Improvement of the analysis of flow rate in limited energy constrained wireless sensor networks using the genetic algorithm

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Abstract – **Recently, the research is great towards the wireless sensor networks (WSN) since they can be used in many applications in many fields. In this paper, we used the genetic algorithm (GA) to optimize a limited energy constrained WSN to achieve maximum flow rate to a sink (data aggregator) where this network has limited lifetime. We used the obtained results to propose a method for designing a small application WSN.**

Keywords – **flow rate, limited lifetime, sensor nodes, WSN, genetic algorithm.**

I. INTRODUCTION

Wireless sensor networks are limited networks where they depend on limited energy devices called sensor nodes so they have a limited lifetime. This type of networks has many applications in civil, military and medicine fields. There was a great trend always to have maximum flow rate or data extraction from all sensor nodes (sources of information which sense data and collect it then send it) to the sink (data aggregator) and also limit the consumption energy i.e. increasing their lifetime. Also there are some applications which are time sensitive, so it is better to have small end-to-end delays in communications between the sensor nodes. The engineers who design and build the wireless sensor networks take into consideration some constraints which control the network operation of them to achieve a high Quality of Service (QoS) [1] & [2]. Recent years have witnesssed a growing interest in the application of wireless sensor networks in unattended environments [3]. Nodes in such applications are equipped with limited energy supply and need careful management in order to extend their lifetime. Lifetime of sensor nodes in the WSN depends on the energy consumption for transmitting, processing and receiving data or information form other sensor nodes. Also, it depends on the distances between them where the path loss factor affects greatly on the long distances and the transmitting power has to be considerable value that achieves a specific value of signal-to-noise ratio.

Some applications using WSN require the random positioning of sensor nodes where the first target is to collect the information rapidly with small delay. Also, others require some specifications on the transferred data in the size of data packets and the loss packet ratio due to contention between nodes, the collision between the packets and the effect of the round trip time. Others require motion of these nodes to fetch for certain data or information in a specific area.

Optimization techniques can be used to achieve optimal solutions for the limited constrained WSN. The objective of this optimization process is to maximize the flow rate to a certain node which is called the sink or the data collector. We used the GA on two constrained problems described in [4] and [5]. The first problem is to maximize the flow rate to a sink in a WSN composed of five sensor nodes with seven constraints. The second problem is to maximize the lifetime of this network to meet given constraints.

This paper uses the GA in improving the flow rate and the lifetime in limited constrained WSN. The rest of papers is organized as follows. Section II describes the two optimization problems for the flow rate and the lifetime in limited constrained WSN with some modifications. Section III provides the obtained results and the analysis. Section IV provides the discussion and conclusion.

II. OPTIMIZATION PROBLEMS FOR FLOW RATE AND LIFETIME IN LIMITED CONSTRAINED WSN

A. First problem

The following equations represent the used objective function of flow rate delivered to the sink with its constraints as presented in [4] and an additional constraint (1g) which describes the viability of applying TCP/IP protocol in WSN was added.

$$\max \sum_{j=1}^{n} f_{j,n+1} \quad (1)$$

$$s.t.\ \sum_{j=1}^{n} f_{j,i} - \sum_{j=1}^{n+1} f_{i,j} \le 0 \quad (1a)$$

$$\sum_{j=1}^{n+1} f_{i,j} - \sum_{j=1}^{n} f_{j,i} - R_i \le 0 \quad (1b)$$

$$\sum_{j=1}^{n+1} f_{i,j} - \sum_{j=1}^{n} f_{j,i} - \alpha_i \sum_{j=1}^{n} f_{j,n+1} \le 0 \quad (1c)$$

$$\sum_{j=1}^{n+1} P_{i,j} + \sum_{j=1}^{n} f_{j,i} C - E_i \le 0 \quad (1d)$$

$$f_{i,j} - \log\left(1 + \frac{P_{i,j} d_{i,j}^{-2}}{\eta}\right) \le 0 \quad (1e)$$

$$f_{i,j} \ge 0, P_{i,j} \ge 0 \quad (1f)$$

$$f_{i,j} - \left(\frac{1.22 * M}{RTT * \sqrt{p}}\right) \le 0 \quad (1g)$$

Where $f_{i,j}$, $P_{i,j}$ and $d_{i,j}$ are matrices of (n+1× n+1) elements represent the flow rate, the transmission power and the distance between the sensor nodes i and j respectively. R_i ,α_i and E_i are vectors of length (n+1) represent the source rate, the fairness constraint and the energy required for node i respectively. C is the consumption energy per data unit (bits). η is the noise intensity in the communication channel. M is the packet size in bits. RTT is the round trip time from the moment of requesting the data until the reception. p is the packet loss ratio. The number of source nodes is four and there is one sink.

B. Second problem

Equation (2) represents the objective function for the used limited lifetime problem with its constraints as presented in [5] with a modification in the constraint (2a) that the difference between the sent/received aggregated data can not be greater than the prepared data to be sent by a sensor node in the network lifetime. This equation describes the network lifetime $T_{nwk}(f,E)$ which equals the smallest lifetime of a sensor node in this network.

$$\max \min_{\forall i \in [1,n]} \frac{E_i}{\sum_{j\in[1,n+1]}\left(f_{i,j}\varepsilon_{tx}^{i,j} + f_{j,i}\varepsilon_{rx}\right) + R_i \varepsilon_s} \quad (2)$$

$$s.t.\ \sum_{j=1}^{n+1} \hat{f}_{j,i} + R_i \cdot T_{nwk}(f,E) - \sum_{j=1}^{n+1} \hat{f}_{i,j} \le 0 \quad (2a)$$

$$\sum_{j=1}^{n+1}\left(\hat{f}_{i,j} \cdot \varepsilon_{tx}^{i,j} + \hat{f}_{j,i} \cdot \varepsilon_{rx}\right) + R_i \cdot T_{nwk}(f,E) \cdot \varepsilon_s - E_i \le 0 \quad (2b)$$

$$\sum_{i=1}^{n+1} E_i \le E_{total} \quad (2c)$$

$$\hat{f}_{i,j} \ge 0 \quad (2d)$$

$$\hat{f}_{i,i} = 0 \quad (2e)$$

$$\hat{f}_{n+1,j} = 0, \forall j \in [1,n] \quad (2f)$$

Where $\hat{f}_{i,j}$ represents the aggregate data transferred between the sensor nodes i,j during the network lifetime. $\varepsilon_{tx}^{i,j}$, ε_{rx} and ε_{s} are the costs per data unit for transmitting, receiving and sensing between the two nodes i,j respectively. E_{total} is the total energy required for all sensor nodes in the WSN.

III. RESULTS AND ANALYSIS

The first problem is solved using the GA with the seven constraints and the results show an improvement in the total flow rate to the sink obtained in [4]. The optimization process by GA is applied to two cases. The first was run under different initial population sizes for the problem. The second was with different numbers of generations for the best obtained result from the previous case. Table I and II show the results.

TABLE I. THE OBJECTIVE FUNCTION VALUE AT DIFFERENT INITIAL POPULATION SIZES

Initial Population Size	Objective Function Value
10	9.337
20	9.428
30	9.247
40	9.4
50	9.31
60	9.2
70	9.278
80	9.06
90	9.174
100	9.218

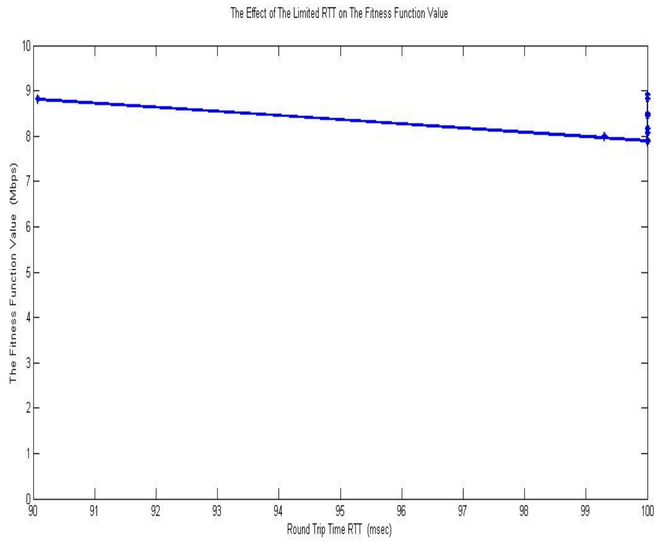
TABLE II. THE OBJECTIVE FUNCTION VALUE AT DIFFERENT NUMBERS OF GENERATIONS AT INITIAL POPULATION SIZE OF 20

Numbers of Generations	Objective Function Value
100	9.428
200	9.434
300	9.434
400	9.434
500	9.434
600	9.434
700	9.434
800	9.434
900	9.434
1000	9.434

The two cases have the same variables in the optimization parameters vector which were the flow rate, the transmission power and the distances between the sensor nodes. Indeed, it included the energies, the three dimensions positions of these nodes and the parameters of the seventh constraint when applying TCP/IP in a small WSN which are RTT, M and p.

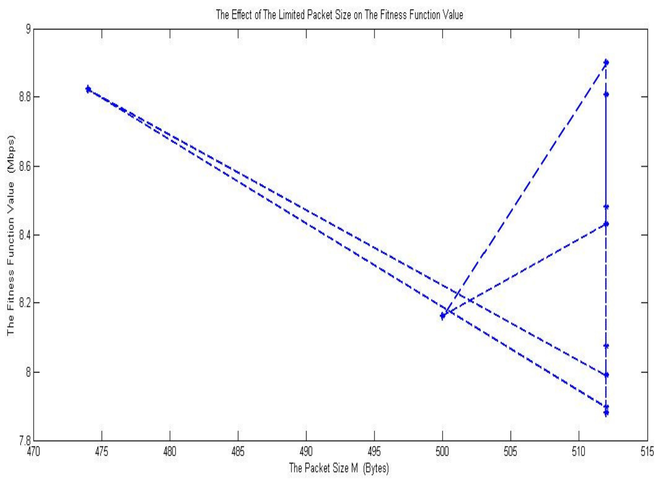
The first problem was performed with some restrictions on the values of RTT, M and p to be 100 msec, 512 bytes and 0.01% respectively. The purpose for that is to get a constrained small WSN with capability of having good QoS at applying the TCP/IP. The following figures show the effect of the previous parameters on the obtained value of the objective function.

Figure 1. The effect of the limited RTT on the value of



the objective function

Figure 2. The effect of the limited M on the value of the objective function



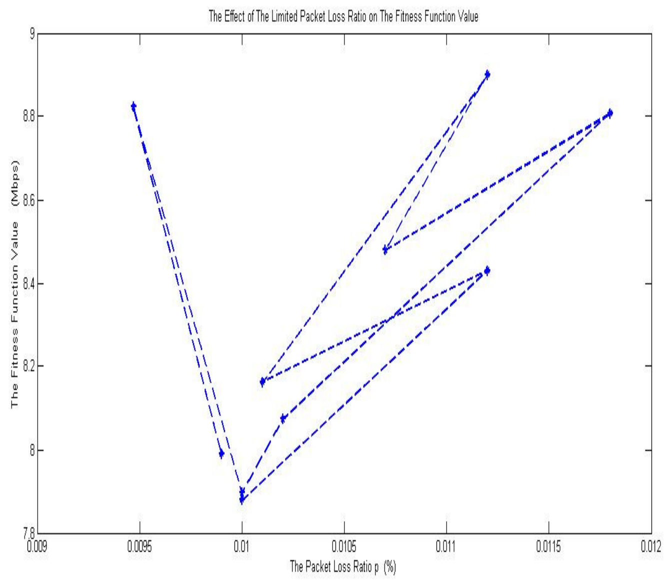


Figure 3. The effect of the limited p on the value of the objective function

From the above figures, we conclude that the limited RTT, M and p parameters affect the value of the fitness function value that it did not reach values as obtained in tables I & II. The best obtained value was at initial population size of 20 where the values of RTT, M and p are 90.08 msec, 474 bytes and 0.00947% respectively with a value of 8.823 Mbps for the objective function. The WSN (as a limited network in its energy resources) was optimized taking into consideration that the consumption of energy and the delay, getting some figures of merit. The most affecting parameter on the obtained values was the distance between the sensor nodes.

The second problem is applied with its constraints and a combination of constraints from the first problem. The suggestion that there is a small WSN with limitation in the energies and lifetimes of sensor nodes and also some constraints required to achieve a certain QoS in it. Table III shows the obtained results at applying the combined constraints in the first problem with the constraints in this problem and we took the other parameters from the first problem. The target of this problem was to improve the flow rate to the sink (the objective function of the first problem). The optimization process is applied at 1000 generations.

TABLE III. THE EFFECT OF APPLYING THE SECOND PROBLEM WITH SOME CONSTRAINTS FROM THE FIRST PROBLEM ON THE FLOW RATE TO THE SINK

Initial Population Size	Flow rate to the Sink (Mbps)	RTT (msec)	M (Bytes)	p (%)
10	8.404	107.3	560	0.01
20	8.46	109.4	570	0.011
30	9.12	124.5	679	0.012
40	8.76	107.6	568	0.011
50	9.26	79.6	806	0.013
60	9.07	143.3	759	0.01
70	9.005	104	613	0.0043
80	8.57	109	561	0.011
90	8.133	106.5	547	0.011
100	8.96	109.1	650	0.012

V. CONCLUSIONS

Combinations of two optimization problems in the same field with converging parameters and having the same aim in the end, can lead to improve the objective function of one these problems. Studying the optimization problem with its constraints and the effect of each parameter in it can greatly affect the results. The distances between the sensor nodes have a great effect on the operation of the WSN and its QoS.

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