

Research Article

Performance Evaluation of the WSN Routing Protocols Scalability

L. Alazzawi and A. Elkateeb

Electrical and Computer Engineering Department, College of Engineering, University of Michigan, Dearborn, MI48128-2406, USA

Correspondence should be addressed to A. Elkateeb, elkateeb@umich.edu.

Received 22 July 2008; Accepted 23 December 2008

Recommended by Cheng-Xiang Wang

Scalability is an important factor in designing an efficient routing protocol for wireless sensor networks (WSNs). A good routing protocol has to be scalable and adaptive to the changes in the network topology. Thus scalable protocol should perform well as the network grows larger or as the workload increases. In this paper, routing protocols for wireless sensor networks are simulated and their performances are evaluated to determine their capability for supporting network scalability.

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1. INTRODUCTION

Sensor networks consist of a large number of small sensor devices that have the capability to take various measurements of their environment. For instance, such measurements can include acoustic, magnetic, and video information. Each of these devices is equipped with a small processor and wireless communication antenna and is powered by a battery making it very resource constrained. These sensors are typically scattered around a sensing field to collect information about their surroundings.

Deferent routing protocols are designed and implemented for WSNs [1]. The design of these routing protocols is influenced by many factors where the scalability factor is considered as one of these important factors. The sensor networks scalability is the ability to support network expansion to include more nodes that might not be anticipated during the initial network design stage. Therefore, the routing protocols used for wireless sensor networks should support network scalability where such protocols should continue to perform well as the network grows larger or as the workload increases [2].

As the routing packets within a large-scale wireless sensor network occur on nodes that have very limited resources of packets storage and updates routing table processing, the routing processing has become a very challenging issue.

Therefore, in order to constrain such limitations, efficient and scalable routing protocols design is required for routing packets in sensor networks [2]. Such routing protocols should avoid degrading the performance of the wireless sensor networks as the network expanding.

The evaluation of the scalability issue with wireless sensor networks is a real challenge due to the variety of routing protocols, the large nodes number, and the wide range of sensor networks applications. Therefore, the evaluation of the sensor networks scalability is not practically feasible over a real network, and using network simulator will provide a meaningful perspective into the study of the sensor networks scalability [3]. Thus the goal of this paper is to develop a detailed simulation framework, which can accurately model different sensor networks routing protocols.

2. ROUTING PROTOCOLS FOR SCALABILITY EVALUATION

Many routing protocols have been proposed for routing data in wireless sensor networks. These routing protocols have considered the characteristics of sensor nodes along with the application and architecture requirements [4]. Three different protocols have been selected in this evaluation study: the flooding protocol (FP) [5], the beacon vector

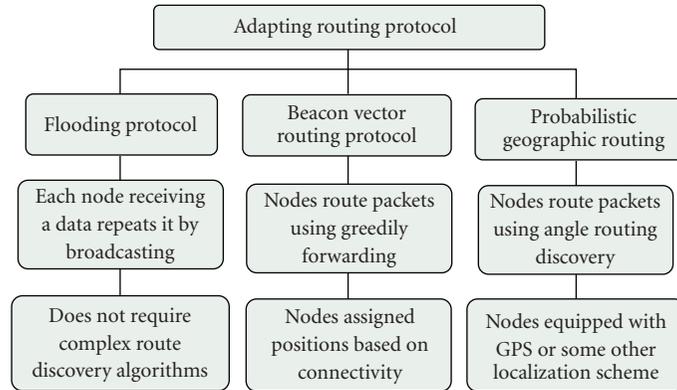


FIGURE 1: Selected routing protocols for scalability evaluation.

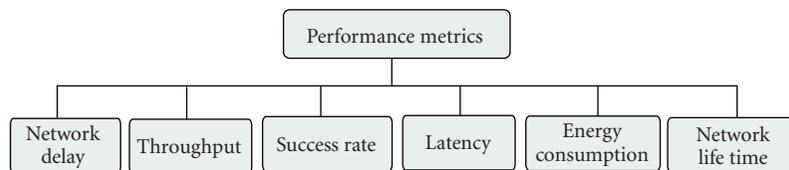


FIGURE 2: A set of performance metrics.

routing protocol (BVR) [6], and the probabilistic geographic routing protocol (PGR) [7] (see Figure 1). Using these three different protocols for evaluating scalability issue in WSNs can be expanded in future work to support other protocols.

The beacon vector routing protocol (BVR) is a hierarchical-based routing protocol which is assigned coordinates to the nodes based on the vector of hop count distances to a small set of beacons, and defines distance metric on these coordinates. The BVR routes packets greedily forwarding to the next hop. That is, the closest to the destination according to this beacon vector routing. The probabilistic geographic routing protocol (PGR) is location-based routing that assumes each node is aware of its geographical coordinates through some localization scheme, such as the GPS. The flooding protocol (FP) is one of the available flat-based routing protocols. In this protocol, each intermediate node that receives a packet simply forwards it to all its neighbors until it reaches the destination. Flooding protocol is selected because of the simplicity of this flat protocol that can be used to compare other protocols scalability with this flooding protocol [4].

3. THE COMPARISON QUANTITATIVE METRICS

In order to compare FP, BVR, and PGR protocols' scalability, the quantitative metrics are used to measure and evaluate the performance of the simulated routing protocols. For all metrics, the average over multiple experiments is determined. The set of performance metrics used for comparing the

selected routing protocols of this work is shown in Figure 2. Each of these metrics parameters can be described briefly as follows [8].

(a) Network delay

This performance metric is used to measure the average end-to-end delay of data packet transmission. The end-to-end delay implies the average time taken between a packet initially sent by the source, and the time for successfully receiving the message at the destination. Measuring this delay takes into account the queuing and the propagation delay of the packets.

(b) Network throughput

The end-to-end network throughput measures the number of packets per second received at the destination. It is considered here as an external measure of the effectiveness of a protocol.

(c) Success rate

The total number of packets received at the destinations verses the total number of packets sent from the source.

(d) Latency

The average message latency is defined as the average amount of time between the start of disseminating a data and its arrival at a node interested in receiving the data. Hence,

the latency measures time performance for the individual message [9].

(e) Energy consumption

The energy consumption is the sum of used energy of all the nodes in the network, where the used energy of a node is the sum of the energy used for communication, including transmitting (Pt), receiving (Pr), and idling (Pi). Assuming each transmission consumes an energy unit, the total energy consumption is equivalent to the total number of packets sent in the network.

(f) Network lifetime

It is considered as the time until message loss rate is above a given threshold. The more complete definition for the lifetime of the network is “time to network partition” [10]. Network partition occurs when there is a cut-set in the network. It will be introduced as a new metric, which will use energy variance:

$$\begin{aligned} \text{Network lifetime} &= E - (\underline{U} + \sigma), \\ \text{where } \underline{U} &= \frac{\sum U_i}{N}. \end{aligned} \quad (1)$$

E is the total initial energy at each node (full battery charge), U_i is the average used energy, N is the total number of nodes in the network, and σ is expressed as

$$\sigma^2 = \frac{(U_i - \underline{U})^2}{N}. \quad (2)$$

All these metrics are calculated using their cumulative average values, that is, at time t , the performance value is the average from 0 to t (seconds) [11].

(g) Packet generation rate

It is the number of packets that the sensor node transmits in one time period which is usually one second.

4. SIMULATOR

Many network simulators are currently available such as SensorSim [12], TOSSIM [13], NS2 [14], OPNET [15]. However, we decided to use the prowler simulator in this research work because of our previous experience with this simulator, easy to use, and it is available online [16].

We have used the prowler network simulator to evaluate the protocols performance and specifically to measure their scalability. A prowler is an event-driven tool that simulates the nondeterministic nature of the communication channel and the low-level communication protocol of the wireless sensor nodes [4]. To produce replicable results while testing the application, prowler can be set to operate in deterministic mode also. It can incorporate arbitrary number of nodes on arbitrary and even dynamic topology. Prowler models all the important aspects of the communication channel and the application. The tool is implemented in MATLAB, thus it

provides a fast and easy way to prototype applications, and has nice visualization capabilities [10].

The nondeterministic nature of the radio propagation is characterized by a probabilistic radio channel model. The applications interact through a set of events and commands just like in actual TinyOS applications. The radio propagation model determines the RF signal strength at a particular point in the space for all transmitters in the system. Based on this information, the signal reception conditions at the receivers can be evaluated and collisions can be detected. Similarly to the real TinyOS framework, prowler applications are event based.

The simulator signals important events for the application code, such as initialization completed, packet sent, packet received, packet collided, and clock ticked. The application in turn can initiate actions such as set clock and send packet. These can cause further events. Several debugging/visualization tools are also available, including switching mote LEDs on/off, drawing lines and arrows, and printing text messages.

4.1. Protocols performance

A set of simulations are used to evaluate the performance of the protocols: FP, BVR, and PGR. The simulations are all performed using prowler under the default radio model $\sigma_\alpha = 45$, $\sigma_\beta = 0.02$, and $p_{\text{error}} = 0.05$. The average radio range of transmission was a radius of 10 m. However, the radio model in prowler was set up to model the transmission range as an imperfect circle. The network setup consisted of 100 nodes dispersed in an area depicting 100 m \times 100 m. The simulations are run on random networks model, where the nodes placements are changed randomly in uniformly square area. The sensors are deployed in a regular grid with random offsets.

The performance of the protocols is evaluated under two setting referred to firstly in the relation of simulation time in seconds with defiant quantitative metrics include (success rate, latency, and throughput. Secondly, it is reflected through the relation between average delays, total throughput, and total energy used. All the results are driven from five runs for the random network models for each of the three protocols. Figures 3, 4, 5, and 6 illustrate the performance of the flooding protocol. Figures 7, 8, 9, and 10 illustrate the performance of the PGR protocol and Figures 11, 12, 13, and 14 illustrate the performance of the BVR protocol.

4.1.1. Flooding protocol performance

Figures 3–6 are illustrating the flooding protocol performance.

4.1.2. PGR protocol performance

Figures 7–10 are illustrating the PGR protocol performance.

4.1.3. BVR protocol performance

Figures 11–14 are illustrating the BVR protocol performance.

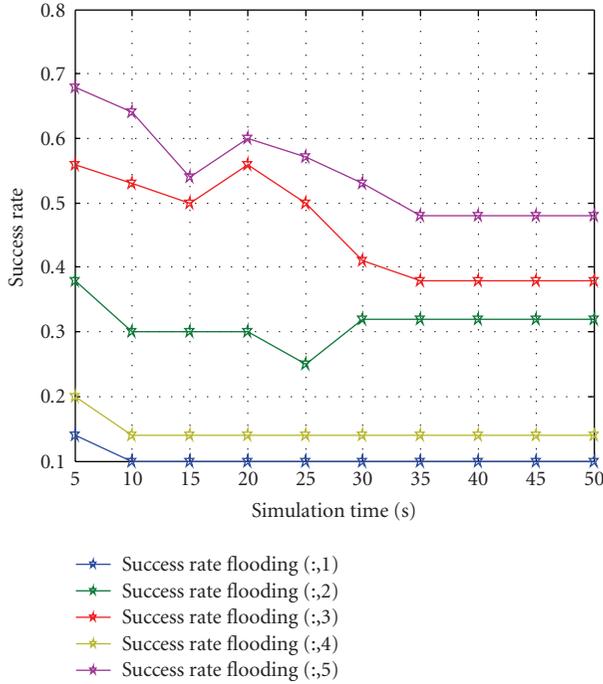


FIGURE 3: Simulation time and success rate.

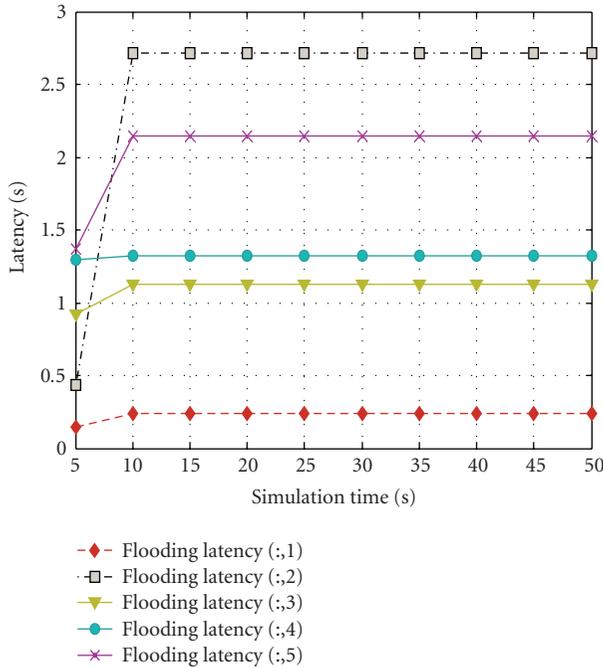


FIGURE 4: Simulation time and latency.

4.2. Effects of routing metrics on the scalability according to the packet generation rate

The first study of the network scalability for the selected routing protocols is by using different packet generation

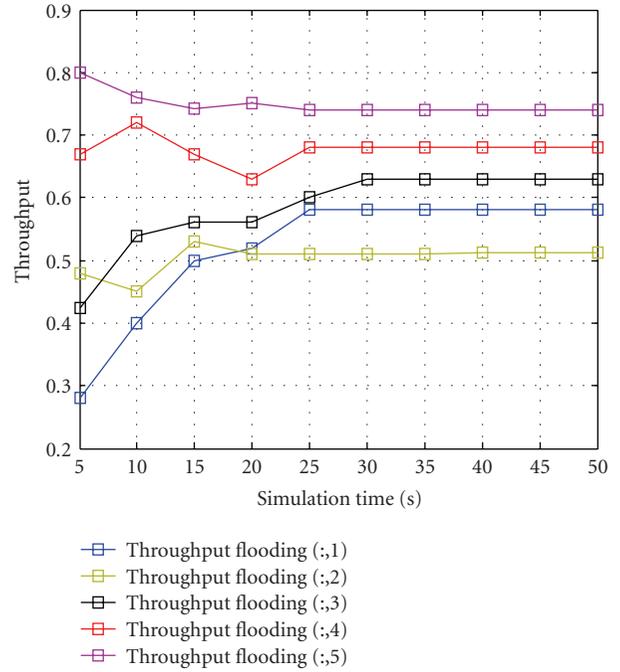


FIGURE 5: Simulation time and throughput.

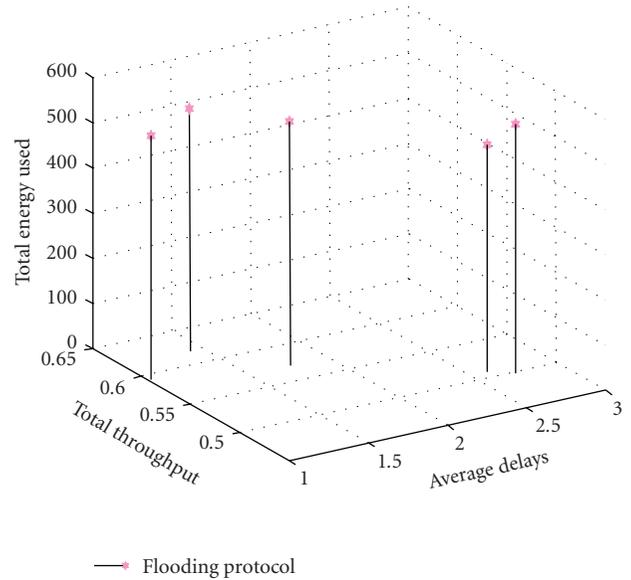


FIGURE 6: Average delays—total throughput—total energy used.

rates in a prowler simulator. We randomly place 100 sensor nodes in a 100 m × 100 m sensor field for each protocol. The default prowler radio model is used. Each routing protocol test is performed (with query and event locations randomly selected) which, started by one packet and then increased the number of packets. In this section, performances of the selected routing protocols with increased workload are evaluated as follows.

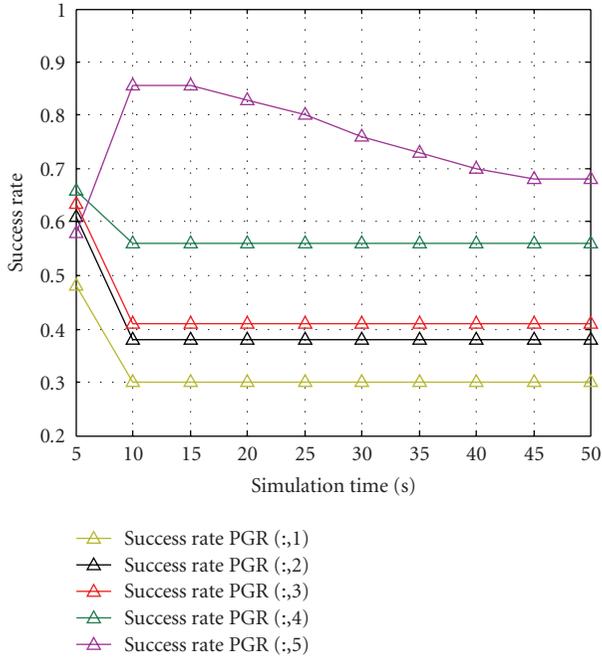


FIGURE 7: Simulation time and success rate.

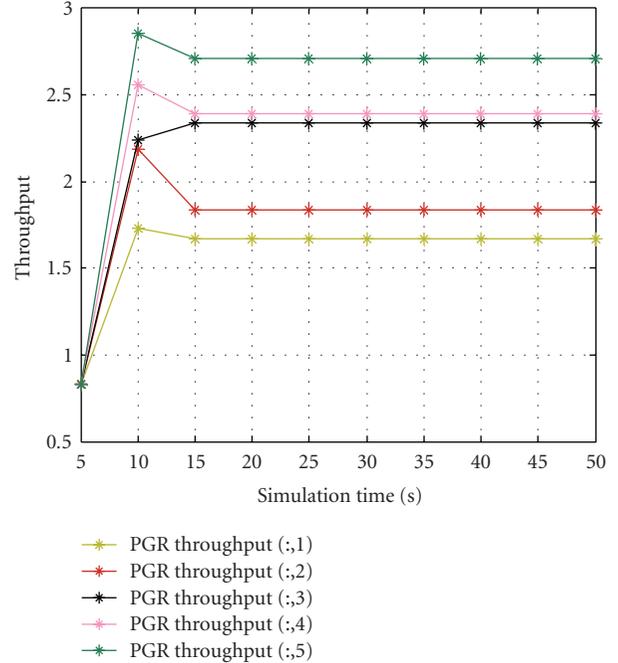


FIGURE 9: Simulation time and throughput.

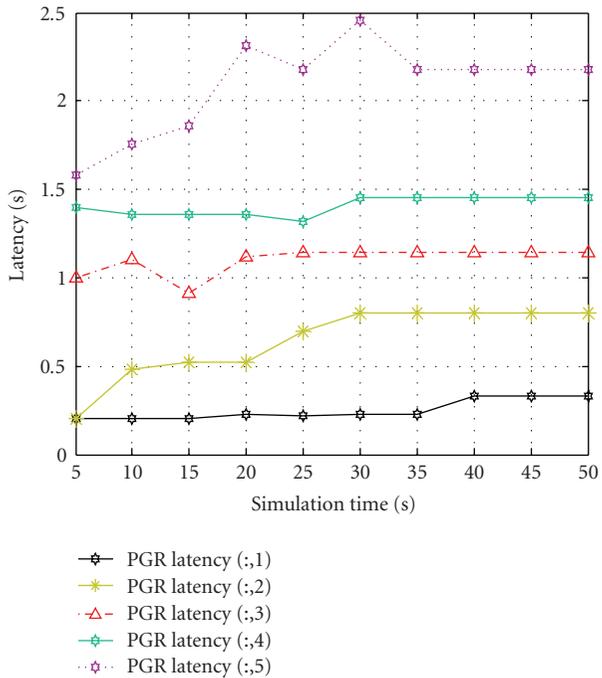


FIGURE 8: Simulation time and latency.

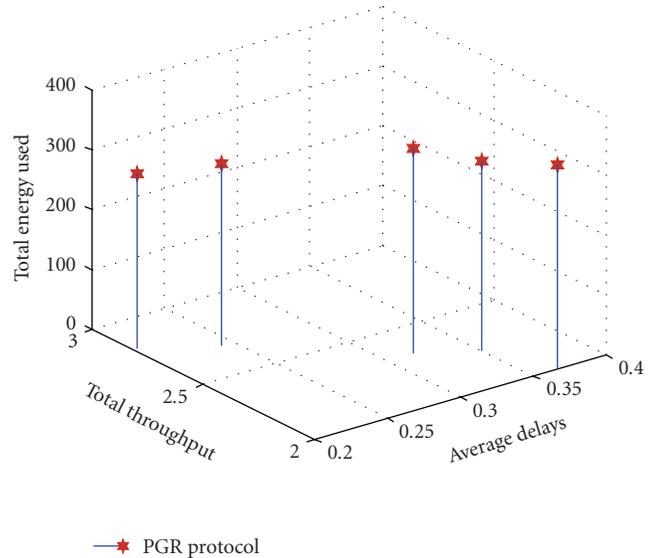


FIGURE 10: Average delays—total throughput—total energy used.

Figure 15 compares the energy used for the flooding, BVR, and PGR protocols with respect to packet generation rate. The results show that the energy used experienced by BVR protocol is lower than the other protocols.

The message latency can be an important parameter for the scalability of the protocols. The intrinsic relative low

latency characteristic can be used as a tradeoff to extend the network performance in accordance with the protocol constraints. The BVR protocol gave the lowest latency among the PGR and flooding protocols with increasing the packet generation rate as shown in Figures 16.

With increasing the packet generation rate, the average packet delay in the flooding protocol gave the highest delay among others as shown in Figure 17. As an average, this highest value was 0.264 second. For the BVR protocol, this was the best because it gave much lower delay than the

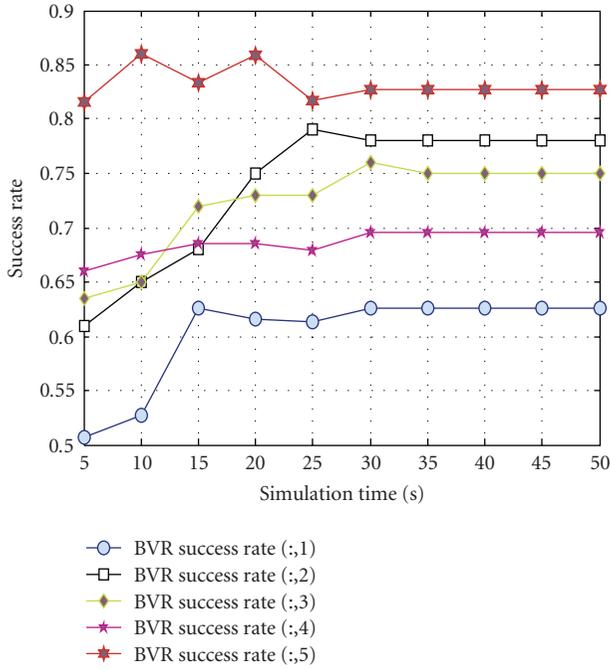


FIGURE 11: Simulation time and success rate.

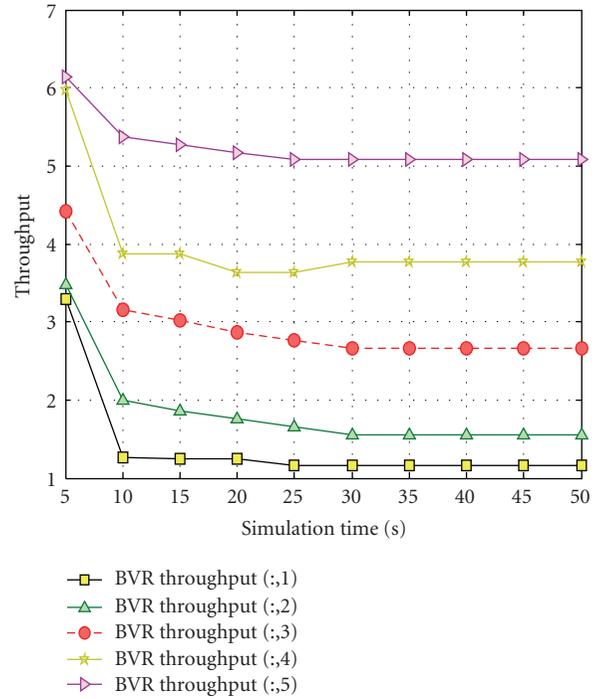


FIGURE 13: The simulation time and throughput.

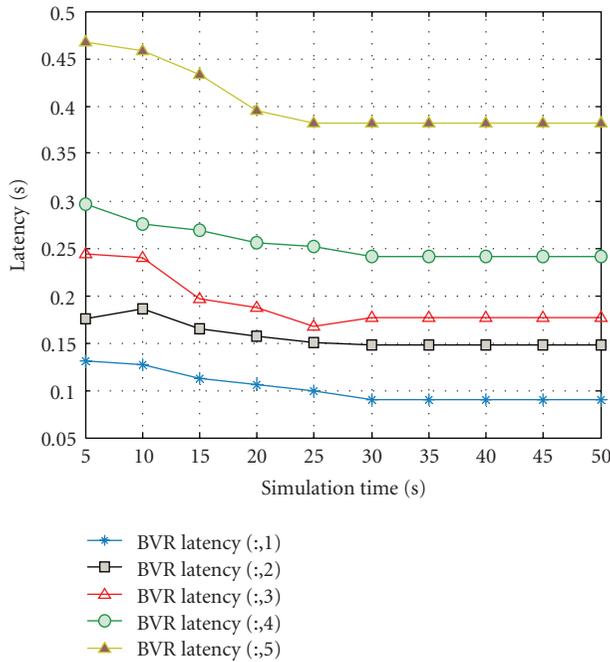


FIGURE 12: Simulation time and latency.

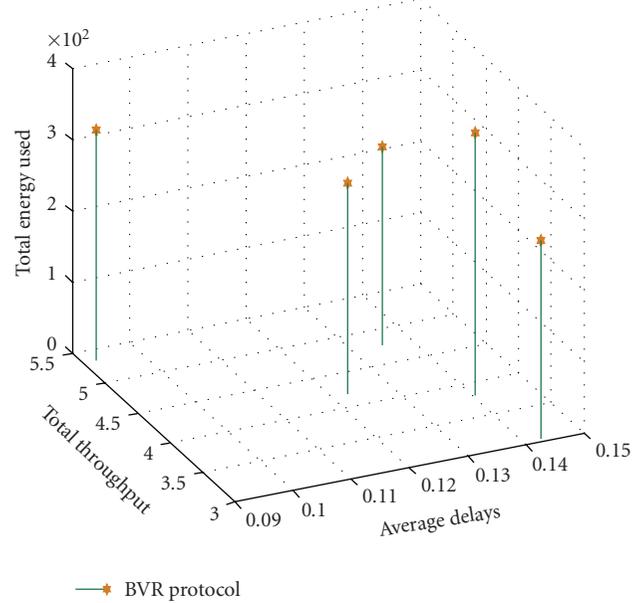


FIGURE 14: Average delays—total throughput—total energy used.

two other protocols that intern it gave an average of (0.075) second.

Figure 18 shows the network lifetime of the three protocols as the packet generation increases. We observe that the network lifetime of each protocol is decreased. The BVR protocol was the longest network lifetime while the

flooding protocol gave the shortest network lifetime. This was expected since flooding is a very energy-consuming task.

4.3. Effects of routing metrics on the scalability according to the network size

This section turns our attention from the scalability to the behavior of the protocols with respect to increasing the

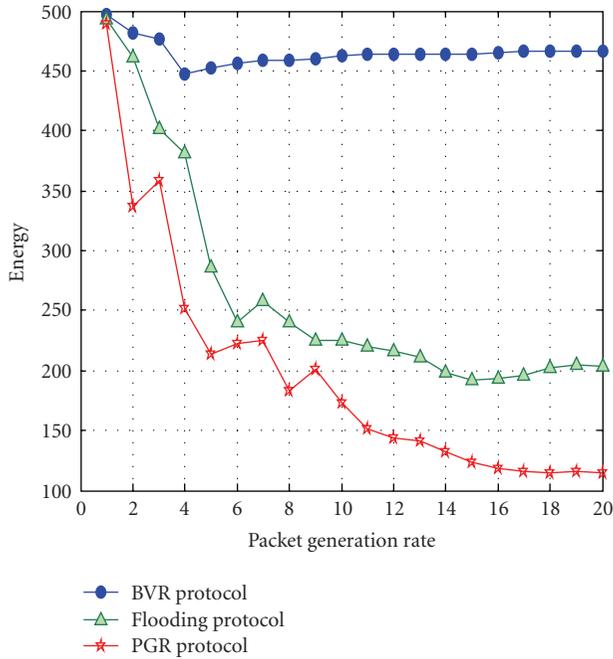


FIGURE 15: Energy test.

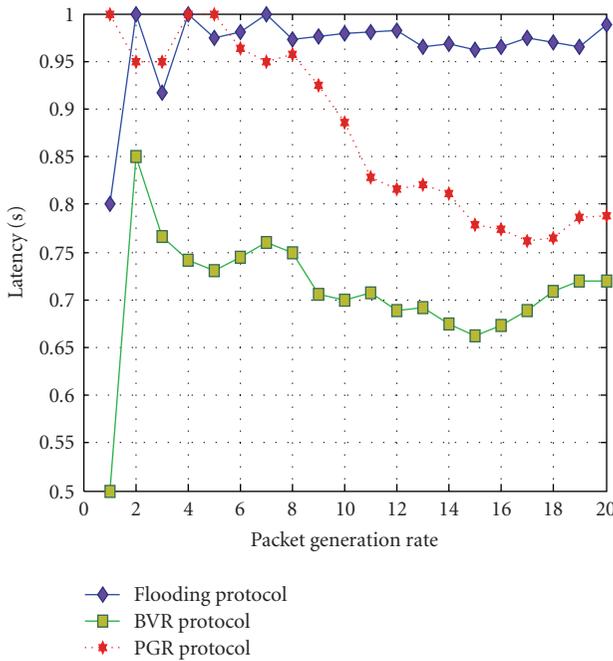


FIGURE 16: Latency test.

number of nodes in the network. The transmission range of each mote is set to 10 units and runs the protocols with 50 to 500 nodes in steps of 50 sensor nodes (motes placed) in a grid. From the observed performance metrics for each of these protocols with increasing of network size, we obtain the following.

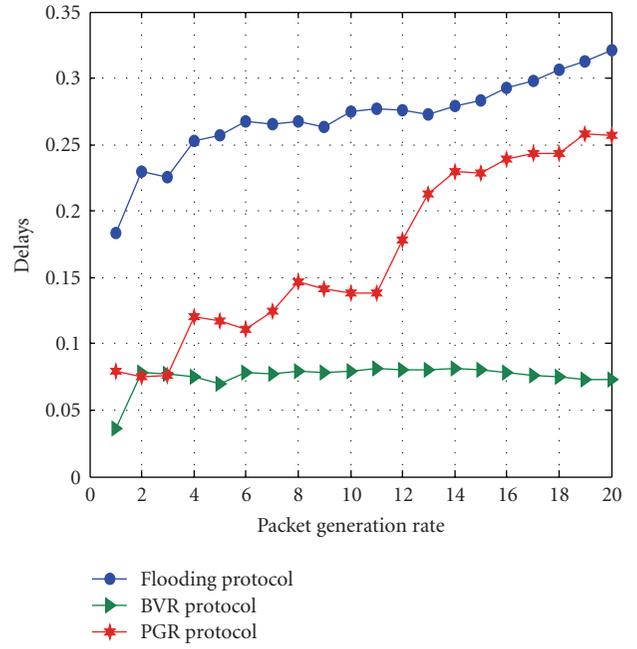


FIGURE 17: Average packet delay test.

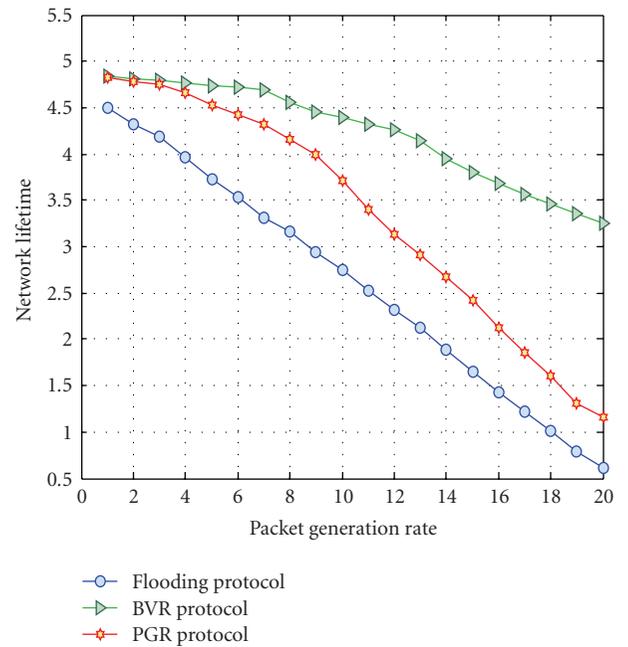


FIGURE 18: Network lifetime test.

- (i) The BVR protocol achieved the best success rate over different network sizes in comparison with PGR and flooding protocols that gave a lower success rate, respectively, as shown in the Figure 19.
- (ii) The average throughput for BVR was about 73% over different network sizes as shown in Figure 20. While the flooding protocol has about 43% throughput and PGR protocol has about 47% throughput when the number of sensor nodes in the networks is increased.

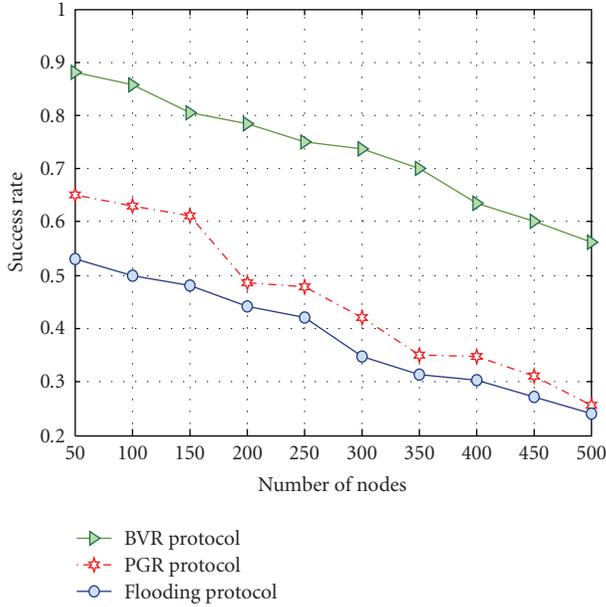


FIGURE 19: Success rate test.

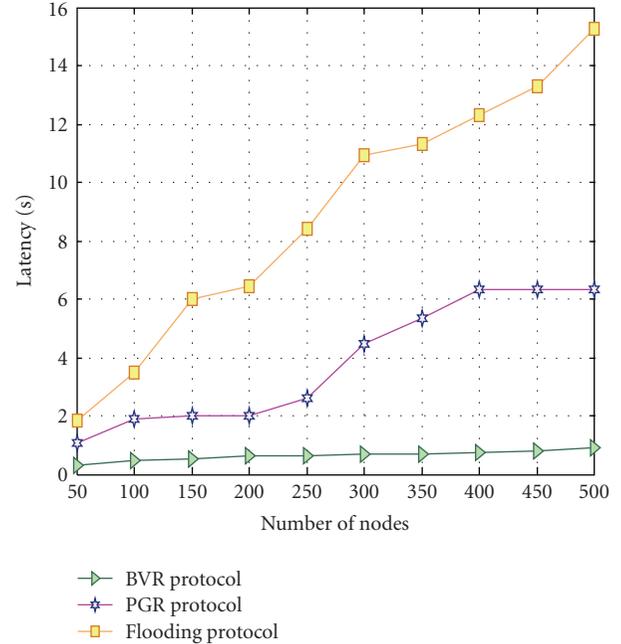


FIGURE 21: Latency test.

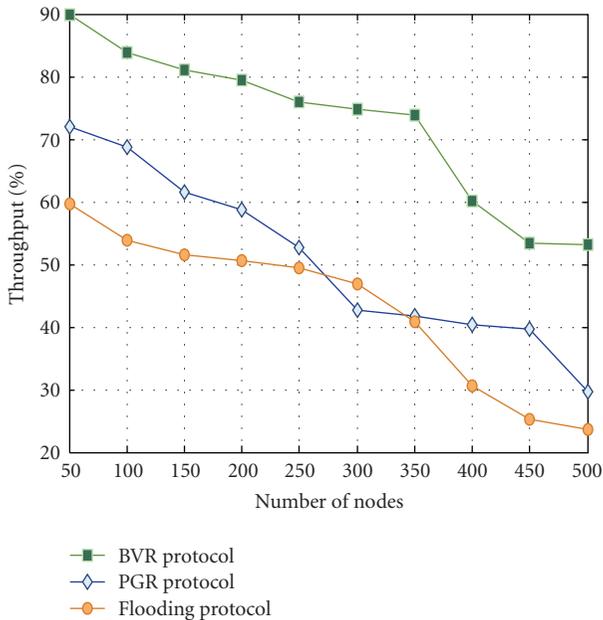


FIGURE 20: The throughput test.

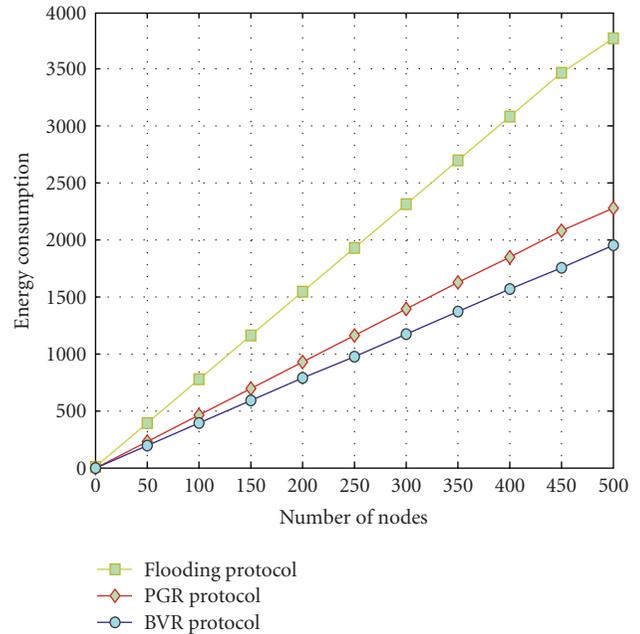


FIGURE 22: The energy consumption test.

- (iii) The PGR protocol gave a lower latency than the flooding protocol with increasing of network size as shown in Figure 21. Among them the BVR protocol gave the lowest latency with increasing the network size.
- (iv) The energy consumption of the BVR protocol was the lowest in comparison with the rest of protocols according to the increasing number of nodes as shown in Figure 22.

5. CONCLUSIONS

In this work, three WSN protocols, namely, BVR, PGR, and FP were simulated using advance wireless sensor simulator (prowler). Several tests were carried out using different network parameters of WSNs. The performance of different routing protocols is measured to determine the most efficient one for the scalability. After evaluating several metrics which are throughput, latency, energy consumption,

and delay, it was found that the BVR protocol is the most efficient scalable protocol.

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