On Performance Evaluation of WSN Routing Protocols for MICA and MICAz using Different Radio Models

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Abstract

In this paper, we extend the Prowler simulator by integrating radio model with Rician fading into it and comparatively analyze the Constrained Flooding, the Real-Time Search and the Adaptive Tree sensor network protocols on MICA and MICAz motes using normal radio model, radio model with SINR, radio model with Rayleigh fading (default radio models in Prowler) and radio model with Rician fading. Here an attempt has been made to demonstrate the behaviour of routing protocols in presence of realistic radio models. Moreover, our simulation results show that the energy consumption decreases and lifetime of sensor networks increase when MICA motes are used instead of the MICAz motes. Hence, MICA motes could be used to improve sensor network performance in real time.

Keywords: *Constrained flooding, real-time search, adaptive tree, radio model and wireless sensor networks*

1. Introduction

Wireless sensor networks (WSNs) contain hundreds or thousands of sensor nodes equipped with sensing, computing and communication abilities. Each node has the ability to sense elements of its environment, perform simple computations and communicate among its peers or directly to an external base station (BS) [1].

Routing in sensor network, however, has very different characteristics than routing in traditional communication networks. Firstly, address-based destination specification is replaced by a more general feature-based specification, such as geographic location [2] or information gain [3]. Secondly, routing metrics are usually multiple objectives, including energy usage [4] and information density [3]. Thirdly, multicast (one-to-many) and converge-cast (many-to-one) are major traffic patterns in sensor networks.

Three distributed meta routing strategies based on real-time reinforcement learning [6]: real-time search [7], constrained flooding [8] and adaptive spanning tree [9] have been proposed in the sensor network literature. However, it has been observed that the performance of routing protocols for WSNs has not been evaluated in the presence of realistic fading models. In this work, an attempt has been made to extend the Prowler simulator by developing and integrating radio model based on Rician fading in it. Consequently, the performance analysis and comparisons of routing protocols Constrained Flooding (CF), Real-Time Search (RTS) and Adaptive Tree (AT) for wireless sensor networks have been done using Prowler for MICA and MICAz. The comparison has been done on the basis of various performance metrics throughput (data packets/sec), energy consumption and lifetime (years). Simulation results show that the adaptive tree protocol can be applied to achieve better energy consumption and lifetime in real time. Further, use of MICA motes decreases the energy consumption and increases the lifetime of wireless sensor networks.

The remainder of the paper is organized as follows. Section 2 describes the simulation model used. Section 3 analyzes the protocol via simulation and compares performances in case of normal radio model (NRM), radio model with SINR (RMSINR); radio model with Rayleigh fading (RMRYF); and radio model with Rician fading (RMRCF). Section 4 concludes the paper.

2. Simulation Model

PROWLER (Probabilistic Wireless Network Simulator) [10] 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 [11]. 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.

2.1. Radio and MAC models

Our protocol study uses the MAC layer communication model and the radio propagation models: normal radio model, radio model with SINR & radio model with Rayleigh fading provided by Prowler as well as radio model with Rician fading developed by us.

The simple radio model in PROWLER attempts to simulate the probabilistic nature in wireless sensor communication. The 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 transmission model is given by [11, 12]:

$$P_{rec,\ ideal}\,(d) \leftarrow P_{transmit}\,(1/(1+d^{\gamma}))\text{where } 2 \leq \gamma \leq 4 \quad (1)$$

$$P_{rec}(i,\ j) \leftarrow P_{rec,ideal}(d_{i,j})\ (1+\ \alpha(i,\ j))\ (1+\beta(t)) \quad (2)$$

where $P_{transmit}$ is the signal strength at the transmitter and $P_{rec,\ ideal}\,(d)$ is the *ideal* received signal strength at distance d, α and β are random variables with normal distributions $N(0,\ \sigma_{\alpha})$ and $N(0,\ \sigma_{\beta})$, respectively. Here α is static depending on locations i and j only, 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. The default radio model in PROWLER has $\gamma = 2$, $\sigma_{\alpha} = 0.45$, $\sigma_{\beta} = 0.02$, $\Delta = 0.1$ and $p_{error} = 0.05$. Fig.1 (a) shows a snapshot of the radio reception curves in this model.

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

$$P_{rec}(i,j) \leftarrow P_{rec,ideal}(d_{i,j})(1+\alpha(i,j)) \quad (3)$$

where all the variables have the same values and meaning as in case of normal radio model described above. Fig.1 (b) shows a snapshot of the radio reception curves in this model.

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

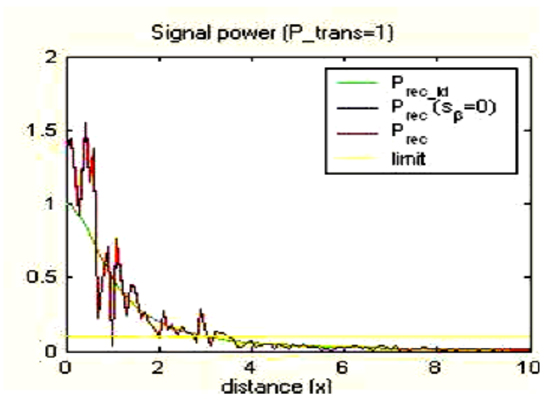
$$P_{rec}\,(i,\ j) \leftarrow P_{\ rec,\ ideal}\,(d_{i,j})\ (R) \quad (4)$$

where R is a random variable with exponential distribution (mu=1). The coherence time is tau = 1 sec. Fig.1 (c) shows a snapshot of the radio reception curves in this model.

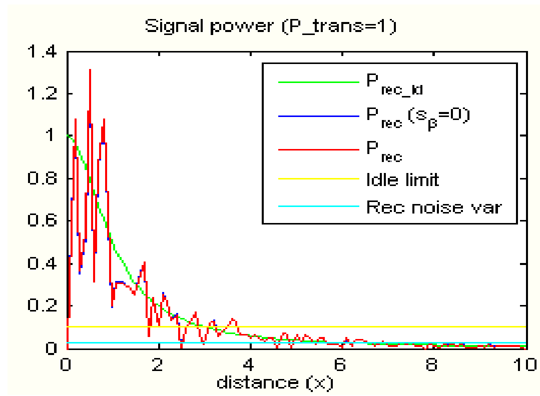
The transmission model for radio model with Rician fading in PROWLER is given by:

$$P_{rec}(i, j) \leftarrow \text{filter}(\text{chan}, P_{rec,\ ideal}(d_{i,j})) \quad (5)$$

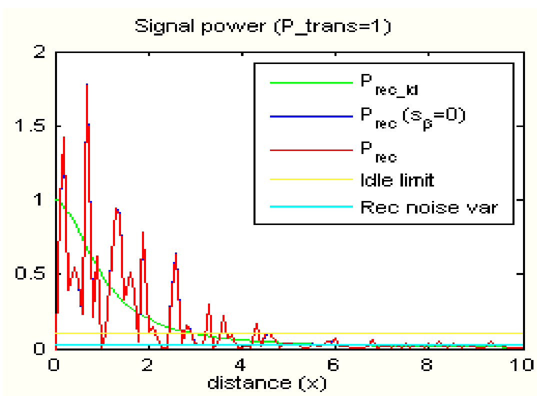
where chan = Ricianchan(ts, fd, k).Here ts = 1e-4 is the sampling time, fd = 100 is the doppler shift and k = 5 is the Rician factor. Fig.1 (d) shows a snapshot of the radio reception curves in this model.



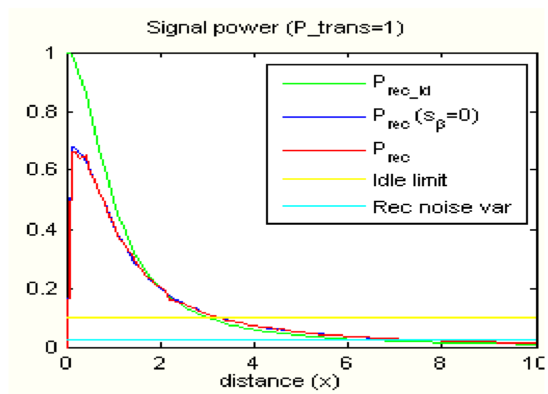
(a)



(b)



(c)



(d)

Fig.1 Snapshot of Radio Reception Curves for (a) NRM (b) RMSINR (c) RMRYF (d) RMRCF

The MAC layer communication is modeled by a simplified event channel that simulates the Berkeley motes' [13] CSMA MAC protocol. Our simulation tests were done in RMASE (Routing Modeling Application Simulation Environment) [14], an application built on Prowler. Rmase provides network generation and performance evaluations for routing algorithms.

3. Results and Discussions

We use a real application to test the performance of the energy-aware and shortest path protocols. The application, Pursuer Evader Game (PEG) [15], is to use the sensor network to detect an evader and to inform the pursuer about its location. In our tests, the network is a 7x7 sensor grid with small random offsets. The maximum radio range is about 3*d*, where *d* is the standard distance between two neighbor nodes in the grid. Fig.2 shows an instance of the connectivity of such a network.

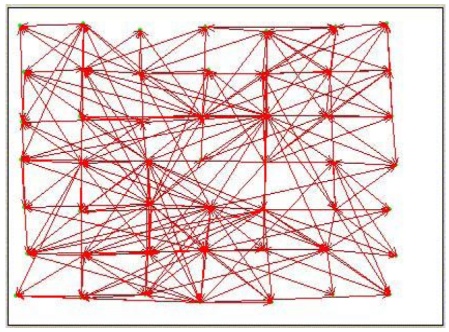
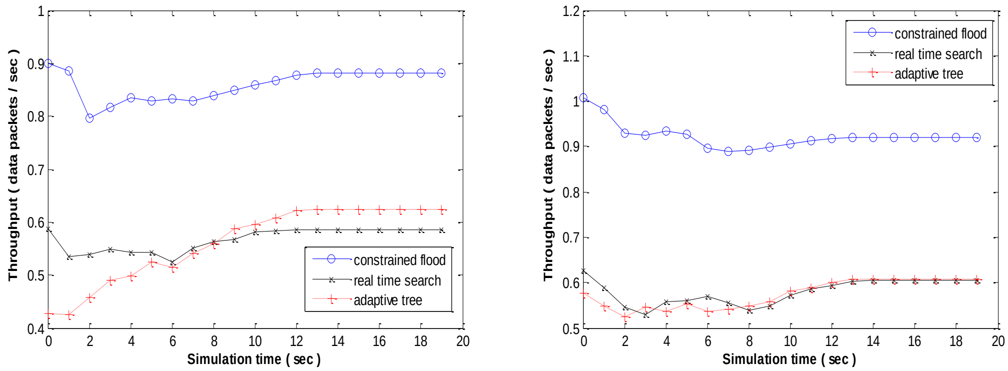


Fig.2 Instance of Radio Connectivity

The radio data rate is 40 kbps [16] and each packet has 960 bits. On the other hand, for MICAz motes the radio data rate is 250 kbps [17] with each packet having 960 bits. The application sends out one packet per second from the sources. The results are based on the average of 10 random runs.

3.1. Case 1: Normal Radio Model

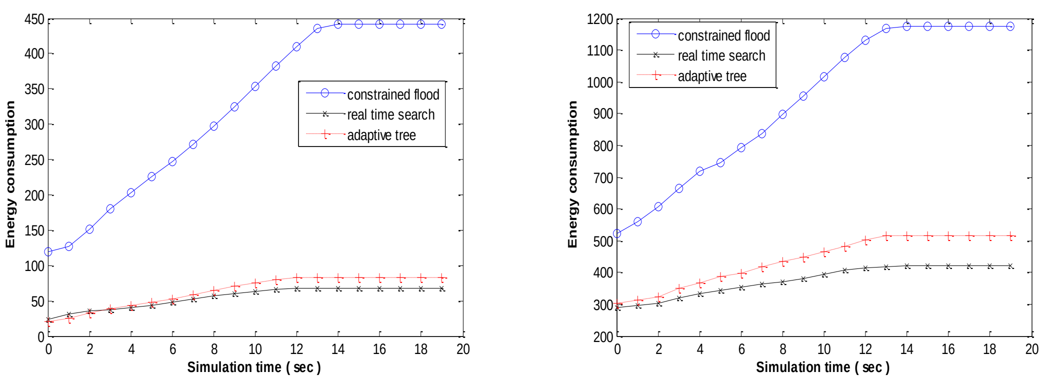
Fig.3 (a) shows that the throughput of the CF protocol in case of MICA is 0.9 data packets/sec initially which then decreases to 0.88 data packets/sec at simulation time of 14 sec after which it stabilizes. However, in case of MICAz, (Fig.3 (b)), the throughput of CF protocol is 1 data packet/sec initially which varies till simulation time of 13 sec and stabilizes at 0.92 data packets/sec. For RTS protocol the throughput is 0.59 data packets/sec initially in case of MICA which then fluctuates to stabilize at 0.59 data packets/sec at simulation time of 12 sec. However, in case of MICAz, the throughput is 0.63 data packets/sec initially and later on varies to stabilize at 0.6 data packets/sec at simulation time of 14 sec. For AT protocol the throughput in case of MICA is 0.43 data packets/sec initially and stabilizes at 0.62 data packets/sec at simulation time of 12 sec. However, in case of MICAz, the throughput is 0.58 data packets/sec initially which fluctuates to stabilize at 0.61 data packets/sec at simulation time of 13 sec. Thus, in case of NRM, we conclude that the CF protocol shows the highest throughput and the RTS protocol indicates the lowest throughput in case of MICA and MICAz. However, the throughput in case of MICAz is much higher as compared to MICA.



(a) (b)

Fig.3 Throughput Comparison of different Protocols for a Normal Radio Model (a) MICA (b) MICAz

Fig.4 (a) shows that the energy consumption of the CF protocol in case of MICA is 120 initially which then increases sharply to 440 at simulation time of 14 sec stabilizing thereafter. However, in case of MICAz, (Fig.4 (b)), the energy consumption of CF protocol is 530 initially which then increases steeply till simulation time of 14 sec and stabilizes at 1190. For RTS protocol the energy consumption is 30 initially in case of MICA which then rises to 60 at simulation time of 11 sec and stabilizes. However, in case of MICAz, the energy consumption is 290 initially and later on increases to stabilize at 390 at simulation time of 13 sec. For AT protocol the energy consumption in case of MICA is 30 initially and stabilizes at 80 at simulation time of 13 sec. However, in case of MICAz, the energy consumption is 300 initially which increases to stabilize at 500 at simulation time of 13 sec.



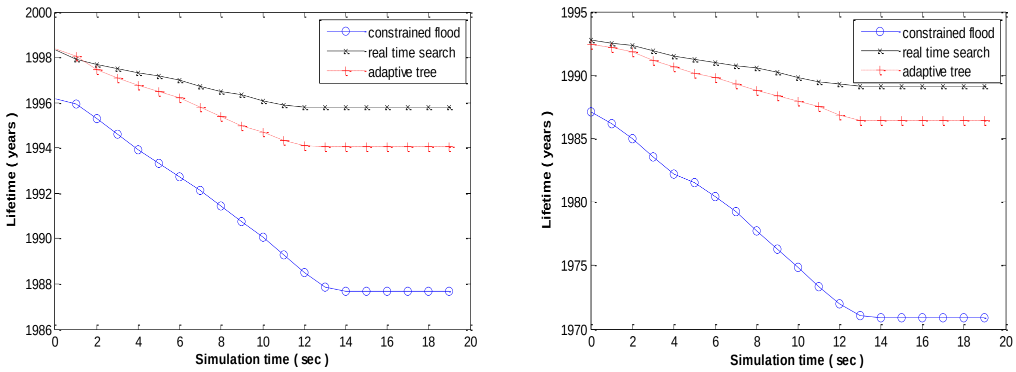
(a) (b)

Fig.4 Energy Comparison of different Protocols for a Normal Radio Model

(a) MICA (b) MICAz

Thus, in case of NRM, we conclude that the CF protocol shows the highest energy consumption and the RTS protocol indicates the lowest energy consumption in case of MICA and MICAz. However, the energy consumption in case of MICAz is much higher as compared to MICA.

Fig.5 (a) indicates that the lifetime of the CF protocol in case of MICA is 1996 years initially and decreases to 1988 years till simulation time of 14 sec and stabilizes. However, in case of MICAz, (Fig.5 (b)), the lifetime of CF protocol is 1987 years initially which then decreases steeply till simulation time of 14 sec when it stabilizes at 1971 years. For RTS protocol the lifetime is 1998 years initially in case of MICA which then decreases to 1996 years at simulation time of 12 sec and stabilizes. However, in case of MICAz, the lifetime is 1993 years initially and later on decreases to stabilize at 1989 years at simulation time of 13 sec. For AT protocol the lifetime in case of MICA is 1998 years initially and stabilizes at 1994 years at simulation time of 12 sec.



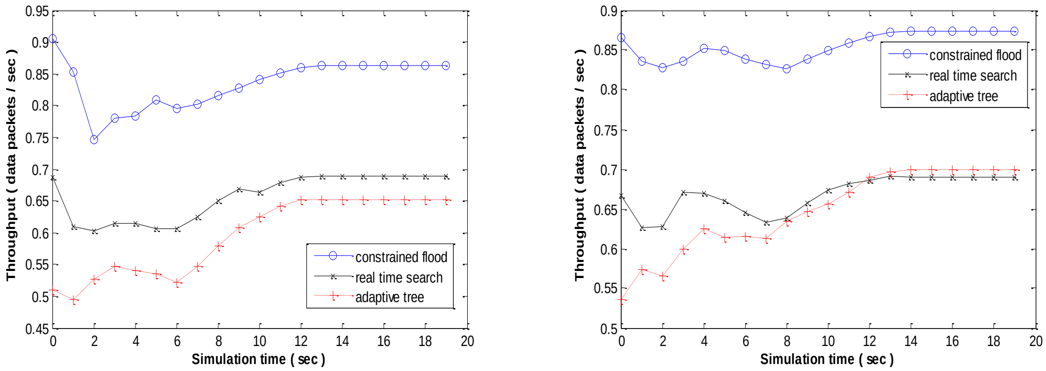
(a) (b)

Fig.5 Lifetime Comparison of different protocols for a Normal Radio Model (a) MICA (b) MICAz

However, in case of MICAz, the lifetime is 1993 years initially which decreases to stabilize at 1987 years at simulation time of 13 sec. Thus, in case of NRM, we conclude that the CF protocol shows the lowest lifetime and the RTS protocol indicates the highest lifetime in case of MICA and MICAz. However, the lifetime in case of MICAz is much lower as compared to MICA.

3.2. Case 2: Radio Model with SINR

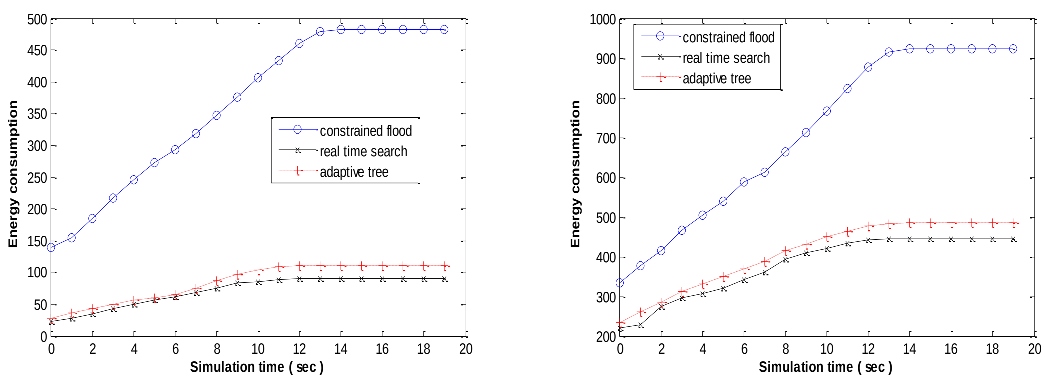
Fig.6 (a) depicts that the throughput of the CF protocol in case of MICA is 0.9 data packets/sec initially; then decreases sharply to 0.75 data packets/sec at simulation time of 2 sec and then increases to 0.85 data packets/sec at simulation time of 13 sec after which it stabilizes. However, in case of MICAz, (Fig.6 (b)), the throughput of CF protocol is 0.87 data packets/sec initially which then varies till simulation time of 13 sec stabilizing at 0.87 data packets/sec. For RTS protocol the throughput is 0.69 data packets/sec initially in case of MICA which then fluctuates to stabilize at 0.69 data packets/sec at simulation time of 13 sec. However, in case of MICAz, the throughput is 0.67 data packets/sec initially and later on varies to stabilize at 0.68 data packets/sec at simulation time of 14 sec. For AT protocol the throughput in case of MICA is 0.51 data packets/sec initially and stabilizes at 0.65 data packets/sec at simulation time of 12 sec. However, in case of MICAz, the throughput is 0.54 data packets/sec initially and then varies to stabilize at 0.7 data packets/sec at simulation time of 14 sec. Thus, in case of RMSINR, we conclude that the CF protocol shows the highest throughput in case of MICA and MICAz. The RTS protocol indicates the lowest throughput in case of MICAz and the AT protocol shows the lowest throughput in case of MICA. However, the throughput in case of MICAz is much higher as compared to MICA.



(a) (b)

Fig.6 Throughput Comparison of different Protocols for a Radio Model with SINR (a) MICA (b) MICAz

Fig.7 (a) depicts that the energy consumption of the CF protocol in case of MICA is 140 initially which then increases sharply to 480 at simulation time of 14 sec after which it stabilizes. However, in case of MICAz, (Fig.7 (b)), the energy consumption of CF protocol is 340 initially which then increases steeply till simulation time of 14 sec and stabilizes at 920. For RTS protocol the energy consumption is 20 initially in case of MICA which then rises to 90 at simulation time of 12 sec and stabilizes. However, in case of MICAz, the energy consumption is 220 initially and later on increases to stabilize at 440 at simulation time of 13 sec. For AT protocol the energy consumption in case of MICA is 30 initially and stabilizes at 110 at simulation time of 12 sec. However, in case of MICAz, the energy consumption is 240 initially which increases to stabilize at 460 at simulation time of 13 sec.

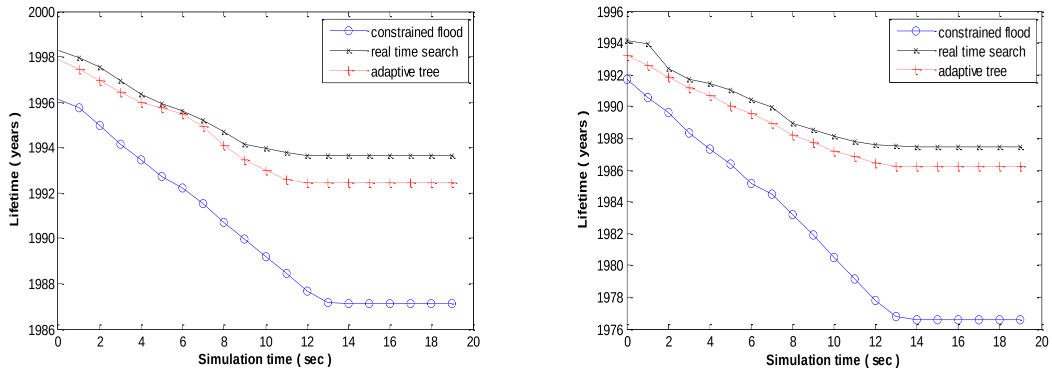


(a) (b)

Fig.7 Energy Comparison of different Protocols for a Radio Model with SINR (a) MICA (b) MICAz

Thus, in case of RMSINR, we conclude that the CF protocol shows the highest energy consumption and the RTS protocol indicates the lowest energy consumption in case of MICA and MICAz. However, the energy consumption in case of MICAz is much higher as compared to MICA.

Fig.8 (a) shows that the lifetime of the CF protocol in case of MICA is 1996 years initially and decreases to 1987 years till simulation time of 14 sec stabilizes thereafter. However, in case of MICAz, (Fig.8 (b)), the lifetime of CF protocol is 1992 years initially which then decreases steeply till simulation time of 14 sec stabilizing at 1977 years. For RTS protocol the lifetime is 1998 years initially in case of MICA which then decreases to 1994 years at simulation time of 12 sec and stabilizes.



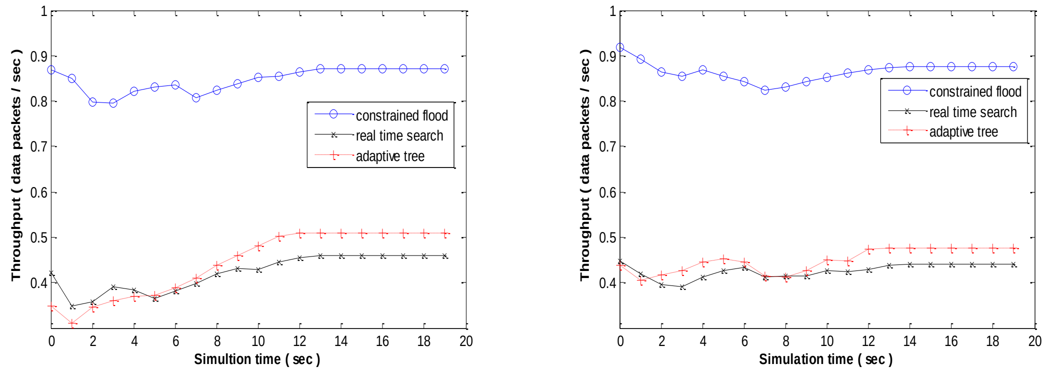
(a) (b)

Fig.8 Lifetime Comparison of different protocols for a Radio Model with SINR (a) MICA (b) MICAz

However, in case of MICAz, the lifetime is 1994 years initially and later on decreases to stabilize at 1988 years at simulation time of 13 sec. For AT protocol the lifetime in case of MICA is 1998 years initially and stabilizes at 1993 years at simulation time of 12 sec. However, in case of MICAz, the lifetime is 1993 years initially which decreases to stabilize at 1987 years at simulation time of 13 sec. Thus, in case of RMSINR, we conclude that the CF protocol shows the lowest lifetime and the RTS protocol indicates the highest lifetime in case of MICA and MICAz. However, the lifetime in case of MICAz is much lower as compared to MICA.

3.3. Case 3: Radio Model with Rayleigh Fading

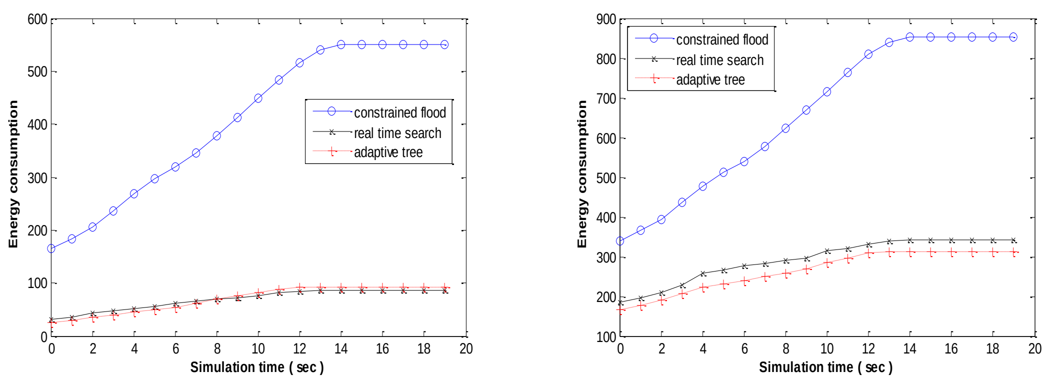
Fig.9 (a) indicates that the throughput of the CF protocol in case of MICA is 0.88 data packets/sec initially which then varies till 0.88 data packets/sec at simulation time of 13 sec after which it stabilizes. However, in case of MICAz, (Fig.9 (b)), the throughput of CF protocol is 0.9 data packets/sec initially which then fluctuates till simulation time of 13 sec stabilizing at 0.86 data packets/sec. For RTS protocol the throughput is 0.42 data packets/sec initially in case of MICA which then varies to stabilize at 0.45 data packets/sec at simulation time of 13 sec. However, in case of MICAz, the throughput is 0.45 data packets/sec initially and later on fluctuates to stabilize at 0.44 data packets/sec at simulation time of 14 sec. For AT protocol the throughput in case of MICA is 0.35 data packets/sec initially and stabilizes at 0.5 data packets/sec at simulation time of 12 sec. However, in case of MICAz, the throughput is 0.44 data packets/sec initially which varies to stabilize at 0.48 data packets/sec at simulation time of 13 sec. Thus, in case of RMRYF, we conclude that the CF protocol shows the highest throughput and the RTS protocol indicates the lowest throughput in case of MICA and MICAz. However, the throughput in case of MICAz is much higher as compared to MICA.



(a) (b)

Fig.9 Throughput Comparison of different Protocols for a Radio Model with Rayleigh Fading (a) MICA (b) MICAz

Fig.10 (a) indicates that the energy consumption of the CF protocol in case of MICA is 170 initially which then increases sharply to 550 at simulation time of 14 sec after which it stabilizes. However, in case of MICAz, (Fig.10 (b)), the energy consumption of CF protocol is 340 initially which then increases steeply till simulation time of 14 sec and stabilizes at 850. For RTS protocol the energy consumption is 30 initially in case of MICA which then rises to 70 at simulation time of 12 sec and stabilizes. However, in case of MICAz, the energy consumption is 199 initially and later on increases to stabilize at 340 at simulation time of 14 sec. For AT protocol the energy consumption in case of MICA is 20 initially and stabilizes at 80 at simulation time of 12 sec.



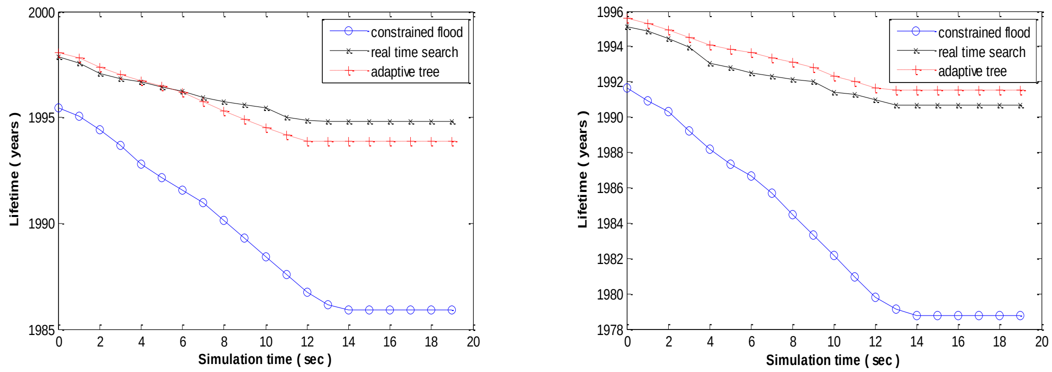
(a) (b)

Fig.10 Energy Comparison of different Protocols for a Radio Model with Rayleigh Fading (a) MICA (b) MICAz

However, in case of MICAz, the energy consumption is 197 initially which increases to stabilize to 300 at simulation time of 13 sec. Thus, in case of RMRYF, we conclude that the CF protocol shows the highest energy consumption in case of MICA and MICAz. However, in case of MICA, the RTS protocol indicates the lowest energy consumption while in case of MICAz, the AT protocol shows lower energy consumption. However, the energy consumption in case of MICAz is much higher as compared to MICA.

Fig.11 (a) depicts that the lifetime of the CF protocol in case of MICA is 1995 years initially and decreases to 1986 years at simulation time of 14 sec stabilizing thereafter.

However, in case of MICAz, (Fig.11 (b)), the lifetime of CF protocol is 1992 years initially which then decreases steeply till simulation time of 14 sec and stabilizes at 1979 years. For RTS protocol the lifetime is 1998 years initially in case of MICA which then decreases to 1995 years at simulation time of 12 sec and stabilizes.



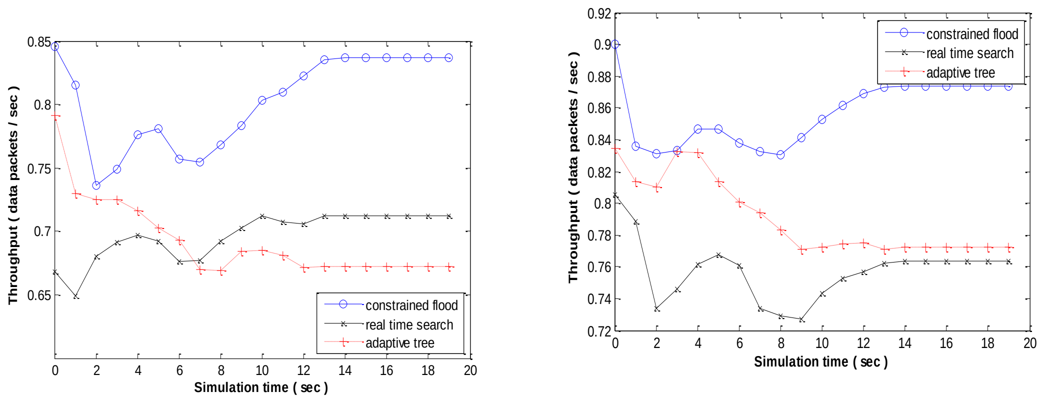
(a) (b)

Fig.11 Lifetime Comparison of different protocols for a Radio Model with Rayleigh Fading (a) MICA (b) MICAz

However, in case of MICAz, the lifetime is 1995 years initially and later on decreases to stabilize at 1991 years at simulation time of 13 sec. For AT protocol the lifetime in case of MICA is 1998 years initially and stabilizes at 1994 years at simulation time of 12 sec. However, in case of MICAz, the lifetime is 1996 years initially which decreases to stabilize at 1992 years at simulation time of 13 sec. Thus, in case of RMRYF, we conclude that the CF protocol shows the lowest lifetime in case of MICA and MICAz. However, in case of MICA, the RTS protocol indicates the highest lifetime while the AT protocol depicts the highest lifetime in case of MICAz. Thus, the lifetime in case of MICAz is much lower as compared to MICA.

3.4. Case 4: Radio Model with Rician Fading

Fig.12 (a) shows that the throughput of the CF protocol in case of MICA is 0.85 data packets/sec initially which then decreases to 0.73 data packets/sec at simulation time of 2 sec; later increasing to stabilize at 0.84 data packets/sec at simulation time of 14 sec. However, in case of MICAz, (Fig.12 (b)), the throughput of CF protocol is 0.9 data packets/sec initially which then fluctuates till simulation time of 14 sec stabilizing at 0.87 data packets/sec. For RTS protocol the throughput is 0.66 data packets/sec initially in case of MICA which then varies to stabilize at 0.71 data packets/sec at simulation time of 13 sec. However, in case of MICAz, the throughput is 0.80 data packets/sec initially and later on fluctuates to stabilize at 0.76 data packets/sec at simulation time of 14 sec. For AT protocol the throughput in case of MICA is 0.79 data packets/sec initially and stabilizes at 0.67 data packets/sec at simulation time of 13 sec.

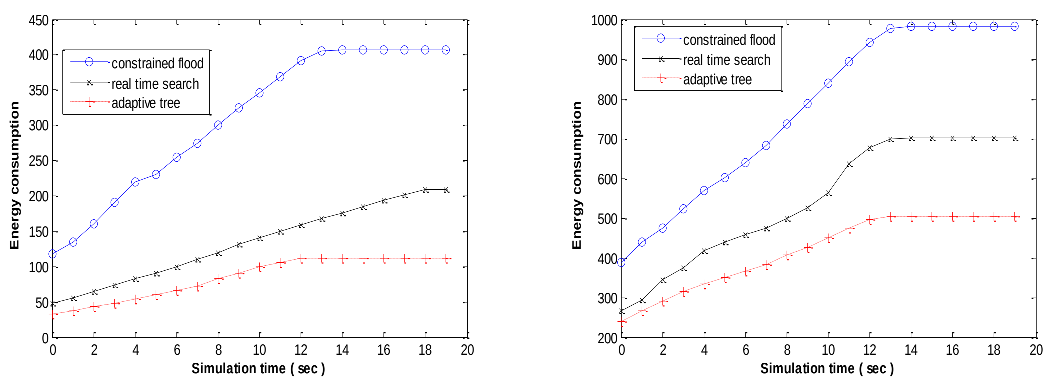


(a) (b)

Fig.12 Throughput Comparison of different Protocols for a Radio Model with Rician Fading (a) MICA (b) MICAz

However, in case of MICAz, the throughput is 0.83 data packets/sec initially which varies to stabilize at 0.77 data packets/sec at simulation time of 14 sec. Thus, in case of RMRCF, we conclude that the CF protocol shows the highest throughput in case of MICA and MICAz. The RTS protocol indicates the lowest throughput in case of MICAz while the AT protocol indicates the lowest throughput in case of MICA. Thus, the throughput in case of MICAz is much higher as compared to MICA.

Fig.13 (a) shows that the energy consumption of the CF protocol in case of MICA is 120 initially which then increases sharply to 400 at simulation time of 14 sec stabilizing thereafter. However, in case of MICAz, (Fig.13 (b)), the energy consumption of CF protocol is 400 initially which then increases steeply till simulation time of 14 sec and stabilizes at 990. For RTS protocol the energy consumption is 50 initially in case of MICA which then rises to 200 at simulation time of 18 sec and stabilizes.

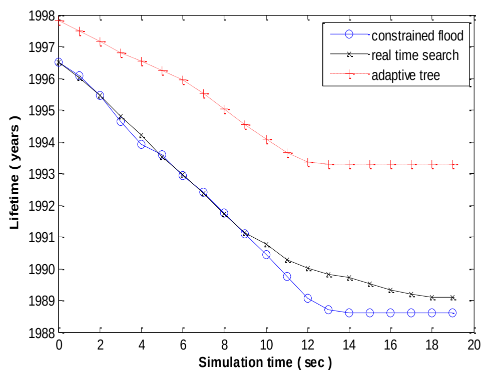


(a) (b)

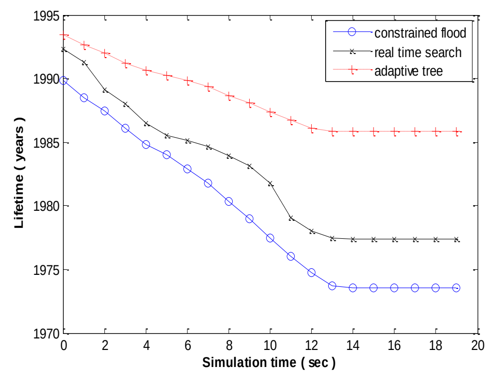
Fig.13 Energy Comparison of different protocols for a Radio Model with Rician Fading (a) MICA (b) MICAz

However, in case of MICAz, the energy consumption is 280 initially and later on increases to stabilize at 700 at simulation time of 14 sec. For AT protocol the energy consumption in case of MICA is 30 initially and stabilizes at 100 at simulation time of 13 sec. However, in case of MICAz, the energy consumption is 220 initially which increases to stabilize at 490 at simulation time of 14 sec. Thus, in case of RMRCF, we conclude that the CF protocol shows the highest energy consumption and the AT protocol indicates the lowest energy consumption in case of MICA and MICAz. However, the energy consumption in case of MICAz is much higher as compared to MICA.

Fig.14 (a) indicates that the lifetime of the CF protocol in case of MICA is 1996.5 years initially and decreases to 1989 years at simulation time of 14 sec and stabilizes thereafter. However, in case of MICAz, (Fig.14 (b)), the lifetime of CF protocol is 1990 years initially which then decreases steeply till simulation time of 14 sec and stabilizes at 1974 years. For RTS protocol the lifetime is 1996.5 years initially in case of MICA which then decreases to 1989.5 years at simulation time of 18 sec stabilizing thereafter. However, in case of MICAz, the lifetime is 1993 years initially and later on decreases to stabilize at 1978 years at simulation time of 14 sec. For AT protocol the lifetime in case of MICA is 1998 years initially and stabilizes at 1993.5 years at simulation time of 13 sec.



(a)



(b)

Fig.14 Lifetime Comparison of different protocols for a Radio Model with Rician Fading (a) MICA (b) MICAz

However, in case of MICAz, the lifetime is 1994 years initially which decreases to stabilize at 1986 years at simulation time of 13 sec. Thus, in case of RMRCF, we conclude that the CF protocol shows the lowest lifetime and the AT protocol indicates the highest lifetime in case of MICA and MICAz. However, the lifetime in case of MICAz is much lower as compared to MICA.

4. Conclusions

In this paper, the simulation results of the comparative investigation of the performance of routing protocols Constrained Flooding (CF), Real-Time Search (RTS) and Adaptive Tree (AT) for wireless sensor networks studied using advance wireless sensor simulator (prowler) on different realistic radio models have been presented. The results show that the AT protocol performs significantly better than CF and RTS routing protocols with tradeoffs in energy consumption and lifetime on one hand and throughput on the other hand. The simulation results indicate that the energy consumption decreases and lifetime of sensor networks increase when MICA motes are used instead of the MICAz motes. It has been observed that the energy consumption decreases in the range of 60-80 %, 35-79 %, 48-79 % and 63-85 % in case of RMRCF, RMRYF, RMSINR and NRM respectively for MICA motes. It has been, thus, concluded that in case of all the radio models MICA is preferably better than MICAz keeping in consideration the energy savings obtained using MICA motes in case of all the three routing protocols.

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