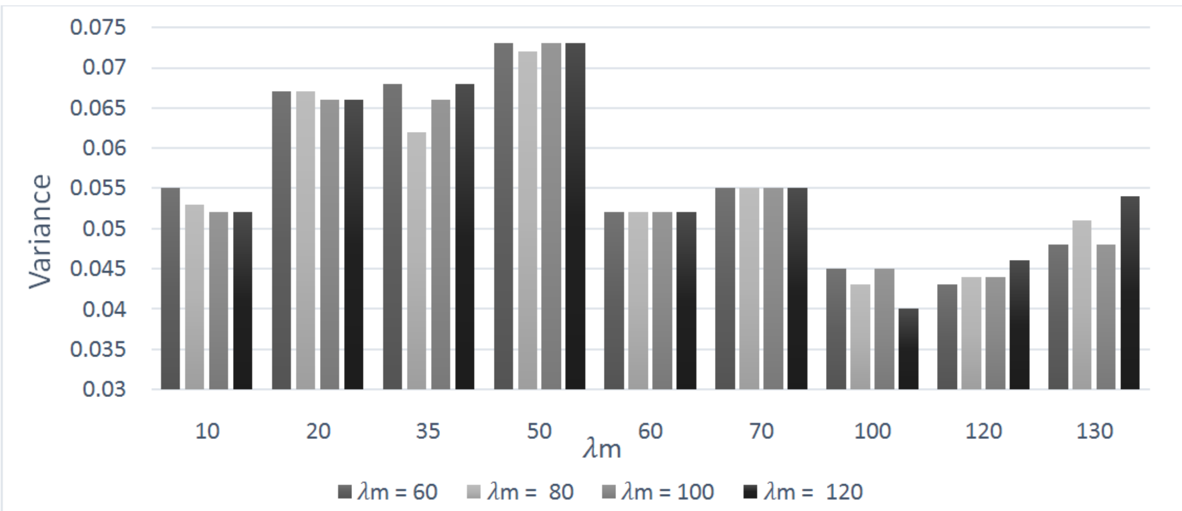

FIGURE 2. A comparison between variance & λ_m values

Figure 2 describes the relation between the varience and the λ values, it shows the instability of the sensor network occurs when λ value becomes higher. This can be seen from the variance difference values when λ started with 60 and ended with 120.

A comparison was made between the proposed QoS approach and other approaches such as MIMO, Swarm Optimization and LEACH, that was proposed in [14,5,6] respectively to prove the efficiency in consuming energy and stability of sending all packet without high failing rate. Figure 3 represents the overall consumed energy between our approach and the proposed results in [14,5,6].

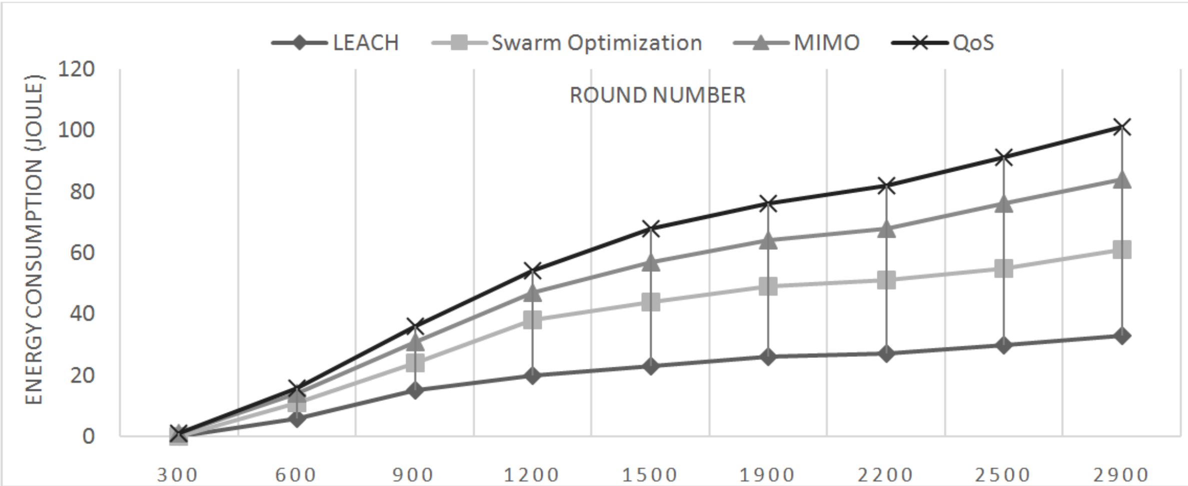

Figure 3. A comparison of total consumed energy during each round excecution in the ad-hoc WSN

As it is shown in Figure 3 above, the proposed LEACH approach in [6] was the lowest approach to consume energy in all the rounds in ad-hoc wireless sensor networks' systems with only 33 joule. However, there is a convergence of results between MIMO approach (23 joule) and QoS technique (17 joule) with 7 joule difference, which proves that QoS provided a higher rate in consuming energy. However, LEACH and Swarm Optimization methods were the lowest rate approaches with values of 2546 and 2854 successful sent packets respectively. QoS has provided a high rate of successful sent packets with 6865 packets. It is still arguable about the results in large-scale ad-hoc wireless sensor networks for all approaches after long period of times (e.g., years and decades).

6. **Conclusion.** This paper investigated the problem of topology control using the QoS to be able to reduce the consumed energy between the nodes in the wireless ad-hoc networks. The threshold constraint has a major effect on the routing decision. The λ variation has a huge impact on the result; as there is a direct correlation between the λ value and the number of lost packets, the higher λ value, the more packet loss, which results in the system instability. The topology control problem was discussed and formulated using integer linear programming. The result of the experiment demonstrated the presence of un-predictable traffics as there is an ability to prevent QoS requests. Additionally, the effects of threshold constraint on the sent packets through the network prove the higher constraint number becomes the less possibility of losing packets and maximize the sensor ad-hoc WSN overall performance. Finally, to keep the topology at its optimal level, the proposed algorithm for topology control should run iteratively to achieve both, the reduction of energy consumption and improving the lifetime of the whole network.

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