Fair, Optimized Routing Protocol Based on Fuzzy Variables in Wireless Sensor Networks

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***Abstract*— Providing desired QoS is one of the crucial issues in routing protocols design in wireless sensor networks. In this paper, a mechanism for routing in wireless sensor networks is presented using nonlinear optimization. Providing fairness in nodes energy consumption and increasing network lifetime are considered as the main parameters. Proposed routing protocol, which is called FORP (Fair, Optimized Routing Protocol), performs routing using nonlinear optimization. Furthermore, in order to improve proposed protocol efficiency, we will use fuzzy variables to consider environmental contention influences on the quality of data transmission in wireless connections. We can formulate network conditions better while fuzzy variables have been used in optimization solution. We will study proposed protocol efficiency using Opnet simulator. Simulation results confirm that FORP has achieved its goals.**

***Index Terms*— Fuzzy variable, Nonlinear optimization, Providing fairness, Routing protocol, Wireless sensor networks.**

I. Introduction

In recent years wireless sensor networks (WSN) have been regarded greatly. Many applications were designed for these networks. Wireless sensor networks consist of hundreds nodes that have been distributed in a field; they gather data from environment. A set of sensors are deployed in each network node. These networks have unique characteristics compared to conventional networks [1].

One of the most important features of wireless sensor networks are the deficiency of the network nodes resources, such as: processing power, storage capacity, radio range and energy source. Primary energy sources of sensor nodes are limited and in most applications they cannot be reinforced. Under such circumstances, efficient use of energy is crucial [2]. The lifetime of sensor network is depended on its nodes, if a network nodes die, it can not perform its task well enough. Using efficient and fair routing protocols, leads to the boost of networks lifetime. Performing fairness means, as identical as possible in energy consumption of the network nodes. In other words, node's remaining energy level should be closer together. If the fairness cannot be respected part of the network nodes, that are being used more, it will lose their energy sooner and become out of service. In this case, the network is divided and cannot preserve its performance and its energy consumption, but actually increases it. By choosing different ways, one can divide the energy between nodes with more fairness.

In this article, the data transmission process in wireless sensor networks is formulated using an optimization based method. The main parameters are the providing fairness in network nodes' energy consumption and accordingly network lifetime. In other words, the main purpose is to reduce variance of nodes available energy based on conditions and limitations of wireless sensor networks. FORP performs routing based on the results which are obtained from the optimization solution.

In this paper, a QoS aware routing protocol for wireless sensor networks is proposed. FORP uses non-linear optimization method to perform routing. Efficiency of the proposed protocol using simulations is evaluated. In section 2 related works are discussed. We have discussed about problem formulation is section 3. Proposed routing protocol (FORP) is explained in Section 3.a in details. Improved Optimization method is considered in Section 4. In Section 5 results of performed simulations are presented. Finally, in section 6 we have concluded the paper and future works are discussed.

II. Related Works

Optimization methods have been used vastly used in various applications in the field of computer networks. To the best of our knowledge, field of wireless sensor networks, is open and good research area. Wireless sensor networks have unique and different QoS parameters; including network lifetime, providing fairness in energy consumption, congestion, delay, jitter, etc. In many routing protocols, fair energy consumption is considered as the main parameter in wireless sensor networks. The just protocol increases network lifetime. If network lives more, its services will be available longer.

As it was mentioned before, optimization problem is used in various network protocols [3]. In traditional networks, such as ad hoc networks [4] and in cellular networks various protocols have been implemented using optimization methods [5]. In [6] two parameters delay and data volume collected by the sink is considered as the goals of optimization problem in wireless sensor networks. Two modes have been considered for data collection parameter: first, flow conservation rule and in second, packet loss. In [6] also 3 applications based on the optimization problem have been proposed: routing in environmental monitoring system, flow control and energy aware flow control; eventually to it uses Makovian chain to model delay. In [7] the queue theory is used. First, the hierarchical topology is considered and then on the data forwarding within the clusters has been discussed. Following three types of sensor nodes, acoustic, cluster head and sink are defined for the network. Acoustic sensor node queue type is considered as *M/M/l* and *M/ G/ l* is considered for cluster head queue. Considering number of cluster member nodes and end to end delay, optimization problem has been presented. Parameters values are depended on the application. In [8] cross layer optimization is considered as a primary goal. Two following parameters are intended in this article, sending rate and energy consumption. Proposed problem in this paper is non- linear and non- convex. In [9] and [10] fuzzy controller is considered beside optimization problem in routing process. In [11] the goal is to locate network nodes in target area due to achieve most efficient routing process. In [12] the wireless sensor network topology with multiple sources and a sink is considered. The aim is to increase the network lifetime by regarding the data link layer and network layer. Proposed problem in this paper is non – linear and convex.

III. Problem Formulation

Optimization problem as expressed in [13] comes in two main parts. The first part called Object, describes the aims of optimization objectives. Objective function can be linear or nonlinear [14]. It is better to present optimization problems with linear objective functions. Generally, solving linear functions is much easier than solving nonlinear functions. The second part of optimization problem is called Subject [13]. Subject contains conditions that should be considered in solution. Subjects can also be linear or nonlinear. In the proposed problem formulation object is nonlinear and subjects are linear.

In this article, routing protocols for wireless sensor networks using optimization is presented. Objective function considers providing fairness in network energy as main parameter. When fairness is provided better, network lifetime will be prolonged undoubtedly. Objective function F is calculated using equation (1).

$$F = \sum_{i \in N_k} F_i \tag{1}$$

(N_k) is the number of network nodes. Each network node calculates F_i using formula (2).

$$F_i = \sum_{j=1}^{n} \sum_{k=1}^{m} \left(e_{ij} - e_{kj}\right)^2 \tag{2}$$

Variable T is considered as the lifetime of the network. We divide the period T to n equal smaller period. The remaining energy of each node in each period is calculated independently and it will be used in the optimization problem. e_{ij} is the remaining energy of j^{th} node in i^{th} time period.

e_{ij} is calculated using Formula (3).

$$e_{ij} = j \times \left[\left(\sum_i X_{ij} \times e_r\right) + \left(\sum_k X_{jk} \times e_s\right)\right] \times timeslice \tag{3}$$

Vector X, determines the portion of each link in the data transmission process. In other words, each link in network is related to one of X's items. Vector X plays main role in proposed FORP routing protocol. By solving optimization problem, vector X is calculated and used in routing. The variables used in the formula (3) are explained respectively.

- X_{ij} , forwarded traffic between nodes i and j through their direct link.
- e_r , Energy used for receiving a data unit
- e_s , Energy used for sending a data unit
- $T = n \times$ *time slice*
- $\sum_i X_{ij}$, input traffic volume to node j through upstream nodes.
- $\sum_k X_{jk}$, output traffic volume from node j toward downstream nodes.

Optimization problem used in the proposed method is expressed in equation (4).

$$Min\ F \tag{4}$$

subject to

$$\sum_{j \in N_k} \left\{ \sum_i X_{ij} = \sum_k X_{jk} \right\} \tag{4-1}$$

$$\sum_{j \in N_k} \left\{ \left[\left(\sum_i X_{ij} \times e_r\right) + \left(\sum_k X_{jk} \times e_s\right)\right] \times T < e_j \right\} \tag{4-2}$$

$$\sum_{i,j \in N_k} \left\{ 0 < X_{ij} < B \right\} \tag{4-3}$$

Function F is considered as the objective function which is calculated using formulas (1, 2 and 3). As presented in formula (2), function F calculates difference between remaining energy of network nodes. Generally, the greater remaining node energy difference is, the larger numeric value for the function F is obtained, so the ultimate goal of optimization function is to minimize function F.

At the rest of this section we will discuss subjects. In equation (4-1) flow conservation role is represented. Simply equation (4-1) expresses that arrival traffic to each network node is equal to its output traffic. Equation (4-2) considers energy consumption in each node. Node's energy consumption should not be more than its initial energy source.

e_j is the primary energy of node j. In this paper, homogeneous sensor network is considered, so all nodes have equal initial energy. Primary energy is independent from node so symbol *e* can be used without *j* index.

In equation (4-3), capacity of network links has been determined. In fact, forwarding traffic from a link should not exceed its capacity. N_k is set of network nodes.

In equations (1, 2, 3 and 4) variables *B*, *N*, e_s, e_r, N_k and network topology are known. Numbers of vector *X* elements are determined based on network topology. As explained before, corresponding to each link, there is an element in vector *X*. Variables q_i , vector *X* and *T* are undetermined; they are output of optimization problem. In sensor networks, some nodes act as a relay node. They only forward their neighbours data and do not collect information from environment. Of course, this behaviour can be limited to a specific timeframe. q_i is node *i* traffic production rate; of course node *i* cooperates in gathering information from environment. Therefore, for this type of nodes equation (4-1) is altered as equation (5).

$$\sum_{j\in N_k}\left\{q_j+\sum_i X_{ij}=\sum_k X_{jk}\right\} \tag{5}$$

After solving equation (4), vector *X* and variable *T* values are determined. Vector *X* will be used in FORP routing protocol.

A. The Proposed Routing Protocol, FORP

As it was mentioned in the previous section, vector *X* contains a set of elements which represents a link in the network. Therefore number of vector *X* elements is depended on network topology. FORP is applicable for all of the wireless sensor networks applications. But it is recommended to use FORP for intra cluster routing.

Each network node knows its downstream neighbors. The aim of routing protocols as other routing protocols is to choose one of downstream neighbors as next hop. FORP uses vector *X* to perform the routing. Downstream neighbors are the nodes which located in the node's radio range and have shorter distance to sink or cluster head. Values of vector *X* elements determine the traffic volume which must be passed through corresponding link. After solving optimizations equations, as discussed in section 3, the volume of traffic which must be passed through each network link will be determined.

Each network node has its own routing table. Table elements are all the downstream neighbours. For each of table elements, based on its corresponding vector *X* value, using equation (6) selection probability will be determined.

$$P_{ij}=\frac{X_{ij}}{\sum_{k\in N_i} X_{ik}} \tag{6}$$

P_{ij} is the probability of transporting traffic through *ij* link. Link *ij* is the link directly connect node *i* to node *j*. X_{ij} (ij[th] elements of vector *X*) is traffic volume which must be passed through direct link between *i* and *j* nodes. N_i is set of downstream neighbours of node *i*; therefore $\sum_{k\in N_i} X_{ik}$ determines overall outgoing traffic from node *i*. By determining P_{ij} for all the outgoing links, next hop node can be selected. When a packet reaches to node, based on each link selection probability, it will be sent through. For example, note to figure 1.

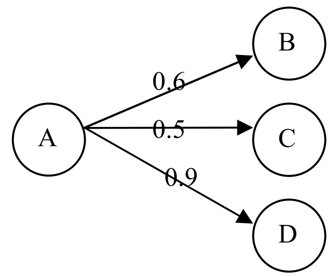

Figure 1- an example for FORP based forwarding

As you can see in figure 1, nodes A, B and C are downstream neighbours of node A. Values of A vector for AB link is 0.4, for AC link is 0.5 and for AD link is 0.9. Mentioned numbers mean that 0.6 of traffic volume should be sent through link AB, 0.5 of traffic volume through link AC and 0.9 of traffic volume through link AC in optimal situation. Based on equation (6), P_{ij} values for B, C, D neighbours in node A routing table are 0.3, 0.25, 0.45 respectively. When node A receives a packet, it will be sent through link AB by 0.3 probability, through link AC by 0.25 probability and through link AD by 0.45 probability.

IV. Adding Fuzzy Variable Due to Controlling Environment Noises

The problem which is formulated in equation (4) is the primary mode of issue considered in this article. In this section by adding environmental contention based fuzzy variable and by reducing the flow conservation rule, we have discussed the problem in another manner. As we know, there is contention in both computer and telecommunication networks. Interference (noise) leads reduction in data transmission quality. Based on inherent characteristics of transmission media, different networks have different level of vulnerability on environmental noises. For example, fiber optic earns contention from environment a little but wireless media acts vice versa. Wireless sensor networks uses wireless media to transmit data. Considering that the wireless media is vulnerable on noise more, we have considered environmental contention as one of optimization problem inputs using fuzzy variable.

In equations (4) flow conservation rule has been considered. This means that arrival traffic volume to the node must be equal to outgoing traffic volume. As mentioned before, here we have considered environmental contention in our problem. On other words, part of forwarded traffic has been vanished in communication links because of environmental contention; therefore flow conservation rule is no more valid.

Improved optimization problem is shown in equations (7).

Min F' (7)

subject to

$$\sum_{j\in N_k}\left\{\sum_i X_{ij} \geq \sum_k X_{jk} \geq \tilde{\gamma}\sum_i X_{ij}\right\} \quad (7\text{-}1)$$

$$\sum_{j\in N_k}\left\{\left[\left(\sum_i X_{ij}\times e_r\right)+\left(\sum_k X_{jk}\times e_s\right)\right]\times T < e_j\right\} \quad (7\text{-}2)$$

$$\sum_{i,j\in N_k}\left\{0 < X_{ij} < B\right\} \quad (7\text{-}3)$$

The relationship between F' and F is explained in equation (8).

$$F' = (\lambda \times F) - (q + T) \quad (8)$$

Considering the aim of equation (7) is to minimize the function *F*, based on equation (8) it is expected that variables *q* and *T* must be maximized. They have negative. In other words, goal is to minimize energy variance (through maximizing the providing fairness in network nodes energy consumption) and to maximize network lifetime and transmitted traffic using whole network.

λ parameter determines importance of function *F* in equation (7). Function F is more important if λ parameter gets higher value. In other words, higher value for λ means, providing fairness is more important rather than two other objective parameters. In next section, λ influence on FORP efficiency will be discussed.

Equation (1-7) is the difference between equations (7) and (4). Equation (7-1) is divided into two parts. These two are presented in equations (9-1) and (9-2) are shown.

$$\forall_{j\in N_k}\left\{\sum_k X_{jk} \leq \sum_i X_{ij}\right\} \quad (9\text{-}1)$$

$$\forall_{j\in N_k}\left\{\sum_k X_{jk} \geq \tilde{\gamma}\sum_i X_{ij}\right\} \quad (9\text{-}2)$$

Equation (9-1) states that the node output is at most equal to its input. Equation (9-2) expresses that the least possible output rate calculated by multiplying $\tilde{\gamma}$ and the actual input rate. By considering two equations (9-1) and (9-2) together, output traffic rate boundary will be earned in comparison with input rate. Equation (9-1) is obvious, because the volume of output traffic can not be more than the input traffic (data that is generated by the node is considered as well as the input traffic.)

In equation (9-2) Fuzzy variable $\tilde{\gamma}$ is used. Fuzzy variable performs the effect of environment noise on data quality. The bigger $\tilde{\gamma}$ means lower environmental contention and lower destructive influence on transmitted data. Variable $\tilde{\gamma}$ has following structure as presented in figure 2.

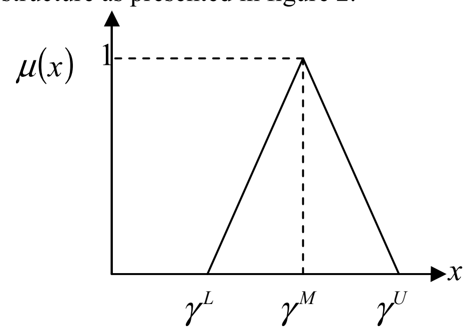

Figure 2- variable $\tilde{\gamma}$ structure

In figure 2, horizontal axis is related to environmental noise and the vertical axis is the membership function of the fuzzy variable $\tilde{\gamma}$. Network designer determines the values for γ^U , γ^M and γ^L based on environment conditions.

Finally, by recognizing variable $\tilde{\gamma}$, equation must be solved with the new conditions. The way to solve the equation should be continued as the following.

Equation (7) should be solved based on the values of variable $\tilde{\gamma}$ separately. Equation (7-1) for different values of $\tilde{\gamma}$ has been improved in equations (10-11-12) respectively. Other equations of (7) will be without any modifications. Therefore, following we have presented only (10-1), (11-1) and (12-1) equations.

$$\sum_{j\in N_k}\left\{\sum_i X_{ij} \geq \sum_k X_{jk} \geq \gamma^U\sum_i X_{ij}\right\} \quad (10\text{-}1)$$

$$\sum_{j\in N_k}\left\{\sum_i X_{ij} \geq \sum_k X_{jk} \geq \gamma^M\sum_i X_{ij}\right\} \quad (11\text{-}1)$$

$$\sum_{j\in N_k}\left\{\sum_i X_{ij} \geq \sum_k X_{jk} \geq \gamma^L\sum_i X_{ij}\right\} \quad (12\text{-}1)$$

By solving equations (10-11-12), values for *F* will be earned separately. We call them F_1, F_2 and F_3 respectively. Now triangular structure must be obtained for the output function, so in equation 13 we have:

$$F_U = \text{Max}\{F_1, F_2, F_3\} \quad (13)$$
$$F_M = \text{Med}\{F_1, F_2, F_3\}$$
$$F_L = \text{Min}\{F_1, F_2, F_3\}$$

Membership function for the conditions is known. With clear output membership function, maximum value for shared area of membership functions should be calculated. In fact, with regard to appropriate value α and based on equation (14) proper point will be found.

Min α (14)

Subject to:

$\mu(F) \geq \alpha$

$\mu(C_i) \geq \alpha$

$\mu(C_i)$ is membership function of each of conditions. By determining α optimal point whom is the answer will be found. In section 5, we will discuss how to use results in modified FORP.

V. PERFORMANCE EVALUATION OF PROPOSED FORP

In this section, FORP efficiency will be studied. We use OPNET [14] as simulator and MATLAB due to solving optimization problem. Following topology which is shown in Figure 3 is used in simulations.

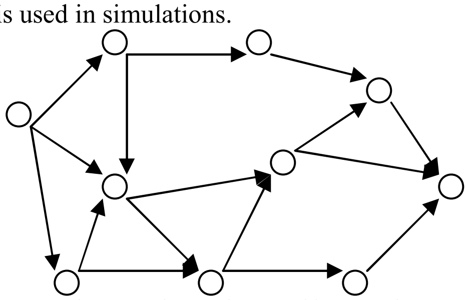

Figure 3- The topology used in network

As you can see in Figure 3, there are 16 links in considered topology; therefore vector *X* should contain 16 elements. We use MATLAB software to solve the optimization problem. We have proposed nonlinear optimization problem, therefore results are related to the corresponding inception point. To catch the best possible answer, we have solved the proposed problem many times. Some of results are presented in table 1.

TABLE 1. DIFFERENT VALUES OBTAINED FOR THE VECTOR X BASED ON THE INCEPTION POINTS

3.27	3.36	3.33	3.11	3.4	3.294
2.62	2.78	3.5	3.36	3.47	3.146
4.1	3.85	3.15	3.52	3.11	3.546
4.1	2.9	2.41	2.5	2.12	2.806
0	0.94	0.74	0.99	0.99	0.732
0.49	1.06	0.76	0.53	0.83	0.734
2.78	2.3	2.577	2.57	2.57	2.5594
0	1.28	1.65	1.93	1.94	1.36
3.11	3.5	3.35	2.95	3.34	3.25
4.1	2.9	2.41	2.52	2.12	2.81
0.57	0.77	1.08	0.94	1.13	0.898
4.67	3.6	3.49	3.47	3.25	3.696
2.18	3.33	3.96	3.77	3.64	3.376
0.35	0.6	1.69	1.75	1.42	1.162
3.14	2.98	2.53	2.75	3.09	2.898
3.14	2.98	2.53	2.75	3.09	2.898
10	10	10	10	10	10
0	0	0	0	0	0

By recognizing the vector *X* in the next phase, using the OPNET simulator FORP efficiency is studied. Cluster head or sink after receiving *X* vector, make and send corresponding routing table to each networks node. Routing table contains all downstream neighbors and probability related to the link connecting the intended neighbor and the node. Nodes determine the next hop neighbor using the routing table.

In figure 4, the energy consumption of nodes has been presented. Vertical axis shows node's available energy and the horizontal axis represents time. Node primary available energy (which is represented by *e*) is 2000 unit.

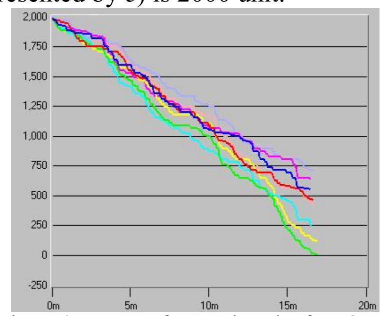

Figure 4- Energy of network nodes for FORP

As observable in Figure 4, the network lifetime is almost equal to 17 minutes. Network lifetime is the duration between the network start time and the time that first node consumed its energy completely. For example, in Figure 4 the node, which is presented by green colored graph, has the highest energy consumption and looses its energy faster than the others. Here providing fairness in node energy can be seen anyhow. At the end of simulation, the most difference is almost 200 units.

To represent proposed protocol efficiency, following two set of graphs has been displayed. First, the results of the stochastic algorithm will be review. Stochastic algorithm selects next hop neighbor between available records in routing table randomly. In other words, all the records have the same chance to be selected as next hop. In figure 5 energy consumption of stochastic algorithm is presented.

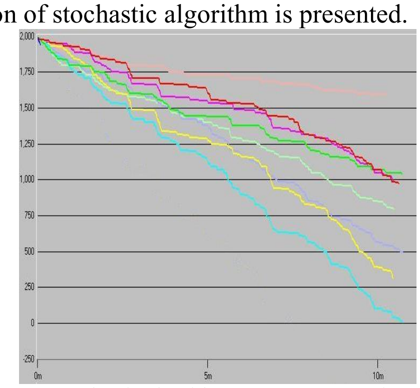

Figure 5- Stochastic algorithm energy consumption graph

As it can be seen in Figure 5, Network lifetime is about 11 minutes. By comparing the results in figures 4 and 5, it is obvious that FORP extends network lifetime by 36 percent. At the end of simulation, the most difference is almost 1600 units. However, the most variance in nodes' energy consumption for FORP protocol was 200 units.

In figure 6, FORP performance has been investigated in another way. One of *X* vector elements is selected randomly and its value has been changed manually in contrast with its previous value. In fact, mentioned *X* vector element is not optimum anymore. In figure 6, 2 different simulation results have been shown for different routing table subversion.

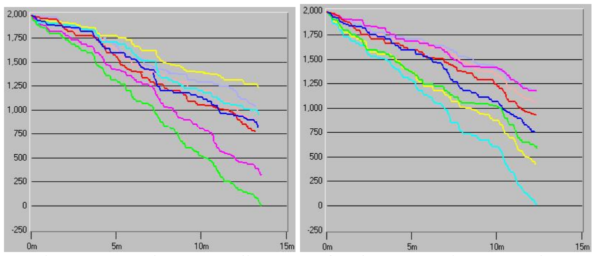

Figure 6 – node energy diagrams, for the non optimum modes

As can be seen in Figure 6, the network lifetime in three modes is 14 and 13.5 minutes respectively. In all three cases, it is observable that the network lifetime has been reduced in comparison with optimum mode. The results are adjusted to our expectations. If any changes are happen in X vector elements values, efficiency won't be optimum anymore and it will be reduced. At the end of simulation, the most variance for three different modes is 1050 and 1200 unit respectively. As the same of network lifetime, providing fairness has been reduced too.

As mentioned in Section 5, performance of objective function in equation (8) is depended on λ. We have considered two values for parameter λ: 1 and 100. In fact, equation (8) is changed into equations (15-1) and (15-2).

$$F' = (1 \times F) - (q + T) \tag{15-1}$$

$$F' = (100 \times F) - (q + T) \tag{15-2}$$

Following values are obtained by solving equation (7). Table 2 shows X vector elements.

TABLE 2. VALUES OBTAINED FOR THE VECTOR X WITH DIFFERENT OBJECTIVE FUNCTION

4.6	0.99	4.3	3.1	1.21	2.46	2.2	1.49	3.2	3.1	1.05	4.18	2.97	0.83	2.8	2.8
3.7	3.44	2.9	2.6	0.32	0.55	3.1	1.3	3	2.6	1.11	3.68	3.27	1.43	2.98	2.98

The first row in Table 2 shows the results of equation (15-2) and second row shows the results of equation (15-1). Node energy variance when equation (15-2) is used is 0.0056 and when equation (15-1) is used is 0.009. It is observable that the variance of node's energy is reduced for the case that providing fairness is more important. For two modes, the input load volume is the same.

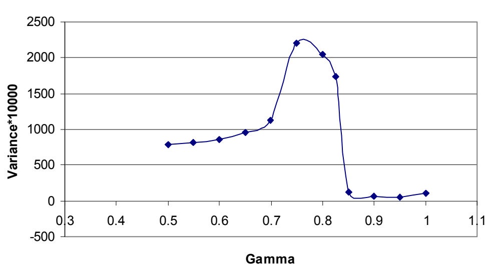

Figure 7- Influence of γ parameter on equation (7)

In figure 7 influence of γ parameter on equation (7) has been investigated.

VI. CONCLUSION

Network lifetime and providing fairness in energy consumption are two key parameters for wireless sensor networks. Of course, these two parameters are depends on each other too. By providing more fair routing process, network lifetime will be prolonged. Routing protocols play an important role in providing quality of service. In this article, using non-linear optimization a new routing protocol which is called FORP is proposed. The main objective of proposed FORP is to provide fairness in node's energy consumption as much as possible. Additionally, using fuzzy variables, we have considered environmental contention in problem formulation. Simulation results show that the proposed routing protocol has achieved its goals. Congestion and delay parameters can be added to optimization process in future.

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