

Performance Analysis of Energy-aware Routing Protocols for Wireless Sensor Networks using Different Radio Models

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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 or 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. Ad hoc networks form a distinct category of networks whereby nodes are wirelessly connected to each other and may be in constant random motion. The performance of ad hoc networks like sensor networks differs with different radio models. This paper present simulation results of a comparative investigation of the performance of energy-aware 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). We further compared Termite-hill and Ad-hoc on Demand Distance Vector (AODV) protocols performance in sink mobility using the Normal Radio Model. 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.

INTRODUCTION

The features of Wireless Sensor Network (WSN) has led to a proliferation in their use in a wide range of applications such as traffic monitoring, target tracking, perimeter/boarder monitoring, military surveillance, environmental monitoring, miners localization and protection and many others. Different WSN applications have varying specific requirements. Authors in [1] proposed a taxonomy of WSN applications and their requirements. Depending on where they are deployed, most

applications require the use of sensors of tiny size. These sensor devices are often referred to as sensor nodes or just nodes [2]. The main disadvantage of a WSN is its limited lifetime. When a node's energy is depleted it stops functioning hence a WSN may be physically damaged if many nodes within the network have their limited battery energy depleted. The lifetime of a WSN depends on node placement, pattern topology and routing protocol applied [2].

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 literature, 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 study and analyse 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, there has not been much in-depth study on 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 is done on the basis of performance analysis and comparisons of lifetime metric (years) using RMASE [8], an application built on PROWLER [9].

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.

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. The RMASE in PROWLER provides a better way to view real applications in a simulation environment. The RMASE environment is embedded with MAC layer, a layer whereby application can be demonstrated (application layer) and a layer for embedding routing protocols (routing layer). We have used some of the radio and MAC models as outlined in the following subsections for comparison among the routing protocols. This will help in the investigation of their performance in selected cases.

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 modeled by a simplified event channel that simulates the Berkeley motes' CSMA MAC protocol, including the random waiting and back-offs. 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 transmission distance, and

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

And for the fading effect,

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

$P_{rec,ideal}$ represents an ideal reception signal strength, whereas $P_{transmit}$ is the transmission signal power, the distance between the transmitter circuit and the receiver circuitry is denoted as d and γ is a decay parameter with typical values of $2 \leq \gamma \leq 4$, α and β are random variables with normal distributions $N(0, \sigma_\alpha)$ and $N(0, \sigma_\beta)$, respectively. The standard radio model which PROWLER depends on $\gamma = 2$, $\sigma_\alpha = 0.45$, $\sigma_\beta = 0.02$, $\Delta = 0.1$ and $P_{error} = 0.05$. Figure 1 (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:

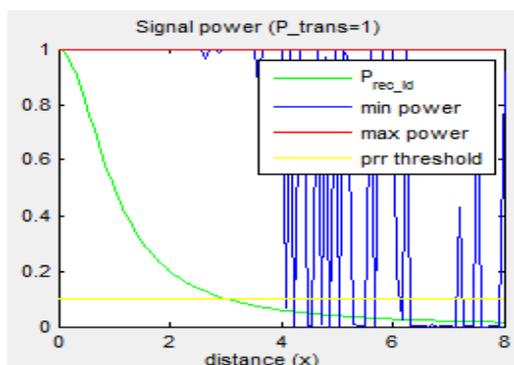
$$P_{rec}(i, j) = P_{rec,ideal}(x_{i,j}) \cdot (1 + \alpha(x)) \tag{4}$$

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.

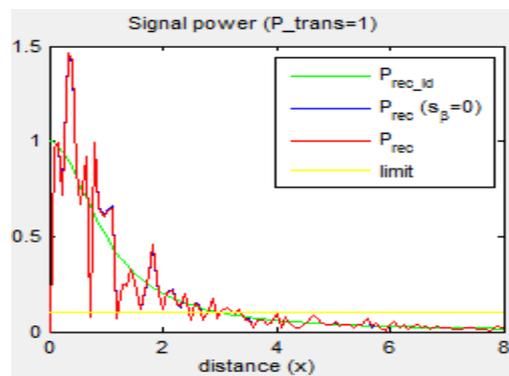
The transmission model for radio model with Rayleigh fading in Prowler is given by:

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

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



(a) Radio Channel Power



(b) Normal radio model

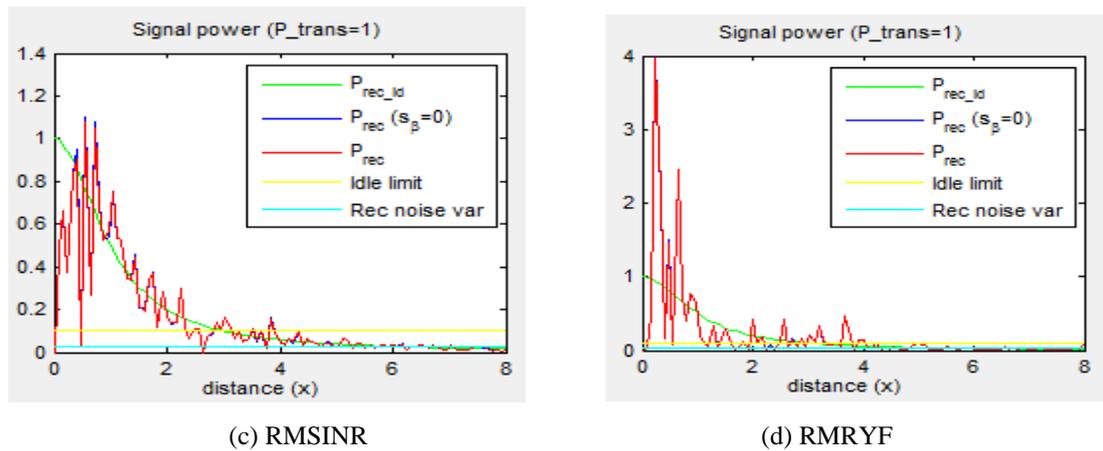


Figure 1: Snapshot of radio reception curves for (a) Radio Channel Power (b) NRM (c) RMSINR (d) RMRYF

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 IEEEABR 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 $3d$ (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.

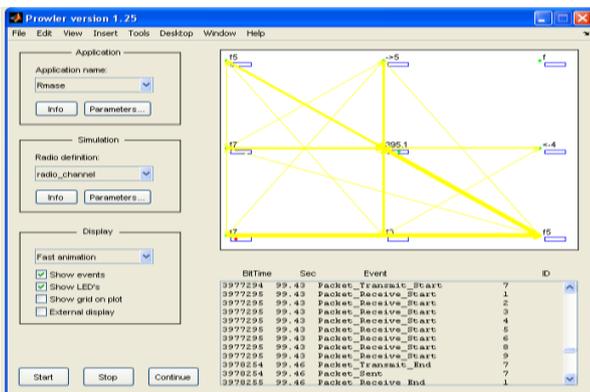


Figure 2: A snapshot of radio connectivity using Termite-hill protocol

Performance evaluation metrics

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

- 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 (%).*
- 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 \times total packet sent to the sink/total energy consumed) (Kbits/Joules).*
- Standard Deviation: this gives the average variation between energy levels of all nodes in the network (Joules).*
- 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.*

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

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

Table 1: Simulation Parameters

Parameters	Values
Routing Protocol	SC, IEEEABR, Termite-hill, AODV
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	Wasp mote-802.15.4, 2s
Simulation Time, Average Simulation times	360s, 10

Case 1: Termite-hill Algorithm

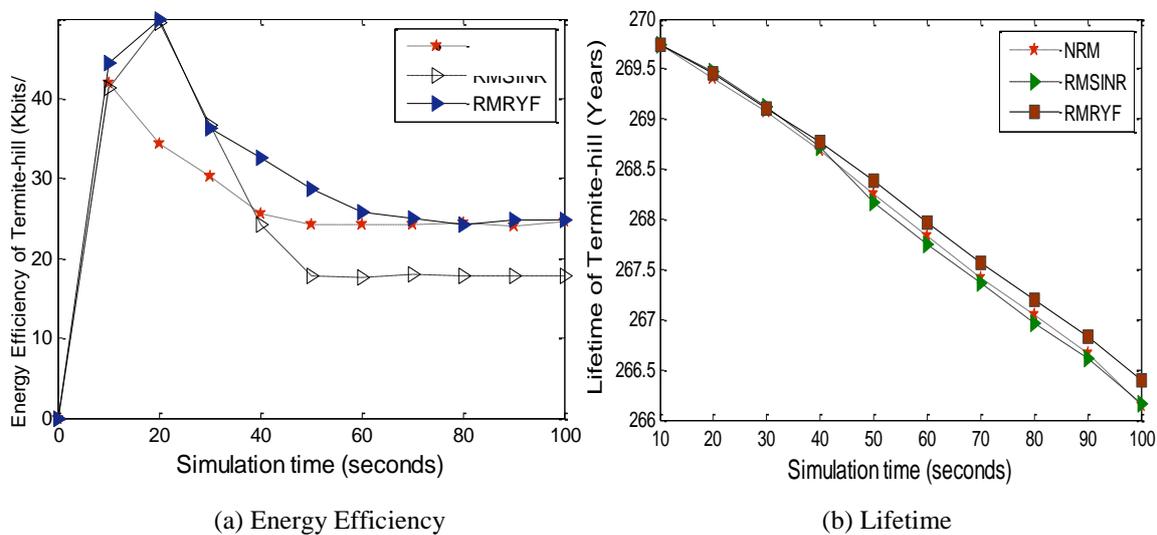


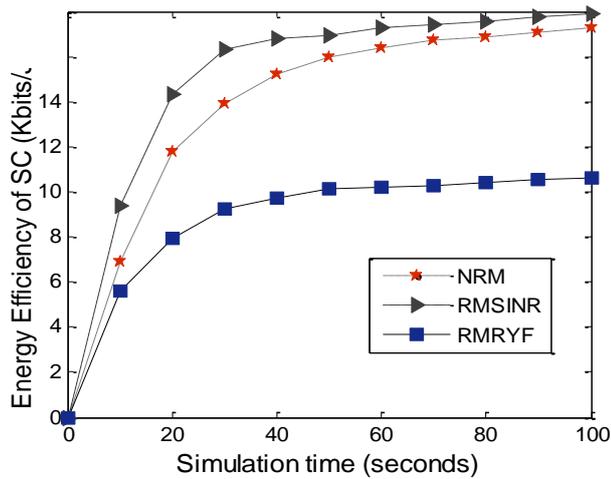
Figure 3: Energy efficiency and Lifetime comparison of Termite-hill routing algorithm for different radio models (NRM, RMSINR and RMRYF).

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

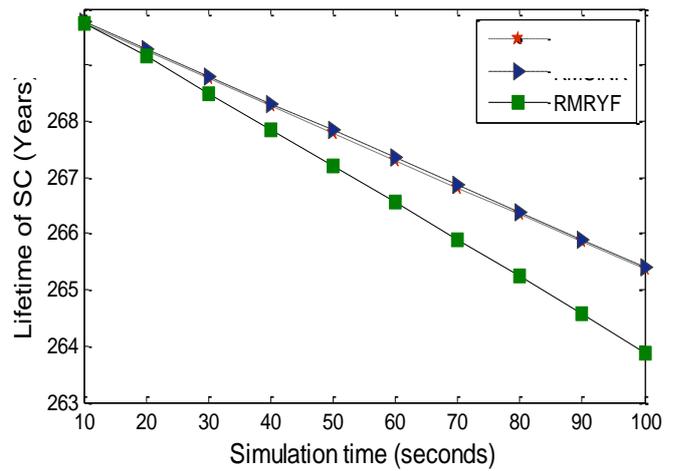
models. It was observed that using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.75 years to the minimum of 266.25 years for RSINR.

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. However, with NRM, in both energy efficiency and lifetime the algorithm performance was better.

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



(a) Energy Efficiency



(b) Lifetime

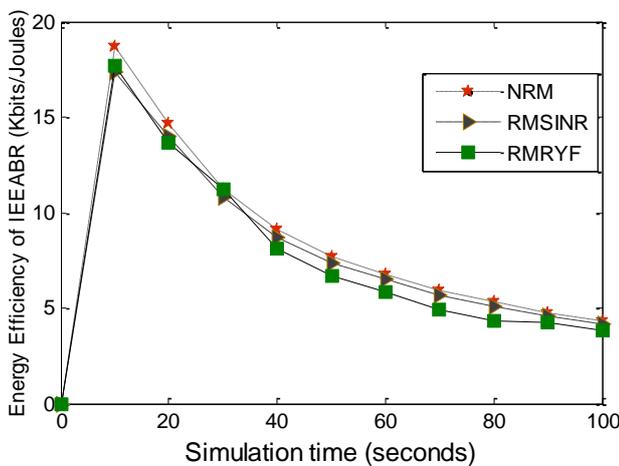
Figure 4: Energy efficiency and Lifetime comparison of SC routing algorithm for different radio models (NRM, RMSINR and RMRYF).

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 the 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

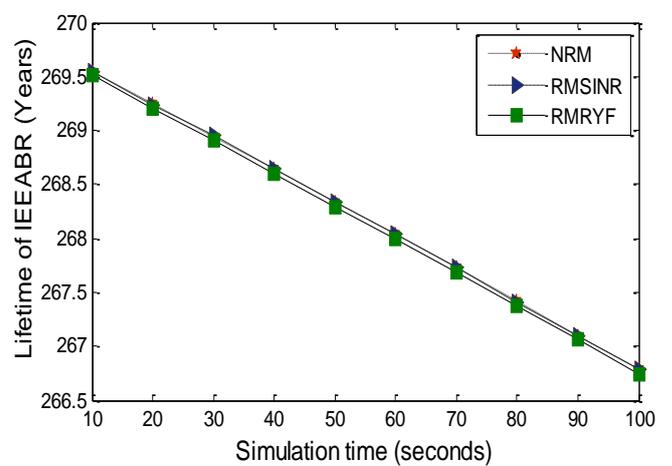
model. Figure 4(b) also shows the lifetime of the algorithm with different radio models. It was observed that, using both radio models, the lifetime of the algorithm keeps decreasing with simulation time from the value of 269.75 years to the minimum of 264 years for RMRYF, which also have poor performance. 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.

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



(a) Energy Efficiency



(b) Lifetime

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

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.

Case 4: Sink Mobility with Static Sensor Nodes using Normal Radio Model

From Figure 6 and Figure 7, we adopted a mobile sink scenario using Prowler standard radio model (Normal Radio Model). Considering packet success rate per arrival unit time (Throughput) as can be seen in Figure 6, both protocols have maximum success rate at the initial level (at the speed of 10m/s). The success rate slightly dropped when the speed increases to 20m/s. It then remain almost constant after the 20m/s. This shows that, even if the speed of the sink increases beyond 20m/s for 100 nodes in the network, the success rate will have no much effect. In Figure 7, results gotten shows that energy efficiency decreases with simulation time, where also, for increase in sink speed, the energy efficiency of the routing protocols increases.

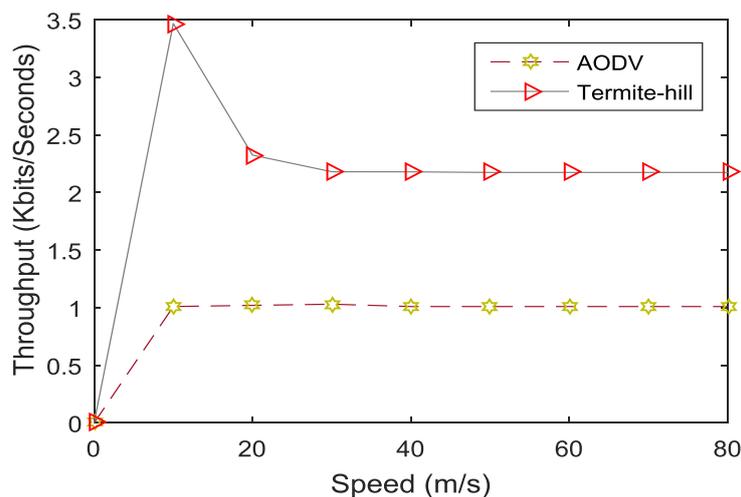


Figure 6: Effect of varying speed on Throughput in classical and swarm based routing protocols.

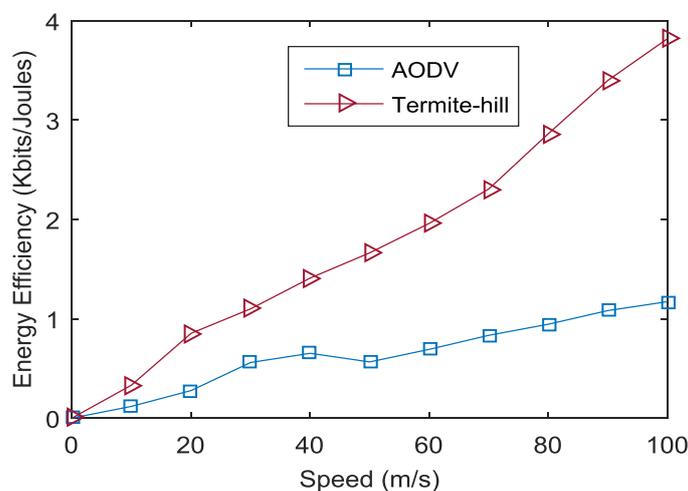


Figure 7: Effect of varying speed on Energy Efficiency in classical and swarm based routing protocols.

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. 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.

Also, we compared the performance of Termite-hill and AODV were we assumed that only the sink is mobile using Prowler standard radio model (Normal Radio Model), and the network having only one data collection centre (sink). In term of successful packet delivery per unit time (Throughput), it should be observed that, both protocols have maximum success rate at the initial level (at the speed of 10m/s). The success rate slightly dropped when the speed increases to 20m/s. It then remain almost constant after the 20m/s. We also observed that unlike in the static scenario whereby energy utilization efficiency decreases with simulation time, in mobility, energy utilization of routing protocols increase rapidly with increase in speed of sink.

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Authors' contributions

All Authors participated in all experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

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