# A new QoS-based data forwarding scheme with wireless sensor networks for environment monitoring

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**Abstract:** In recent years, Wireless Sensor Networks (WSNs) have been emerged as potential challenges in wireless communications. Wireless sensor network consists of the low-cost, low-power, and large-scale wireless sensor nodes. Routing protocols and different mechanism for transmitting data are the principal topics in WSN. In this paper, we propose a new QoS-based data forwarding scheme (QFD) with Wireless sensor network to monitor the environmental conditions. We split whole surface of the environment into several areas. Each area contains information about the environmental status. All sensed data in the areas are transmitted to related cluster head; then they are forwarded to the nearest sink. We use from two sinks in the suitable positions and perform the internal routing by proposed Smart Inner Routing Algorithm (SIRA) for routing data from the cluster heads to the related sink. Furthermore, we propose a Binary Recursive Convergent (BRC) algorithm for data aggregation in the areas. Simulation results show that remainder energy of the sensor nodes is balanced, partly. The performance of the proposed method is compared to DSR protocol. Simulation results illustrate that the proposed method in average delivery ratio, average delay time, network lifetime, consumption energy of nodes, and network traffic is better than other protocol.

[Ali Ghaffari, Amir Masoud Rahmani, Seyyed Hamid Haj Seyyed Javadi. **A new QoS-based data forwarding scheme with wireless sensor networks for environment monitoring.** *Academ Arena* 2018;10(6):55-63]. ISSN 1553-992X (print); ISSN 2158-771X (online). http://www.sciencepub.net/academia. 9. doi:10.7537/marsaaj100618.09.

**Keywords:** Wireless Sensor Network, Monitoring System, Environment monitoring, Data forwarding, Energy efficiency

## 1. Introduction

In WSNs, sensors can sense, collect and send information about the monitored area to sinks. They consist of low cost, large-scale, and low power sensor nodes (Estrin, 2002) (Estrin, govindan, heidemann and komar, 1999). In fact, a Wireless Sensor Network (WSN) is constructed of a large number of the sensor nodes. These sensors collect some of the environmental conditions such as temperature, movement, and pressure (Akyildiz, Su, sankarasubramaniam and Cayirici, 2002) (Karl and willing, 2005). WSN has applications in some ways for internal controlling, environmental monitoring, structural displaying, and medical management (Martinez and Hart, 2004) (Culler, Estrin and Srivastava, 2004) (Akyildiz, Pempili and Melodia, 2005) (Mainwaring, Culler and Plastre, 2002). In this paper, we propose a Wireless sensor network for monitoring the environment conditions to collect and report environmental information. Air and water pollutions in the environment are some of the main reasons to design and implement the proposed system.

Air and water pollution monitoring is a very important and complex task for controlling of the environment. Reporting systems of the air and water pollutions based on the sensor network are not extremely sophisticated (Ma, Richards, Ghanem, Guo and Hassard, 2008) (Hassard, Ghanem, Hassard, Osmond and Richard, 2004). QFD can be implemented as a very flexible and timely system to enhance the environment condition monitoring. The main requirements of QFD are as follows:

- Splitting of monitored area surface into ten areas
- Placing nodes in different areas of the system
- Collecting of the area information for collecting and reporting of the sensed data
- Collecting data of the areas and sending them to the gateway
- Reducing the energy consumption in the areas by data aggregation
- Display the collected data of the areas by statistical methods such as graph lines and tables

- Reporting daily or monthly data and also identifying of the critical conditions

The proposed system consists of the ten areas, two sink, and one gateway in the specified locations. Each area has a cluster head to receive data from the nodes and forward them to related sink. In this system, a Smart Inner Routing Algorithm (SIRA) is proposed for routing data of the sensor nodes to related cluster head. Furthermore, cluster head aggregates the received data by Binary Recursive Convergent (BRC). The aggregated data of cluster heads is transmitted to the related sink directly. Also, sending data of the sinks to gateway is done straightly. SIRA and BRC are principal components of the proposed system.

The subsequent of this paper is structured as the following sections: the related works of the WSN applications are represented in Section 2. In Section 3, the proposed system is discussed. This section consists of the architecture of QFD, packet types, the SIRA algorithm, the BRC technique for data aggregation. The applied hardware chips into the proposed system are described in Section 4. Performance of the proposed methods and comparison results with other routing protocols is represented in Section 5. Finally, the paper will be concluded in Section 6.

## 2. Related Works

In recent years, most applications of the technical fields are designed and implemented by WSN. Military systems, health applications, traffic control systems, environmental observing, habitat monitoring, object tracking, and fire detection are some of the WSN applications (Khemapech, Duncan and Miller, 2005). Controlling, tracking, and monitoring are the major objectives of these applications. Initial applications of the sensor networks are military systems. Recently, most commercial and industrial applications have designed and implemented by WSN. Most applications are developed by these networks to solve problems such as cost and energy constraints.

Monitoring of the human and animal presence can be implemented by WSN. This application consists of the large extent sensors in the required locations (Mainwaring, Culler and Plastre, 2002). In the controlling studies, some of the developed applications by WSN are too expensive compared to the traditional networks. It can be illustrated in the natural proportion of the infrastructure and argumentative status. One of the famous applications in this domain is the Great Duck Island project at Berkley. It consists of a microcontroller, a low-power radio, memory, and batteries.

The sensor networks are applied in the large number of the environmental applications. One of these applications is covering the sensitive zones of forest using WSN. The applied sensors in the mentioned applications detect the origin of the forest fires. In other hands, flood detection system can be implemented by weather sensors. The weather sensors can detect, predict, and prevent the environmental floods. The Forest-Fires Surveillance System (FFSS) (Sen, Her and Kim, 2006) can prevent the forest fires in the South Korean Mountains and alerts an early fire-alarm as a real time state. Some of the environmental information such as humidity, temperature, and smoke can be detected by this system. Moreover, it determines the forest-fires risk-level by a formula. When the forest-fire occurs in the forests, this system alerts an early alarm in the real time. Thus, the economic losses caused by forest fires can be prevented using FFSS. The flood detection and prevention techniques in the ALERT system (ALERT, 2004) have been developed in the US. Rainfalls; in this system, the floods can be detected, predicted, and prevented using water and weather sensors.

Some of the WSN applications can be deployed to control the environments which involve air, water, and soil information. In these applications, sensor nodes are applied to sense information of the environmental conditions and afterwards send them to the related centers. The collected data can be processed by the processing unit and then entered in the decision operations. One of the emerging applications of sensor networks is Precision Agriculture. This system monitors values of the pesticides present in drinking water. Furthermore, the level of soil erosion and air pollution can be controlled by this system (Akyildiz, Su, sankarasubramaniam and Cayirici, 2002). It is noteworthy that the external environment can be controlled by Biocomplexity Mapping system (Keitt, Urban and Milne, 1997). The spatial complexity of the dominant plant species is observed using the related sensors. The surveillance of the marine ground floor is a typical example of this application. This system can be used in places where the erosion process is important for making the offshore wind farms (Heidemann, 2005).

## 3. QFD: The Proposed QoS-based data forwarding scheme for environment monitoring

QFD monitors information about air and water pollution, flood detection, air temperature, water temperature, and intensity of the water waves. In this system, environment surface is divided into ten areas. Each area has a cluster head at the centre point. The cluster head aggregates data of the cluster's nodes; and then sends the aggregated data to the nearest sink. Collected data of the sinks are transmitted to gateway directly. Thus, their location should be such that there is a lower collision signal and less of a barrier between them. Moreover, the proposed system can issue commands to nodes for gathering their information. The overall view and deployment strategy of QFD is shown in Figure 1. The mentioned areas are partitioned based on the 1/100 scale. The major objective is the monitoring the environmental statistic; e.g., temperature and flood detection. Furthermore, surface of the environment is observed by passive microwave remote sensing; e.g., AMSR-E and TRMM. When the surface of water increases significantly, system detects and reports a critical status.

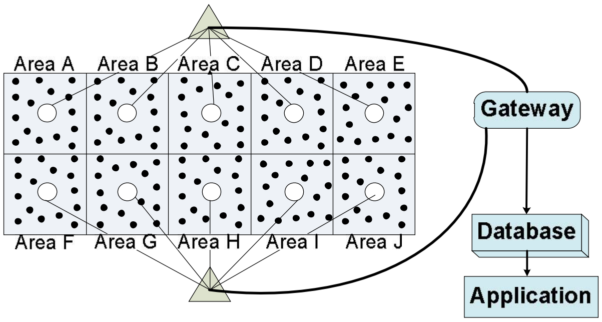


Figure 1. Overall view of the proposed system.

### 3.1 Architecture of QFD

WSN involves of various components such as power, communication, and sensing. Each component performs a special task and is cooperated with other components. Architecture diagram of QFD is depicted in Figure 2.

A brief description of the applied components is represented as below:

- Reading Sensors: The environmental conditions are sensed by reading sensors; then sensed information is transmitted to related cluster heads. Temperature and wet sensors are applied in the proposed system to transmit environmental information to the gateway, ultimately. In this system, we use DS18B20 as the temperature sensor and apply also TLC555 sensor as the wet sensor. Furthermore, exchange of messages between the various sensor nodes is performed by reading transmitters. In this system, we apply HM-T and HM-R transmitters to send and receive data by sensor nodes.
- Power Controller: Each node can be switched to "turn on" and "turn off" states. Thus, this component will start and stop the sensor node; and the required command is just called in the application. The main characteristic of this component is depended to the network simulator.
- Communicator: Communication operation between various components of the system is implemented by the applied simulator. The sockets can provide inter-process communications, actually. Therefore, the simulator manages the sockets by some methods such as "send" and "receive". Furthermore, the proposed SIRA algorithm is applied in this component to select one of the neighbor nodes to transmit data.
- Launcher: Data collector will start the collection operation by this property. This component is based on the delivery mode and is set by the user.
- Data Collector: The collected reading data from the sensor nodes is received by this component. Afterward, it sends the needed messages to notify critical conditions; and it receives the required values, finally. The presented BDET algorithm is applied in this component to eliminate duplicate data.
- Aggregator: Data aggregation of the gathered data is performed using BRC algorithm. Data aggregation is applied by cluster heads of the areas.
- Data Extractor: Extracting data would be designed by SQL queries.
- Data Monitor: The users can see the summarized and statistical information by this element as a table or diagram. Furthermore, the BDET algorithm can be used in this property.
- Data Analyser: The comparison of the gathered data and relation between them are determined by this element. Furthermore, this property causes to extrapolate future readings.
- Node Displayer: Deployment of the sensor nodes in the proposed system can be observed by this component.
- Connection Initiator: This element can be implemented by the simulator. The simulator involves a method to open a database, dedicate a name for database, as well as get a username and password as parameters. Thus, this component is applied to call this method.
- Connection Destructor: The simulator involves a close method to terminate all connections in the system. Also, it saves the latter state. Therefore, this component is used to call this method.

The variant types of the required nodes in the QFD are represented in Table 1. These nodes are deployed in this system as a hierarchy structure. The required strategy to implement the proposed system as below:

- Splitting of the environment region into several areas is the primary step of this strategy. It will lead to better management of very large data. The environment information is collected by the sensor nodes that are located in different areas.

- Each area contains a cluster head to manage its cluster. Cluster head collects data from the sensor nodes, aggregates them, and then sends the aggregated data to related sink.
- The sensor nodes are propagated in the different areas, randomly. They sense the environment information, and then send them to the cluster heads in their respective areas. They use the SIRA routing algorithm to transmit data to cluster head.
- The applied sinks in the proposed system can collect the aggregated data of the cluster heads and transmit them to the gateway. A set of the cluster heads is allocated by any sink. Each sink sends the area information to gateway, directly.
- Finally, gateway transmits the gathered results to the database and designed application.

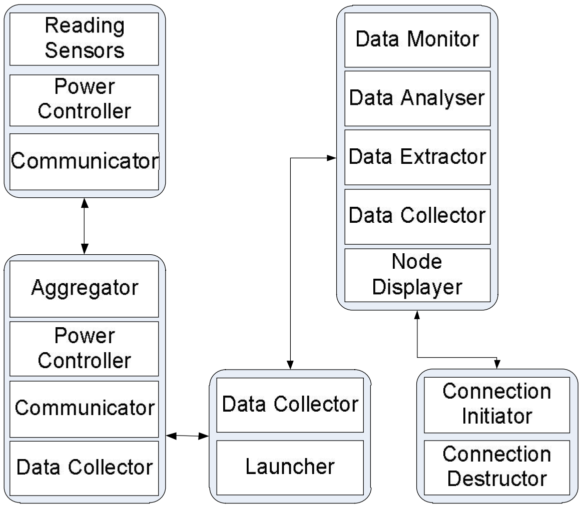


Figure 2. Architecture of QFD.

### 3.2 Packet Types

The proposed system transmits packets at different priorities. Some packets represent the real time events of the system. That is, delay time of these packets is very important. Furthermore, some others are transmitted in a special time. Transmitted packets are classified according to the following priority:

- Critical Packet (CP): Critical packet is the important packet in the presented system. Some of the messages like flood detection are determined as critical conditions; then, they should be transmitted to the respective centers at least time.
- Delay Packet (DP): Some of the packets should be transferred at a specified time. They are identified as delay packet. Detection of the air and water pollutants is a typical example of this packet.
- Reliability Packet (RP): Most packets should be transmitted to the gateway, necessarily. Delay time of these packets is not a very essential factor. Detection of the water temperature is an instance of this packet.
- Ordinary Packet (OP): Some of the packets are specified as the ordinary state. Get healthy or lose these packets is not very important. These packets are considered as lowest priority. Wet detection in the determined environment is a sample of these packets.

Every node consists of a dedicated buffer; and every packet is entered in this buffer. When there is data in the buffer, it will be arranged based on the highest priority. In fact, the packets are sent according to their priority. Therefore, the priority of the packet does not affect on the routing operation.

Table 1. Types of sensor nodes.

| Type of Node | Energy Requirements | Location | Role |
|---|---|---|---|
| Sensor node | Constrained | Random | Sensing and routing by SIRA method |
| Cluster head | Not-Constrained | Fixed | Collection and aggregation |
| Sink | Not-Constrained | Fixed | Collection |
| Gateway | Not-Constrained | Fixed | Collection |

### 3.3 Smart Inner Routing Algorithm (SIRA)

We reached the conclusion that the presented network is needed to an optimal routing into defined areas. We use from SIRA method for inner routing into the mentioned areas. Not generate redundant data and low power consumption are some of the advantages of this method. Mechanism of SIRA is finding a least-cost path from source node to destination node. In here, the source node is the sensor nodes located inside areas, and destination node is the related cluster head.

This method uses a distance-plus-cost heuristic function that is called f (x), usually. It considers the case where the nodes are in the tree. This intelligent algorithm is composed of two main functions:

- First function is the path-cost property that involves the cost from the source node to the current node. It is called g (x), usually. In here, g (x) is the distance between sensor nodes (e.g., g (x) between “x” and “c” is 3.5).

- Another function is an admissible heuristic that is estimated as distance to the destination node. It is called h (x), usually. In here, h (x) is the geographical distance between current node and destination node. Destination node is the placed sink into the area of the source node.

The h (x) property in the f (x) function should be determined as an admissible heuristic. That is, it should not overestimate the distance to the goal. Therefore, h (x) might represent the straight-line to the destination node. In the proposed system, h (x) is the geographical distance to the destination node. This algorithm first searches the routes that appear to be most likely to lead toward the destination node. It is a best first routing as greedy that takes the distance already traveled into routes.

Starting with the source node, this algorithm maintains a priority queue of the nodes to be traversed. It is known as the open set. The lower f (x) for a special node “x” is higher priority of the node. In every step of this algorithm, the node with the lowest f (x) is removed from the queue; and the f (x) and h (x) of the neighbors are updated accordingly; furthermore, the mentioned neighbors are added to the queue. This algorithm continues until a destination node has a lower f (x) than any node in the queue; or until the queue is empty. When the nodes with lower f (x) are remained, the destination node may be passed in the multiple times. Thus, f (x) of the destination node is the length of the shortest path, since h (x) in the destination node is zero. When the actual shortest path is desired, the algorithm may update any neighbor with the immediate predecessor in the best path. These mentioned contents can be applied to reconstruct of the path by working backwards from the destination node. A sample graph for the proposed algorithm is shown in Figure 3. If “X” is the current node and “Y” is the destination node, h (x) is calculated as Eq. 1.

$$h(x)=\sqrt{(X_2-X_1)^2+(Y_2-Y_1)^2} \tag{1}$$

Where X1 and X2 are the geographical coordinates of the X; and Y1 and Y2 are the geographical coordinates of the Y. If L (X) is the selected path from source node to node “x”, and L (Y) is the chosen path from source node to node “y” in the proposed method, then any path X from the source node to node “x” is calculated as Eq. 2.

$$L(X)+h(x)\le L(X)+d(x,y)+h(y)=L(Y)+h(y) \tag{2}$$

Where d (x,y) is the distance between node “x” and node “y”. In the searching process based on above equation, any node with the lowest f (x) is removed from the queue in the steps. Furthermore, f (x) and h (x) of the neighbor nodes are updated; then these neighbors are appended to the search queue.

Some of the taken steps to search the best path from node “x” to node “y” are represented as:

Step1:
f (a)=1.5+4
f (b)=2+4.5

Step2:
f (c)=3.5+2
f (b)=2+4.5

Step3:
f (e)=6.5+4
f (b)=2+4.5

Step4:
f (e)=6.5+4
f (d)=5+2

In above steps, for example, when f (b) is lower than f (e) then node “d” is entered in the search process; node “d” is the subsequent node of the node “b”.

### 3.4 Data Aggregation Using Binary Recursive Convergent (BRC)

Data aggregation can be used in most applications of WSN. Some of the proposed algorithms for data fusion and data aggregation have been represented in Refs. (Rajagopalan and Varshney, 2006) (Albert, Kravets and Gupta, 2007). There is a problem in the routing data from sensor nodes to a single managing entity such as a sink; this problem is the collection operation of the transmitted packets by sensor nodes. Redundant data in the managing entity will be reduced by data aggregation (Younis and Fahmy, 2004) (Cao, He, Fang, Abdelzaher, Stankovic and Son). Furthermore, data aggregation involves techniques to reduce redundant data in the network.

The proposed system observes the environmental status of the mentioned zone. If all sensed data by sensor nodes are transmitted to gateway, more energy is consumed by transmitter nodes. Thus, it is possible to reduce total consumption energy of the sensor nodes using data aggregation. In addition, all data of the sensor nodes are not required to transmit to the gateway; in fact, the data packets should be transmitted to the gateway that indicates the range of values or illustrates the critical conditions of the system, mostly. Therefore, data aggregation will not disturb the proper functioning of the system.

There are some of the methods to summarize the gathered data. We have proposed a method that is called as BRC algorithm. It is a beneficial method for data aggregation of the gathered data that is applied by cluster heads. Minimum, median, and maximum values of the data list are selected by this algorithm. It causes the data list to be summarized into three values. In fact, this algorithm reduces the number of data that are transmitted to the sinks. The functionality of the algorithm is as follows:

- The data list is categorized into several groups
- The length of the data list is calculated
- The multiples list is divided into forms as (x1, y1), (x2, y2),…
- E.g., length = 80, multiples = (1, 80), (2, 40), (4, 20), (8, 10), (16, 5)
- The highest number of the groups (maximize x); and the lowest number of the elements per group are chosen, until keeping the elements above a threshold value (minimize y, y > threshold value)
- E.g., length = 80, threshold = 5, optimal pair = (16, 5)
- Lower, middle, and higher values of the list are calculated
- The resulted binary of the sub lists are merged into one list
- This process is repeated until the final list has only three values

## 4. Experimental Results

In this section, we simulate DSR (David, Johnson and Maltz, 1994), and QFD protocols in MATLAB 7.10. The performance of these protocols is evaluated based on following points of view: data delivery ratio, data delivery delay, and network life. Moreover, we illustrate the impacts of the variant parameters on the mentioned protocols. We use from 50 nodes to analyze the performance of protocols. The dimension of the simulated area is considered as 300 m × 300 m. Transmission range of the sensor nodes is 75 m. data generation of the sensor nodes is generated by Poisson distribution with an arrival interval from 100 to 1,000 round/packet. The applied sensor nodes are assumed as immobile and have initial energy of 1,000 Joules. This network is simulated and analyzed in the 4,000 rounds. In some of the simulation results, we use from cycle instead of the round. Every cycle is composed of the 500 rounds. The reason is that showing the results of all rounds cannot be clear. Therefore, we apply cycle number as a discrete point of the simulated rounds. The experimental parameters and their default values are shown in Table 2.

### 4.1 Impact of Data Generation Rate

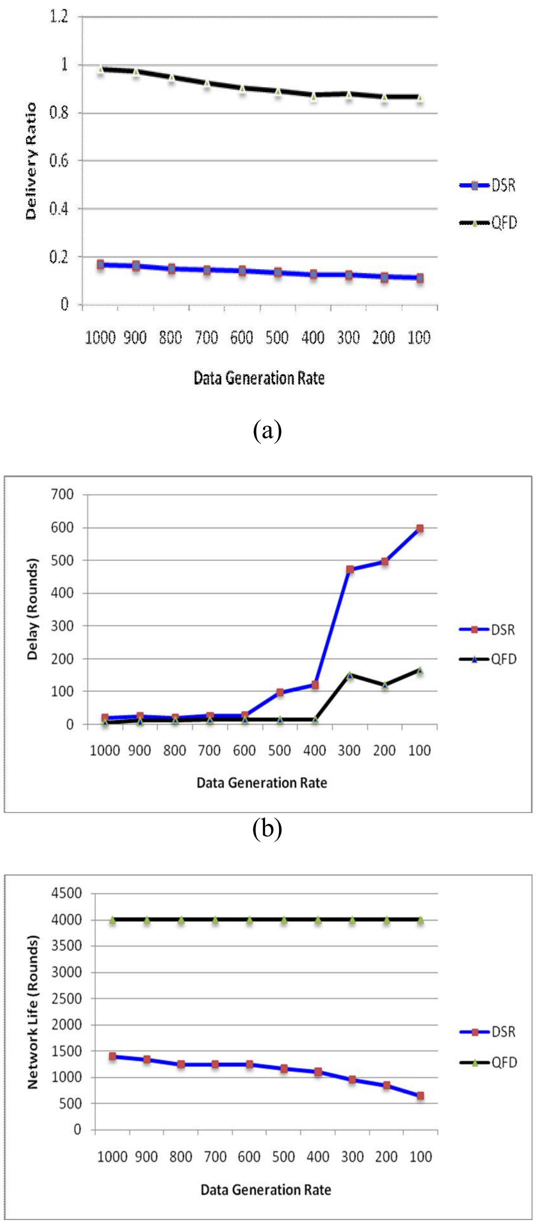
In this section, we evaluate the impact of data generation rate on the delivery ratio, data delay, and network lifetime. This factor analyzes performance of the three protocols in the different generation rates. Data generation rates are varied from 100 to 1,000 round/packet. The performance of these protocols under different transmission load is shown in Figure 3. The simulation results in Figure 3(a) show that performance of QFD is higher than other protocols. The reason is that QFD forward the generated packets through the best path that is selected by the smart proposed algorithm; it this method, every redundant packet is not needed to be transmitted; Thus, network traffic will be low and more packets are transmitted to the gateway. But, much more redundant packets are generated in DSR (David, Johnson and Maltz, 1994) protocol; therefore, performance and delivery ratio of these protocols will be low. We can view from Figure 3(b) that delay time of the proposed method is lower than other protocols, because network traffic in the proposed method is lower than other protocols, and all generated packets are transmitted in less time. Figure 3(c) illustrate network lifetime in QFD is higher than DSR (David, Johnson and Maltz, 1994) scheme; the reason is that much more redundant packets are transmitted in both protocols; thus, much energy is consumed by sensor nodes and network lifetime will be low.

### 4.2 Impact of Initial Energy

The following simulation results in Figure 4 show that network performance of the proposed method is better than other simulated protocols. As shown in the Figure 4 (a), delivery ratio of the QFD is more than other protocols. The reason is that much more redundant packets are generated in DSR (David, Johnson and Maltz, 1994) protocol; thus, network traffic will be high and data packets are transmitted to gateway in much time. Moreover, network performance of all simulated protocols goes up when initial energy of the sensor nodes increases. However, DSR (David, Johnson and Maltz, 1994) protocols have higher-energy requirement.

Table 2. Simulation parameters.

| **Parameter** | **Default value** |
|---|---|
| Network size ($m^2$) | 300 × 300 |
| Number of sensor nodes | 50 |
| Transmission range (m) | 75 |
| Maximum buffer size of nodes (packet) | 10,000 |
| Initial energy (joules) | 1,000 |
| Position of gateway (m) | (500, 500) |



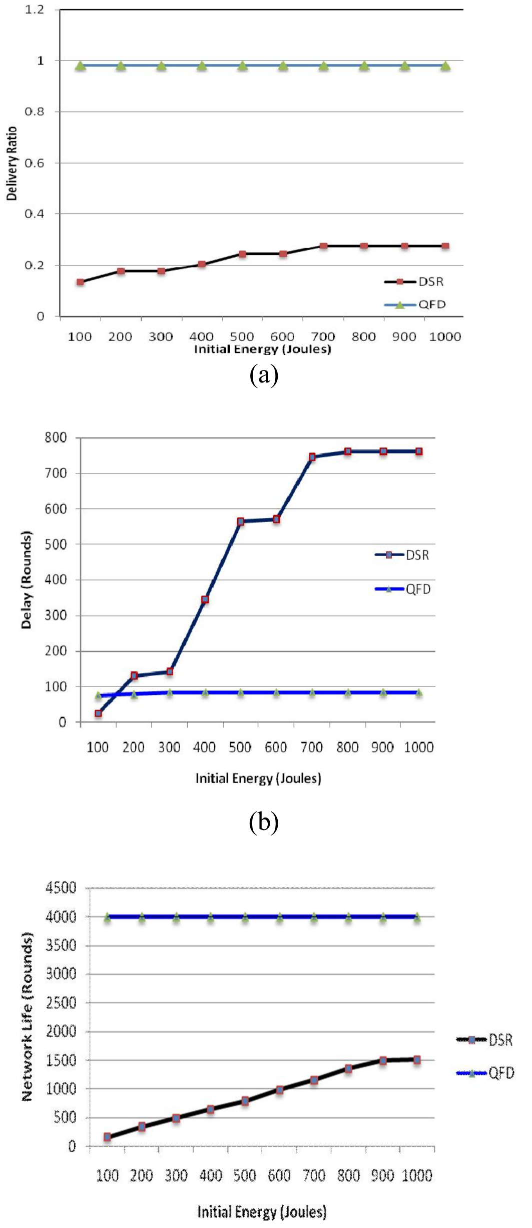
(a)

(b)

(c)

Figure 3. Impact of data generation rate. (a) Average delivery ratio. (b) Average delay. (c) Network lifetime.

As illustrated in Figure 4(b), we see that average delay time of the transmitted packets to gateway in QFD is lower than other protocols; the reason is that network traffic in the proposed method is low and the generated packets often are transferred to gateway in less time; while network traffic in other protocols are transmitted in much time and more time is also needed to transmit data. Furthermore, as the node energy increases, delay time of all protocols will be high; because much more time is needed to transmit the data packets to the gateway and average time of them will be high. The simulation results in the Figure 4(c) show that network lifetime in the proposed method is higher than other protocols; the reason is that much more redundant packets are transmitted in them, and they are needed to more energy for transmission process; thus, consumption energy of sensor nodes in DSR (David, Johnson and Maltz, 1994) will be high and network traffic decrease. Furthermore, the changes in the initial energy have been more effective on the DSR (David, Johnson and Maltz, 1994) protocols; while it has been less effective on the proposed method.



(a)

(b)

(c)

Figure 4. Impact of initial energy. (a) Average delivery ratio. (b) Average delay. (c) network lifetime.

## 5. Conclusions and Discussions

In this paper, we proposed a new QoS-based data forwarding scheme (QFD) for environment monitoring application in Wireless sensor network. The surface of monitored area is partitioned into several areas so that each area has some information about environmental condition status. Furthermore, an internal routing by Smart Inner Routing Algorithm (SIRA) is applied to route data into the partitioned areas. This algorithm removes the duplicated data of the gathered packets. Moreover, a Binary Recursive Convergent (BRC) algorithm is proposed for data aggregation of the sensed data. The cluster heads send the aggregated data to sink by multi-hop delivery. Therefore, QFD is a flexible network, very easy, and powerful system. The simulation results show that network performance of the QFD in the delivery ratio, average delay time, network lifetime, network traffic, and consumption energy of the nodes is better than DSR (David, Johnson and Maltz, 1994) routing protocol. In the our future work we will extend our proposed scheme in order to delete duplicate packets.

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