ISSN 2319-2720
Volume 2, No.4, October - December 2013
International Journal of Computing, Communications and Networking
Available Online at http://warse.org/pdfs/2013/ijccn08242013.pdf

Performance Evaluation of Energy-aware Swarm Intelligence Based Routing Protocols for Wireless Sensor Networks Based on Different Radio Models

Adamu Murtala Zungeru[1], Enesi Asizehi Yahaya[2], Caroline Omoanatse Alenoghena[3]
[1] Federal University of Technology Minna, Nigeria, adamuzungeru@ieee.org
[2] Federal University of Technology Minna, Nigeria, enesi.asizehi@futminna.edu.ng
[3]Federal University of Technology Minna, Nigeria, carol@futminna.edu.ng

ABSTRACT

A routing protocol is the *nervous* system of any computer network. In a network where hundreds or thousands of nodes are working simultaneously, the job of a routing protocol is to identify/discover one or more path connecting a pair of nodes under a given set of constraints. The prime requirement for a routing protocol is to optimize the network performance. On the other hand, ad hoc networks form a distinct category of networks whereby nodes are wirelessly connected to each other and may be in constant random motion. However, in ad hoc networks like sensor networks, the performance differs with different radio models. This paper present simulation results of the comparative investigation of the performance of swarm based routing protocols for wireless sensor networks (WSNs) based on different radio models using routing modeling application simulation environment (RMASE), an application built on a probabilistic wireless network simulator (PROWLER). Our simulation results indicate that the energy aware routing objectives of Termite-hill, Sensor driven and cost-aware ant routing (SC) and Improved Energy Efficient Ant Based routing (IEEABR) protocols increases the network lifetime for Normal Radio Model (NRM), Radio Model with Signal-to-Interference-plus-Noise Ratio (RMSINR) and Radio Model with Rayleigh Fading (RMRYF)..

Keywords: Termite-hill, Beesensor, Energy Efficient Ant Based routing, Radio Model, RMASE, PROWLER, wireless sensor networks.

1. INTRODUCTION

Wireless sensor networks (WSNs) are collections of compact-size, relatively inexpensive computational nodes that measure local environmental conditions, or other parameters and forward such information to a central point for appropriate processing. WSN is used in many applications such as: radiation and nuclear-threat detection systems, weapon sensors for ships, toxins and to trace the source of the contamination in public-assembly locations, structural faults (e.g., fatigue-induced cracks) in ships, volcanic eruption, earthquake detection, aircraft, and buildings, biomedical applications, habitat sensing, and seismic monitoring.
A routing protocol is the *nervous* system of any computer network. In a network where hundreds or thousands of nodes are working simultaneously, the job of a routing protocol is to identify/discover one or more path connecting a pair of nodes under a given set of constraints. The discovered paths are then used for information exchange. A lot of research has been done recently on routing mechanisms that take QoS specifications into consideration as surveyed in [1]. A new routing metric for optimization to increase lifetime in the case of the normal radio model using social insect behaviors has been proposed in [2-4]. However, the effect of energy-aware routing objective has been studied in the case of normal radio model (NRM) only. In the literature, moreover, it has been found that the performance of WSNs with various routing protocols has not been carried out in the presence of realistic fading models. In this work, we studied and analyzed the effect of energy-aware routing objective to increase lifetime in the case of radio model with SINR (RMSINR), radio model with Rayleigh fading (RMRYF) and NRM for Termite-hill [2,4,5], Sensor driven and cost-aware ant routing (SC) [6] and IEEABR [7].

However, as pointed out above, less work has been done in the in-depth study of the effect of the energy-aware routing objective for swarm based routing protocols using different radio models in WSNs. This paper compares the performance of some selected energy optimized and most recent swarm based routing protocols for WSN using different radio models. The comparison has been done on the basis of performance analysis and comparisons of lifetime metric (years) using RMASE [8], an application built on PROWLER [9]. Simulation results show that the Termite-hill protocol can be applied to achieve better energy consumption, efficiency and lifetime in real time as compared to Beesensor and IEEABR protocol.

The remainder of this paper is organized as follows: Section 2 describes the simulation environment and models used. In Section 3, we analyze the performance of protocols with respect to their lifetime for different radio models. We give concluding remarks and discussions in Section 4.

2. SIMULATION MODEL

Presently, there are quite a number of network simulators are available for both commercial use and academic research use such as SensorSim [10], TOSSIM [11], NS2 [12], OPNET

[13]. In this paper a Matlab-based simulation environment RMASE [8], an application built on PROWLER [9] has been used which was developed by NEST, Vanderbilt University. It provides an easy way of application prototyping with nice visualization capabilities. RMASE provides network generation and performance evaluations for routing algorithms. It supports a layered architecture, including at least the MAC layer, a routing layer, and the application layer, with the MAC layer at the bottom and the application layer at the top. It is the algorithm designer's choice to put individual functions at different layers so that common functions can be shared by different algorithms. It is an event-driven tool that simulates the non-deterministic nature of the communication channel and the low-level communication protocol of the wireless sensor nodes [1]. To produce replicable results while testing the application, prowler can be set to operate in deterministic mode also. It can incorporate an arbitrary number of nodes on arbitrary and even dynamic topology. Prowler models all the important aspects of the communication channel and the application. Here the following radio and MAC models have been used for comparison among the routing protocols to investigate their performance.

2.1 Radio, MAC and Routing Models

The simple radio model in PROWLER attempts to simulate the probabilistic nature of wireless sensor communication observed by many. PROWLER consists of radio model as well as a MAC-layer model. The MAC layer simulates communication is modeled by a simplified event channel that simulates the Berkeley motes' CSMA MAC protocol, including the random waiting and back-offs. When the application emits the *Send Packet* command, after a random *Waiting Time* interval the MAC layer checks if the channel is idle. If not, it continues the idle checking until the channel is found idle. The time between idle checks is a random interval characterized by *Back off Time*. When the channel is idle the transmission begins, and after *Transmission Time*, the application receives the *Packet Sent* event. After the reception of a packet on the receiver's side, the application receives a *Packet Received* or *Collided Packet Received* event depending on the success of the transmission.The radio propagation model determines the strength of a transmitted signal at a particular point of the space for all transmitters in the system. Based on this information, the signal reception conditions for the receivers can be evaluated and collisions can be detected. The signal strength from the transmitter to a receiver is determined by a deterministic propagation function, and by random disturbances. Subsequently the comparative findings for the different routing protocols have been reported for the radio propagation models: NRM, RMRYF, RMSINR provided by PROWLER. For radio transmission, the ideal signal power is given by [14]:

$$P_{rec,ideal}(x) = P_{transmit} \times f(x) \tag{1}$$

Where x is the distance, and

$$f(x) = 1/_{1 + x^{\gamma}} \tag{2}$$

And for the fading effect,

$$P_{rec}(i,j) = P_{rec,ideal}(d_{i,j}).(1 + \alpha(x)).(1 + \beta(t)) \tag{3}$$

Where $P_{rec,ideal}$ is the ideal reception signal strength, $P_{transmit}$, the transmission signal power, d, the distance between the transmitter and the receiver, γ, a decay parameter with typical values of 2≤ γ ≤ 4, α and β, are random variables with normal distributions $N(0,\sigma_\alpha)$ and $N(0,\sigma_\beta)$, respectively. A network is asymmetric if $\sigma_\alpha > 0$ or $\sigma_\beta > 0$. In (5), α is static depending on locations *i* and *j* only (distance x), and β is dynamic which changes over time. A node j can receive a packet from node *i* if $P_{rec}(i,j) > \Delta$ where $\Delta > 0$ is the threshold. There is a collision if two transmissions overlap in time and both could be received successfully. Furthermore, an additional parameter P_{error} models the probability of a transmission error caused for any other reason. The default radio model in PROWLER has γ = 2, $\sigma_\alpha = 0.45$, $\sigma_\beta = 0.02$, $\Delta = 0.1$ and $P_{error} = 0.05$. Figure1 (a) and (b) shows a snapshot of the radio power and radio reception curves in this model respectively.

The transmission model for radio model with SINR in Prowler is given by:

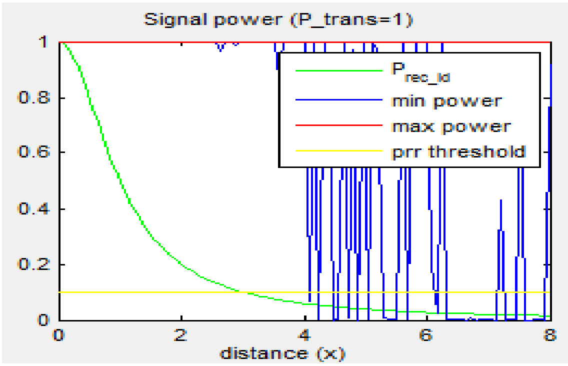
$$P_{rec}(i,j) = P_{rec,ideal}(x_{i,j}).(1 + \alpha(x)) \tag{4}$$

All the parameters and variables of this model have the same meaning with that of normal radio model described above. Figure 1(c) shows a snapshot of the radio reception curve of the RMSINR model.

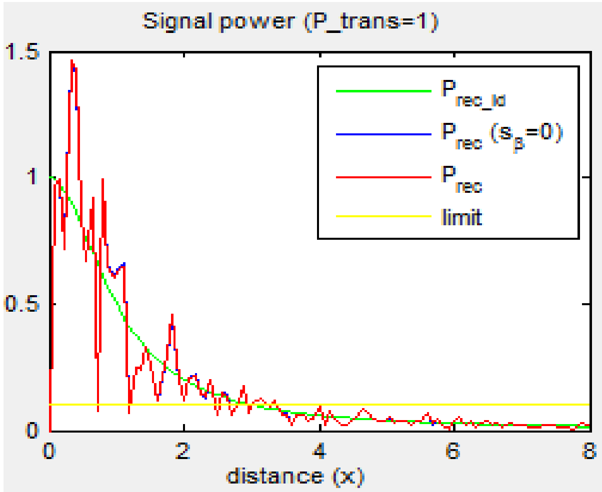
The transmission model for radio model with Rayleigh fading in Prowler is given by:

$$P_{rec}(i,j) = P_{rec,ideal}(x_{i,j}).(R) \tag{5}$$

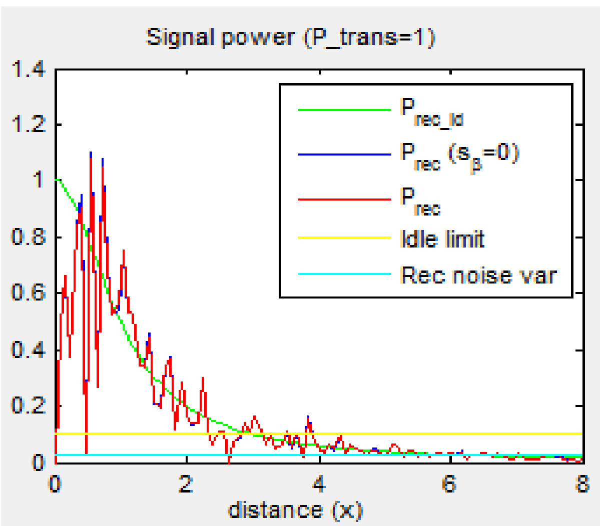
where R is a random variable with exponential distribution $(mu = 1)$. The coherence time is $tau = 1\,sec$. Figure 1(d) shows the snapshot of the radio reception curve of the NMRYF model.



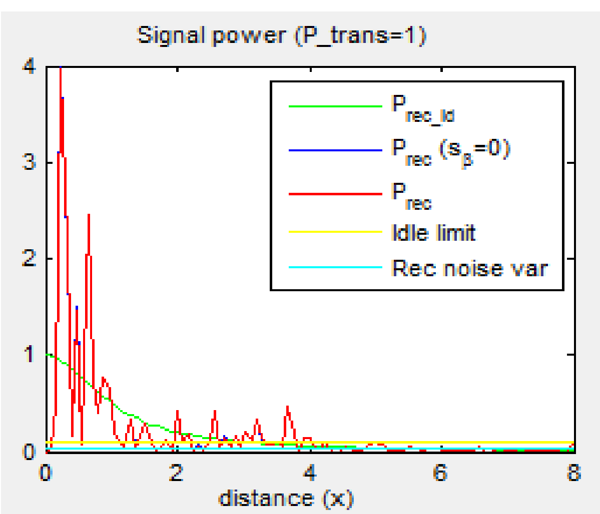
(a) Radio Channel Power



(b) Normal radio model



(c) RMSINR



(d) RMRYF

Figure 1: Snapshot of radio reception curves for (a) Radio Channel Power (b) NRM (c) RMSINR (d) RMRYF

3. RESULTS AND DISCUSSIONS

Here, we have used a real application to test the performance of the energy-aware protocols. We evaluated Termite-hill protocol with two candidate algorithms: Sensor driven and cost-aware ant routing (SC) and IEEABR algorithm using the metrics defined in Section 3.1 based on the experimental results obtained. The experiment was conducted using the normal radio model (NRM, default radio model in PROWLER), radio model with SINR (RMSINR) and radio model with Rayleigh fading (RMRYF) for the different algorithms. The evaluation of the protocols was performed for one application scenario, which is the static scenario. In the scenario, the event has a length of 512-bits and this is generated at a rate of four events per second at each source node. In our experiment, the network topology was a 9 sensor nodes (3x3) grid with small random offsets. The maximum radio range is about 3*d* (The maximum allowable transmission radius of a node was 70m), where *d* is the standard distance between two neighbor nodes in the grid, and the initial energy of each node is set to 5J each for the application type. Each experiment was performed for duration of 100 seconds. The set of results recorded were averaged over ten different simulation results. Figure 2 shows an instance of the connectivity using Termite-hill routing algorithm.

3.1 Performance evaluation metrics

From several results obtained from our simulation experiments, we report the following performance metrics for clarity purpose.

- ***a)*** *Success rate: It is a ratio of total number of events received at the destination to the total number of events generated by the nodes in the sensor network (%).*
- ***b)*** *Energy efficiency: it is a measure of the ratio of total packet delivered at the destination to the total energy consumed by the network's sensor nodes, that is, (success rate ∗ total packet sent to the sink/total energy consumed) (Kbits/Joules).*
- ***c)*** *Standard Deviation: this gives the average variation between energy levels of all nodes in the network (Joules).*
- ***d)*** *Network Lifetime: it is defined as the difference of total energy of the network and the summation of average used energy of nodes and the standard deviation of their energy levels i.e.*

$$Lifetime = \left(total\ network\ energy - \left(\frac{used\ energy}{total\ nodes} + energy\ deviation\right)\right)$$

(Joules). This was taken as a percentage (%) of the obtained values and converted to years.

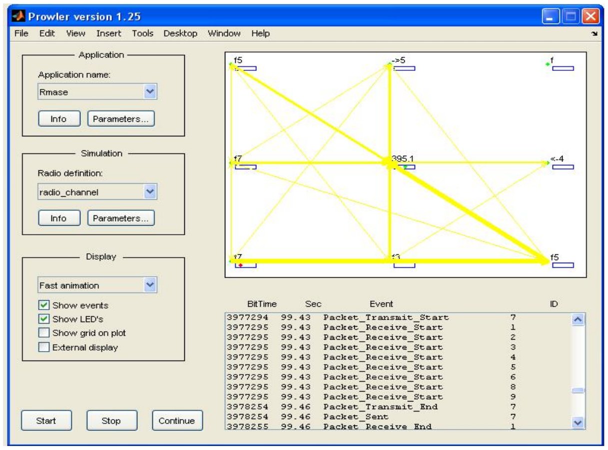
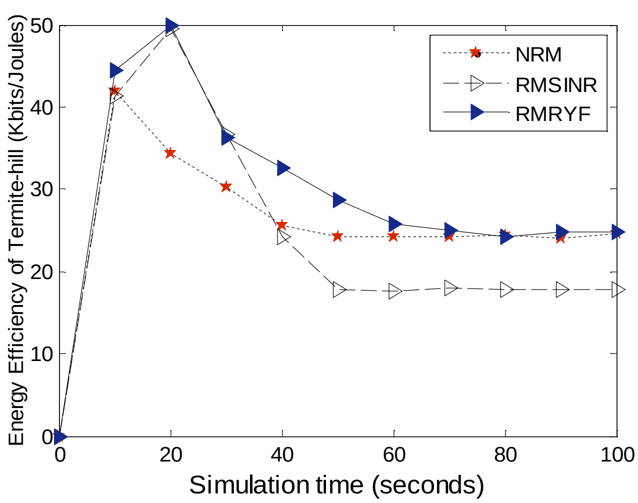


Figure 2: A snapshot of radio connectivity using Termite-hill protocol

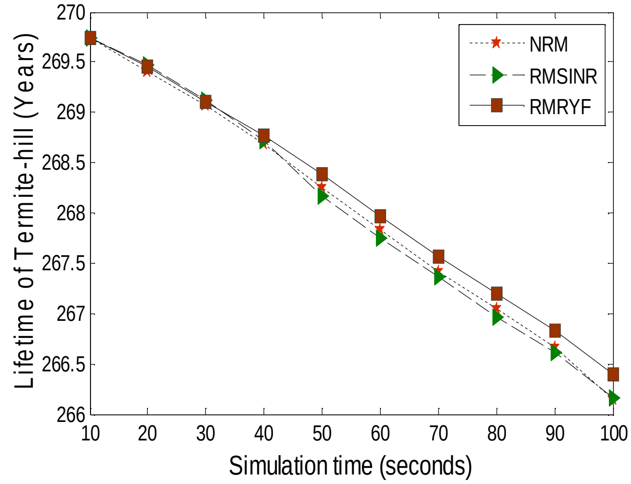
Table 1: Simulation Parameters

Parameters	Values
Routing Protocol	SC, IEEABR, Termite-hill
Size of Topology (A), Distribution of Nodes	100 x 100, Random distribution
Number of Nodes (N)	100
Maximum number of Retransmission (n)	3
Transmission Range (R), Data Traffic	35 m, Constant Bit Rate (CBR)
Data Rate, Propagation model	250 kbps, Probabilistic
Energy consumption, Time of topology change	Waspmote-802.15.4, 2s
Simulation Time, Average Simulation times	360s, 10

3.2 Case 1: Termite-hill Algorithm



(a) Energy Efficiency



(b) Lifetime

Figure 3: Energy efficiency and Lifetime comparison of Termite-hill routing algorithm for different radio models (NRM, RMSINR and RMRYF).

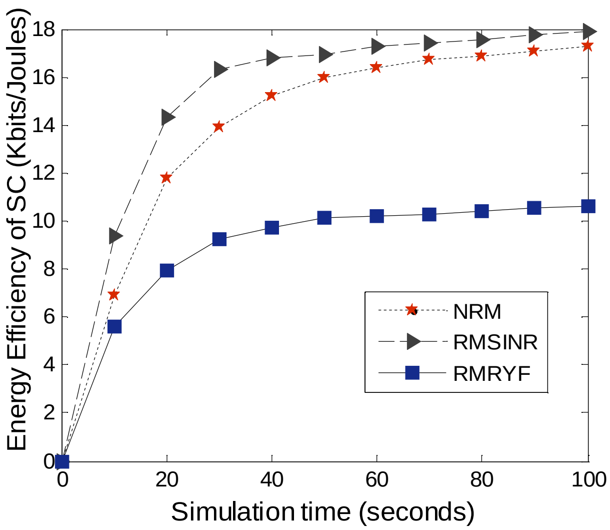
Figure 3 (a) shows the Energy efficiency plots of Termite-hill routing algorithm for different radio models. The graph indicates that at the simulation time of about 20sec, the energy efficiency of both RMSINR and RMRYF attained maximum value of 50Kb/J whereas that of NRM was 35Kb/J. But at about the simulation time of 50sec, the routing algorithm attains stable efficiency, but in this case, the RMSINR dropped to 19Kb/J whereas NRM and RMRYF maintain a value of 24Kb/J. This shows that, as the simulation time increases, the energy efficiency of the protocol maintain a little stable state, but better in the case of NRM and RMRYF, thus the protocol is affected in efficiency with different radio models. Figure 3 (b) also shows the lifetime of the algorithm with different radio models. It was observed that, using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.75 years to the minimum of 266.25 years for RSINR.

On the other hand, the lifetime with RMRYF is better, but having lower energy efficiency when the simulation time approaches 50sec. This is as a result of low success rate of events when adopting RMRYF radio model. But, with NRM, in both energy efficiency and lifetime, the algorithm performance was better.

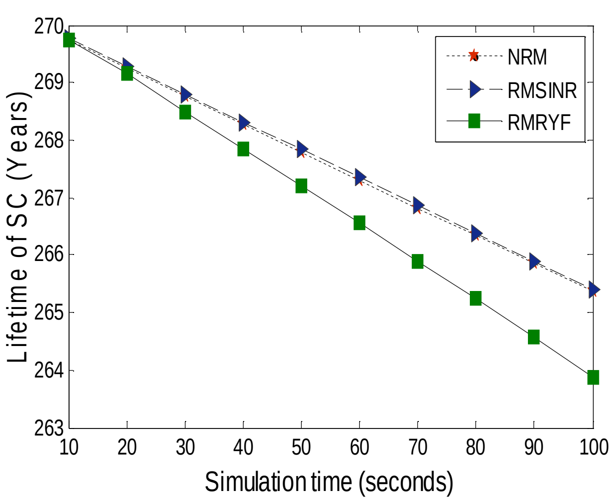
3.3 Case 2: Sensor driven and Cost-aware ant routing algorithm (SC)

Figure 4 (a) shows the Energy efficiency plots of Sensor driven and Cost-aware ant routing algorithm (SC) for different radio models. The graph indicates that with increase in simulation time, the energy efficiency of NRM, RMSINR and RMRYF keeps increasing and maintains a stable state at about 40secs. But at about that simulation time of 40sec, the routing algorithm using RMSINR model is better having energy efficiency value of 17Kb/J and moved to about 18Kb/J for simulation time of 60secs until 100secs. This also follows by NRM radio model. But in the case of RMRYF, the performance maintained its stable state at 9Kb/J. This means that, it is better to use the RMSINR or NRM radio models to achieve better performance in terms of energy efficiency than using RMRYF model. Figure 4 (b) also shows the lifetime of the algorithm with different radio models. It was observed that, using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.75 years to the minimum of 264 years for RMRYF, which also have poor performance. For the use of NRM and RMSINR radio models, the performance is better and almost the same for the two models, and attain minimum of 265.75 for both of them.

On the other hand, the lifetime as well as energy efficiency with NRM, RMSINR is better, but poor with RMRYF, in both energy efficiency and lifetime performance.



(a) Energy Efficiency

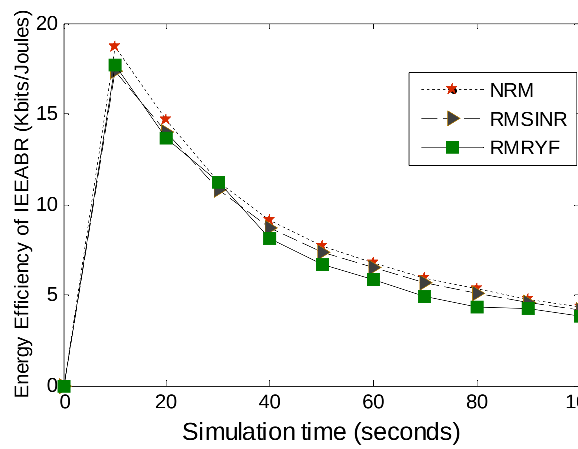


(b) Lifetime

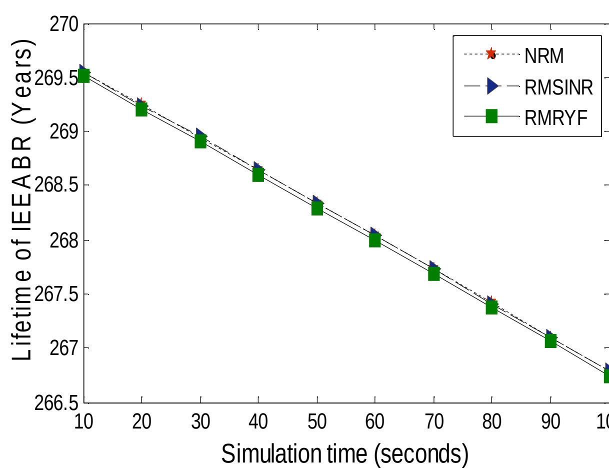
Figure 4: Energy efficiency and Lifetime comparison of SC routing algorithm for different radio models (NRM, RMSINR and RMRYF).

3.4 Case 3: Improved Energy Efficient Ant Based Routing Algorithm (IEEABR)

Figure 5 (a) shows the Energy efficiency plots of IEEABR routing algorithm for different radio models. The graph indicates that with increase in simulation time, the energy efficiency of NRM, RMSINR and RMRYF keeps decreasing with simulation time, but attains maximum value with simulation time of 10secs (initial point) of value 19Kb/J energy efficiency, and minimum at 100secs with energy efficiency value of 4Kb/J. Using both radio models, the routing algorithm has almost equal performance. Though, it is still better with NRM of difference of about 2% in relation to using other radio models. Figure 5 (b) also shows the lifetime of the algorithm with different radio models. It was observed that, using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.5 years to the minimum of 266.75 years for all the radio models. On the other hand, the lifetime as well as energy efficiency with NRM, RMSINR and RMRYF for IEEABR in both energy efficiency and lifetime performance is almost the same, but just little and negligible difference.



(a) Energy Efficiency



(b) Lifetime

Figure 5: Energy efficiency and Lifetime comparison of IEEABR routing algorithm for different radio models (NRM, RMSINR and RMRYF).

4. CONCLUSION

This paper presents the simulation results of the comparative investigation of the performance of the wireless sensor network routing protocols based on energy-aware routing using different radio models. It is evident from the results gathered that each of the protocols studied performs well in some cases yet has certain drawbacks in others. The simulation results indicate that the energy-aware routing objective differs for certain radio models. However, in case of the Termite-hill protocol for NRM, RMSINR and RMRYF, It was observed that, using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.75 years to the minimum of 266.25 years for RMSINR. On the other hand, the lifetime with RMRYF is better, but having lower energy efficiency when the simulation time approaches 50sec. This is as a result of low success rate of events when adopting RMRYF radio model. But, with NRM, in both energy efficiency and lifetime, the algorithm performance was better.

It was also observed that, using both radio models for SC protocol, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.75 years to the minimum of 264 years for RMRYF, which also have poor performance. For the use of NRM and RMSINR radio models, the performance is better and almost the same for the two models, and attain minimum of 265.75 for both of them. That is to say that, the lifetime as well as energy efficiency with NRM, RMSINR is better, but poor with RMRYF, in both energy efficiency and lifetime performance for SC protocol.

In the case of IEEABR protocol, using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.5 years to the minimum of 266.75 years for all the radio models. On the other hand, the lifetime as well as energy efficiency with NRM, RMSINR and RMRYF for IEEABR in both energy efficiency and lifetime performance is almost the same, but just little and negligible difference. It is evidence to conclude that, radio models have a strong effect on the performance of algorithm as can be seen from the results and better for NRM and RMSINR radio models respectively.

REFERENCES

1. A.M. Zungeru, L. -M. Ang, K.P. Seng. **Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison**, *Journal of Network and Computer Applications, ELSEVIER*, vol. 35, Issue 5, pp. 1508-1536, 2012.
2. A.M. Zungeru, L. -M. Ang and K.P. Seng. **Termite-hill: Performance optimized swarm intelligence based routing algorithm for wireless sensor networks**, *Journal of Network and Computer Applications, ELSEVIER*, vol. 35, Issue 6, pp. 1901-1917, 2012.
3. K. Li, C.E. Torres, K. Thomas, L.F. Rossi and C.-C. Shen. **Slime mold inspired routing protocols for wireless sensor networks**, *Swarm Intelligence*, vol. 5(3-4), pp.183-223, 2011.
4. A.M. Zungeru, L. -M. Ang, and Kah Phooi Seng. **Performance of Termite-hill Routing Algorithm on Sink Mobility in Wireless Sensor Networks**, *Advances in Swarm Intelligence*, Springer, vol. 7332 (2), pp. 334-343, 2012.
5. A.M. Zungeru, L. -M. Ang and K.P. Seng. **Termite-hill: From Natural to Artificial Termites in Sensor Networks**, *International Journal of Swarm Intelligence Research (IGI-Publishers)*, vol. 3(4), pp. 1-23, 2012.
6. Y. Zhang, L.D. Kuhn, and M.P.J. Fromherz. **Improvements on ant routing for sensor networks**, *Ant Colony Optimization and Swarm Intelligence, Lecture Notes Computer Science*, **3172**, pp. 289-313, 2004.
7. A.M. Zungeru, K.P. Seng, L. -M. Ang, and W.C. Chia. **Energy Efficiency Performance Improvements for Ant-Based Routing Algorithm in Wireless Sensor Networks**, *Journal of Sensors*, vol. 2013, Article ID 759654, 17 pages, 2013.
8. Y. Zhang, G. Simon and G. Balogh. **High-Level Sensor Network Simulations for Routing Performance Evaluations**", *Proceedings of 3rd International Conference on Networked Sensing Systems*, Chicago, 31 pp. 1-4, May-2 June 2006.
9. G. Simon. **Prowler: Probabilistic Wireless Network Simulator**, *Institute for Software Integrated Systems*, Nashville, 2003. Available at: http://www.isis.vanderbilt.edu/projects/nest/prowler
10. S. Park, A. Savvides and M. B. Srivastava. **SensorSim: A Simulation Framework for Sensor Networks**, Pro-ceedings of the 3rd ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mo-bile Systems, Boston, pp. 104-111, 20 August 2000.
11. P. Levis, N. Lee, M. Welsh and D. Culler. **TOSSIM: Accurate and Scalable Simulation of Entire TinyOS Ap-plications**, *Proceedings of the 1st International Confer-ence on Embedded Networked Sensor Systems*, Los An-geles, pp. 126-137, 5-7 November 2003.
12. K. Fall and K. Varadhan. **The VINT Project**, *The NS Manual*, November 2008. http://www.isi.edu/nsnam/ns/doc/
13. OPNET Technologies, Inc. **The OPNET Simulator**, Bethesda. http://www.opnet.com
14. M. Haenggi. **Probabilistic Analysis of a Simple Mac Scheme for Ad Hoc Wireless Networks**, *Proceedings of IEEE CAS Workshop on Wireless Communications and Networking*, Pasadena, pp. 1-4, 5-6 September 2002.