On Routing Protocols for WSNs with Additional Layers: Future Technology for IT

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Abstract—**WSNs are foreseen as one of the big opportunities in Information Technology. WSN technology is the measure for the future of Ubiquitous Computing. The motes preview a future pervaded by networks of wireless battery-powered sensors that monitor our environment, our machines, and even us. In this paper, we simulate and comparatively analyze the tree-based routing protocols: the Mint, the Broker, the Backbone and the Adaptive Tree using PROWLER. Our simulation results indicate that among all the tree-based routing protocols the adaptive tree protocol with and without additional layers has a low energy consumption, less loss rate and high throughput for all the radio models. However, the broker routing protocol with and without additional layers shows a slightly enhanced lifetime than the adaptive tree protocol with and without additional layers for all the radio models except the normal radio model (NRM). Further, for the NRM, the adaptive tree protocol with and without additional layers depicts a better lifetime than broker, mint and backbone routing protocols with and without additional layers.**

Index Terms—**constraint-based routing, meta-strategies, real-time reinforcement learning, routing tree, wireless sensor networks**

I. Introduction

Wireless sensor networks (WSNs) contain hundreds or thousands of sensor nodes (motes) equipped with sensing, computing and communication abilities. Sensors seem to result in an explosive increase in data flows when networks become more ubiquitous. This increase in the number of sensors operating around us will result in an exposition. This will be the area of concern and also a number of new data mining tools would be required to be developed, which will help us in extraction of relevant information from the voluminous data. Thus, WSN technology is the measure for the future of Ubiquitous Computing. The motes preview a future pervaded by networks of wireless battery-powered sensors that monitor our environment, our machines, and even us. The wireless sensor networks are being extensively used in healthcare, environmental and ubiquitous computing fields. Low-power wireless sensor networks are spearheading what the future of computing is going to look like. The information technology is playing a key role in the quest for the above applications of wireless sensor networks. WSNs are foreseen as one of the big opportunities in Information Technology (IT).

Routing in sensor network, however, has very different characteristics than routing in traditional communication networks. In the last several years, many routing protocols have been developed for wireless sensor networks, including Grid Routing [1], Directed Routing [2], Mint Routing [3], Backbone Routing [4], and the Constraint-based Routing Framework [5, 6]. Most of these routing protocols have been implemented on Berkeley motes [10], a widely used sensor network platform.

In the layered routing architecture [7], different routing components can be used to form a routing protocol. The architecture allows sharing of common components by different algorithms. In the Aggregate Queue (Agg) layer, maximum N packets may be assembled into one packet before sending. At the receiving end a packet is dissembled to N packets. Using Transmit Duplicate (Dup) component, each packet carries a zero age field the first time it is heard. The age field is incremented every time the packet is transmitted. The older the age, the lower the priority. Packets in the transmit queue are ordered by the priorities. Packets reaching the maximum age are dropped.

In the literature it has been found that the performance of WSNs with various routing protocols mentioned above has not been carried out in the presence of realistic fading models. The main contribution of this paper is performance comparison of routing protocols Mint Routing (MR), Broker Routing (BR), Backbone Routing (BbR) and Adaptive Tree (AT) for wireless sensor networks in a simulated environment. The comparison has been done on the basis of various performance metrics like: latency (sec), throughput (data packets/sec), loss rate, success rate, energy consumption, energy efficiency and lifetime (years). Here the performance evaluation is done by means of simulations using event-driven simulator PROWLER (Probabilistic Wireless Network Simulator) [8] and RMASE (Routing Modeling Application Simulation Environment) [7].

The paper is organized as follows: Section 2 describes the simulation model used. Section 3 gives the performance comparison of various routing protocols in the presence of normal radio model (NRM), radio model with SINR (RMSINR); radio model with Rayleigh fading

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(RMRYF); and radio model with Rician fading (RMRCF). Section 4 concludes the paper.

II. Simulation Model

In this section, we analyze the performance of the WSN protocols in the presence of various radio models using Prowler and Rmase. The tool is implemented in MATLAB, thus it provides a fast and easy way to prototype applications, and has nice visualization capabilities.

A. Radio, MAC Models and Routing Application Models

Here the MAC layer communication model and the radio propagation models: NRM, RMSINR, RMRYF and RMRCF have been used to investigate the performance comparison of various routing protocols using Prowler and Rmase.

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 [9]:

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

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

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. A network is asymmetric if $\sigma_{\alpha} > 0$ or $\sigma_{\beta} > 0$. 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. 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 $\gamma = 2$, $\sigma_{\alpha} = 0.45$, $\sigma_{\beta} = 0.02$, $\Delta = 0.1$ 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:

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

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:

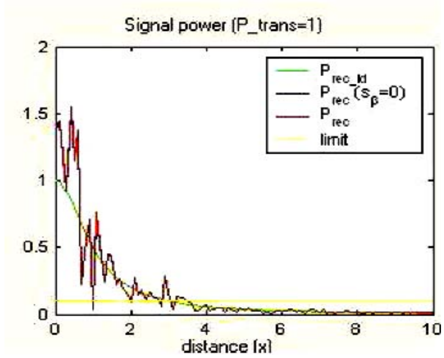
$$P_{rec}\ (i, j) \leftarrow P_{rec,\ ideal}\ (d_{i,j})\ (R) \qquad (4)$$

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.

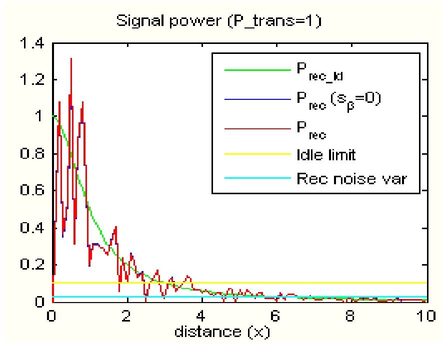
The transmission model for radio model with Rician fading in PROWLER is given by:

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

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)



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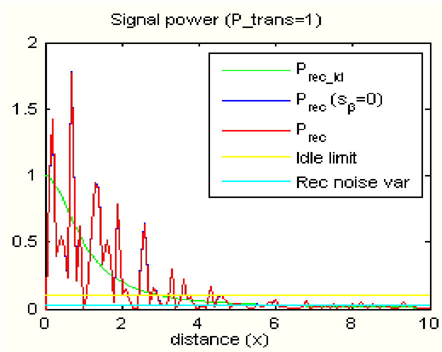

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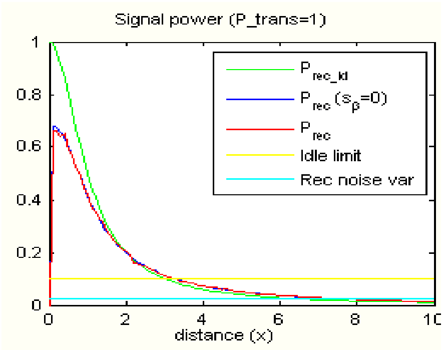


(d)

Figure 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' [10] CSMA MAC protocol.

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 *Backoff 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.

RMASE 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.

III. RESULTS AND DISCUSSIONS

In this paper an application to test the performance of the energy-aware and shortest path protocols has been used. The application, Pursuer Evader Game (PEG) [11], is used in the sensor network to detect an evader and to inform the pursuer about its location. The network used 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.

The radio data rate is 40 kbps [12] and each packet has 960 bits. On the other hand, for MICAz motes the radio data rate is 250 kbps [13] 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.

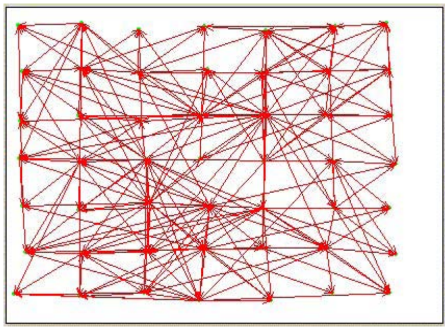
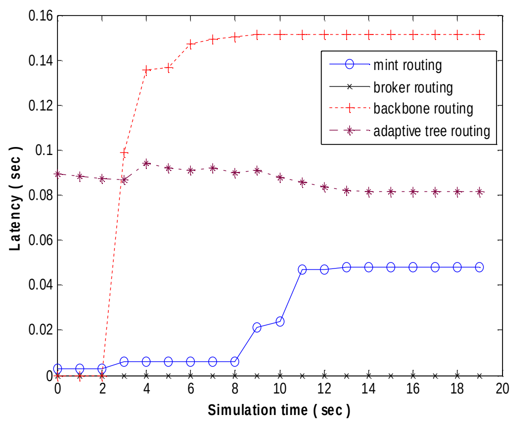


Figure 2. Instance of radio connectivity

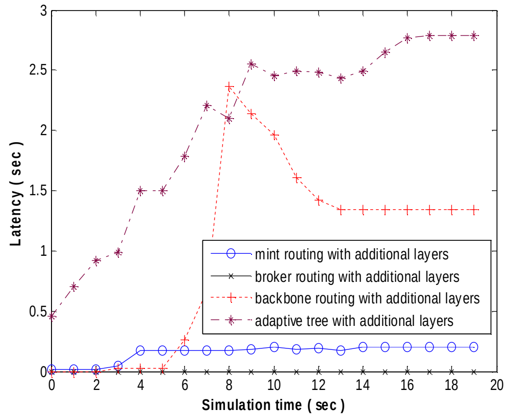
A. CASE 1: Normal Radio Model

We observe that the latency of the MR protocol without Agg and Dup layers Fig. 3 (a) is 0.005 sec initially which then increases to 0.05 sec at simulation time of 13 sec after which it stabilizes. However, in case of the MR protocol with Agg and Dup layers (Fig. 3 (b)), the latency of the MR protocol stabilizes after 0.2 sec. For the BR protocol without and with Agg and Dup layers the latency remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the latency is 0 sec initially and stabilizes at 0.15 sec at simulation time of 9 sec. However, in case of the BbR protocol with Agg and Dup layers, the latency is 0 sec initially which increases sharply and then decreases to stabilize at 1.4 sec at simulation time of 13 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the latency is 0.09 sec initially and then decreases to 0.08 sec at simulation time of 13 sec stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the latency is 0.5 sec which then increases to 2.8 sec at simulation time of 16 sec and stabilizes.

Thus, in case of NRM, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest latency and the BbR protocol without Agg and Dup layers indicates the highest latency whereas the AT protocol with Agg and Dup layers depicts highest latency.

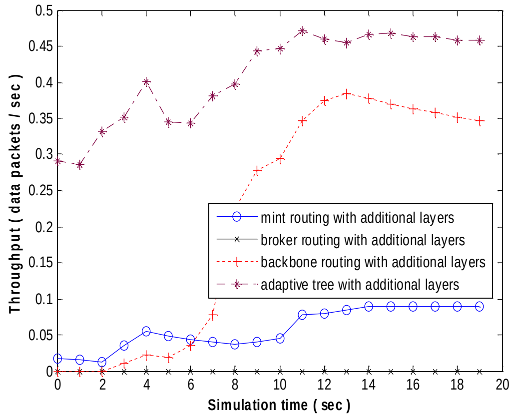


(a)



(b)

Figure 3. Average latency of sensor nodes for different routing algorithms in case of normal radio channel (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers



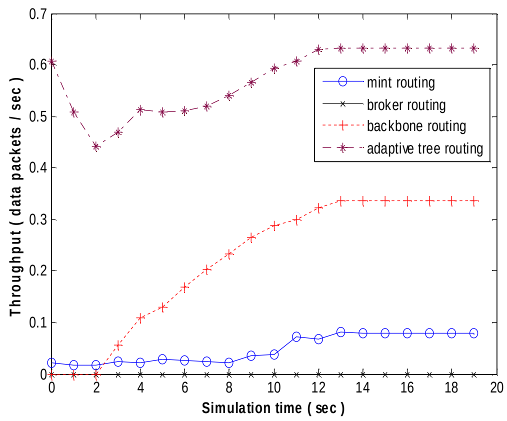
(b)

Figure 4. Average throughput of sensor nodes for different routing algorithms in case of normal radio channel (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

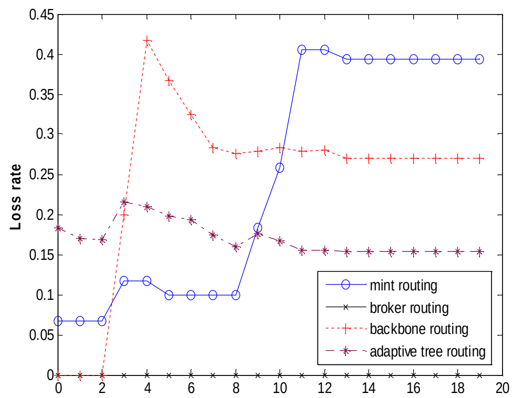
Fig. 4 (a) indicates that the throughput of the MR protocol without Agg and Dup layers is 0.02 data packets/sec initially which then increases to 0.09 data packets/sec at simulation time of 13 sec stabilizing thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 4 (b)), the throughput of the MR protocol is 0.02 data packets/sec initially and stabilizes at 0.09 data packets/sec. For the BR protocol without and with Agg and Dup layers the throughput remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the throughput is 0 data packets/sec initially and stabilizes at 0.34 data packets/sec at simulation time of 13 sec. However, in case of the BbR protocol with Agg and Dup layers, the throughput is 0 data packets/sec initially which increases sharply and then decreases to stabilize at 0.35 data packets/sec at simulation time of 19 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the throughput is 0.6 data packets/sec initially and then fluctuates till 0.62 data packets/sec at simulation time of 14 sec stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the throughput is 0.29 data packets/sec which then increases to 0.46 data packets/sec at simulation time of 18 sec and stabilizes.

Thus, in case of NRM, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest throughput while the AT protocol with and without Agg and Dup layers depicts highest throughput.

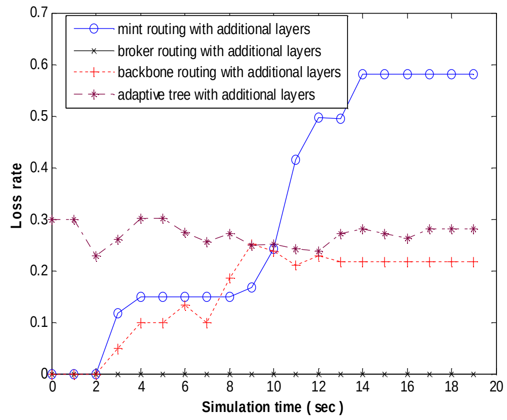
We find that the loss rate of the MR protocol without Agg and Dup layers Fig. 5 (a) is 0.07 initially and increases steeply to stabilize at 0.4 at simulation time of 13 sec. However, in case of the MR protocol with Agg and Dup layers (Fig. 5 (b)), the loss rate is 0 initially and increases to 0.59 at simulation time of 14 sec and stabilizes. For the BR protocol with and without Agg and Dup layers the loss rate remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers, the loss rate increases sharply to 0.42 till simulation time of 4 sec after which it reduces to stabilize at 0.27 at simulation time of 13 sec. For the BbR protocol with Agg and Dup layers the loss rate is 0 initially and thereby increases to stabilize at 0.22 at simulation time of 13 sec. For the AT protocol without Agg and Dup layers the loss rate is 0.18 initially and stabilizes at 0.15 at simulation time of 13 sec. However, in case of the AT protocol with Agg and Dup layers the loss rate is 0.3 initially which decrease to stabilize at 0.28 at simulation time of 17 sec.



(a)

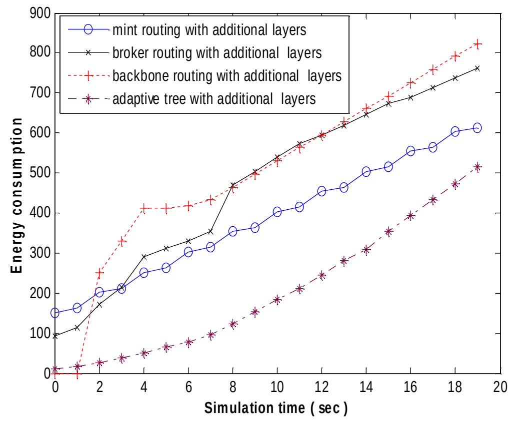


(a)



(b)

Figure 5. Average loss rate of sensor nodes for different routing algorithms in case of normal radio channel (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers



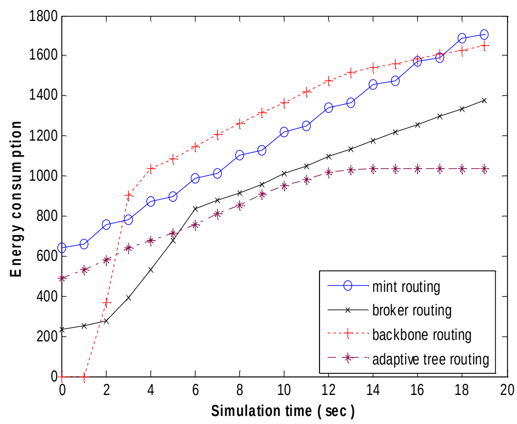
(b)

Figure 6. Average energy of sensor nodes for different routing algorithms in case of normal radio channel (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

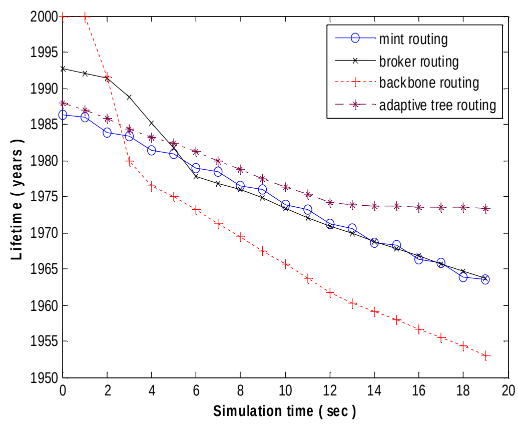
Thus, in case of NRM, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest loss rate. However, the MR protocol with and without Agg and Dup layers indicates highest loss rate.

We observe that the energy consumption of the MR protocol without Agg and Dup layers Fig. 6 (a) is 640 initially which then increases sharply to 1700 till simulation time of 19 sec stabilizing thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 6 (b)), the energy consumption is 150 initially which then increases steeply till simulation time of 19 sec and stabilizes at 600. For the BR protocol without Agg and Dup layers the energy consumption is 240 initially which then rise to 1300 at simulation time of 19 sec and stabilizes. However, in case of the BR protocol with Agg and Dup layers, the energy consumption is 100 initially and later on increases to stabilize at 760 at simulation time of 19 sec. For the BbR protocol without Agg and Dup layers the energy consumption is 0 initially which then rise to 1620 at simulation time of 19 sec after which it stabilizes. However, in case of the BbR protocol with Agg and Dup layers, the energy consumption stabilizes at 820 at simulation time of 19 sec. For the AT protocol without Agg and Dup layers the energy consumption is 500 initially and stabilizes at 1000 at simulation time of 13 sec. However, in case of the AT protocol with Agg and Dup layers, the energy consumption is 10 initially which increases to stabilize to 500 at simulation time of 19 sec. Thus, in case of NRM, it has been concluded that the AT protocol with and without Agg and Dup layers shows the lowest energy consumption while the BbR protocol with and without Agg and Dup layers indicates the highest energy consumption.

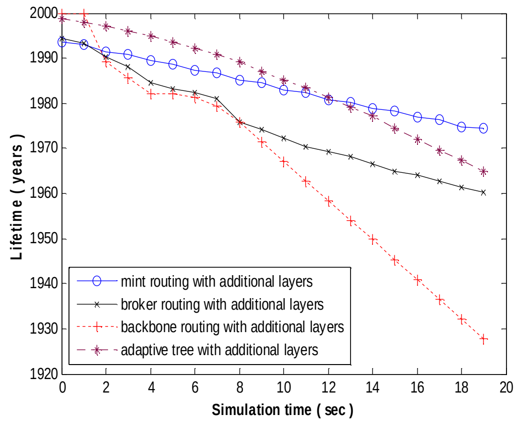
We observe that the lifetime of the MR protocol without Agg and Dup layers Fig. 7 (a) is 1986 years initially and decreases to 1965 years till simulation time of 19 sec and stabilizes. However, in case of the MR protocol with Agg and Dup layers (Fig. 7 (b)), the lifetime is 1994 years initially which then decreases steeply till simulation time of 19 sec and stabilizes at 1975 years. For the BR protocol without Agg and Dup layers the lifetime is 1993 years initially which then decrease to 1964 years at simulation time of 19 sec stabilizing thereafter. However, in case of the BR protocol with Agg and Dup layers, the lifetime is 1995 years initially and later on decreases to stabilize at 1960 years at simulation time of 19 sec. For the BbR protocol without Agg and Dup layers the lifetime is 2000 years



(a)

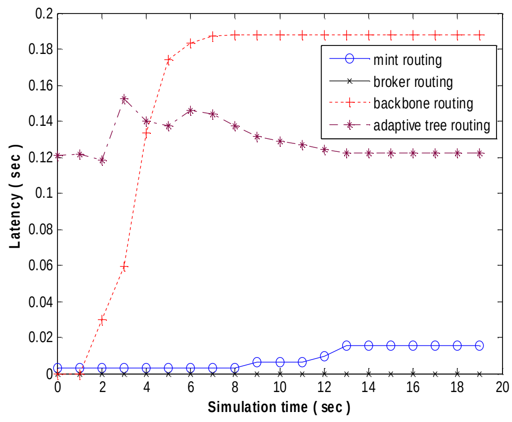


(a)

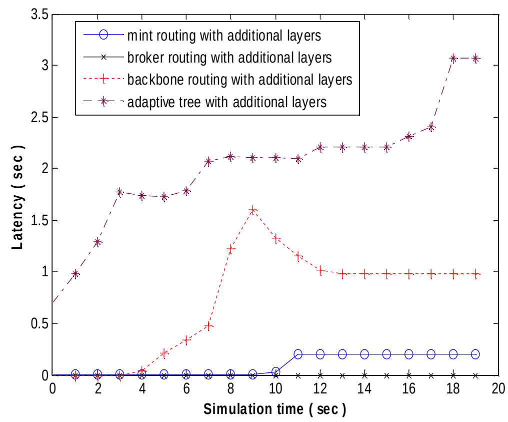


(b)

Figure 7. Average lifetime of sensor nodes for different routing algorithms in case of normal radio channel (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers



(a)



(b)

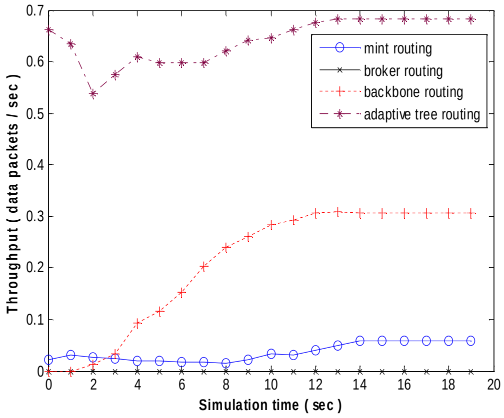
Figure 8. Average latency of sensor nodes for different routing algorithms in case of radio channel with SINR (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1953 years. On the other hand, in case of the BbR protocol with Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1928 years. For the AT protocol without Agg and Dup layers the lifetime is 1988 years initially and stabilizes at 1974 years at simulation time of 13 sec. However, in case of the AT protocol with Agg and Dup layers, the lifetime is 1999 years initially which decreases to stabilize to 1965 years at simulation time of 19 sec. Thus, in case of NRM, it has been concluded that the BbR protocol with and without Agg and Dup layers shows the lowest lifetime while the AT protocol with and without Agg and Dup layers indicates the highest lifetime.

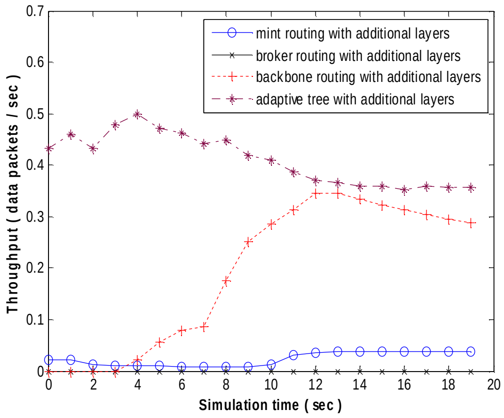
B. *CASE 2: Radio Model with SINR*

Fig. 8 (a) indicates that the latency of the MR protocol without Agg and Dup layers is 0.005 sec initially which then increases to 0.01 sec at simulation time of 13 sec and stabilizes thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 8 (b)), the latency of the MR protocol increases till simulation time of 11 sec and stabilizes at 0.2 sec. For the BR protocol without and with Agg and Dup layers the latency remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the latency is 0 sec initially and stabilizes at 0.19 sec at simulation time of 8 sec. However, in case of the BbR protocol with Agg and Dup layers, the latency is 0 sec initially which increases sharply and then decreases to stabilize at 1 sec at simulation time of 13 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the latency is 0.12 sec initially and then decreases to 0.125 sec at simulation time of 13 sec and stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the latency is 0.7 sec which then increases to 3 sec at simulation time of 18 sec and stabilizes. Thus, in case of RMSINR, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest latency while the BbR protocol without Agg and Dup layers indicates the highest latency whereas the AT protocol with Agg and Dup layers depicts highest latency.

We observe that the throughput of the MR protocol without Agg and Dup layers Fig. 9 (a) is 0.02 data packets/sec initially which then increases to 0.08 data packets/sec at simulation time of 14 sec and stabilizes. However, in case of the MR protocol with Agg and Dup layers (Fig. 9 (b)), the throughput of the MR protocol is 0.02 data packets/sec initially which then increases till simulation time of 13 sec and stabilizes at 0.04 data packets/sec. For the BR protocol without and with Agg and Dup layers the throughput remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the throughput is 0 data packets/sec initially and stabilizes at 0.3 data packets/sec at simulation time of 14 sec. However, in case of the BbR protocol with Agg and transmit duplicate layers, the throughput is 0 data packets/sec initially which increases sharply and then decreases to stabilize at 0.3 data packets/sec at simulation time of 19 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the throughput is 0.67 data packets/sec initially and then

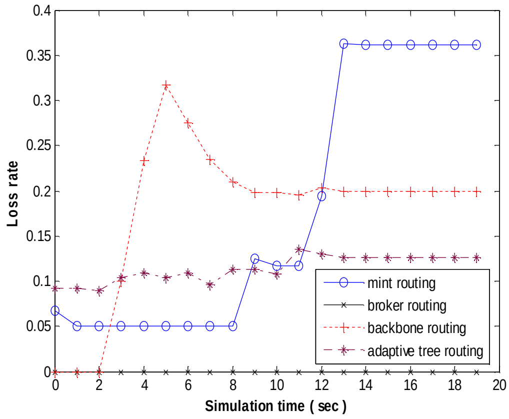


(a)

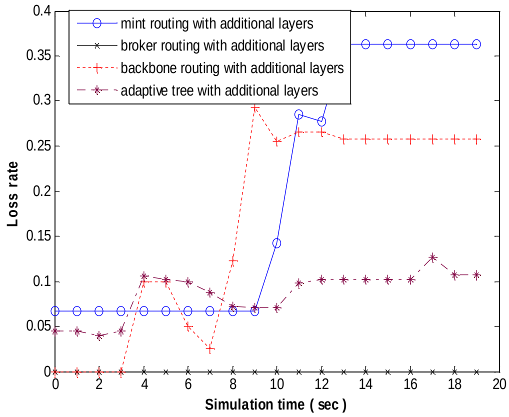


(b)

Figure 9. Average throughput of sensor nodes for different routing algorithms in case of radio channel with SINR (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers



(a)



(b)

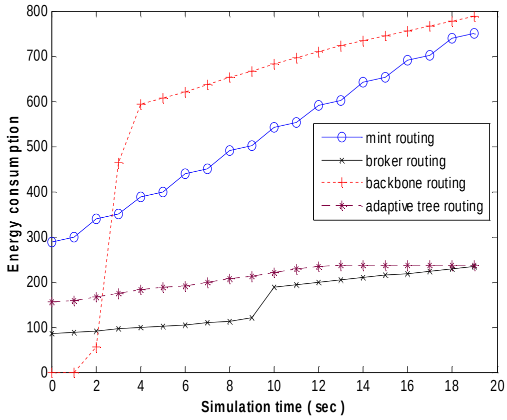
Figure 10. Average loss rate of sensor nodes for different routing algorithms in case of radio channel with SINR (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

fluctuates till 0.69 data packets/sec at simulation time of 13 sec stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the throughput is 0.43 data packets/sec which then varies till 0.37 data packets/sec at simulation time of 17 sec and stabilizes. Thus, in case of RMSINR, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest throughput while the AT protocol with and without Agg and Dup layers depicts highest throughput.

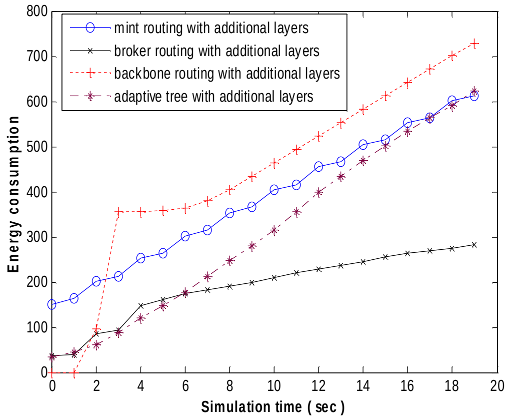
Fig. 10 (a) shows that the loss rate of the MR protocol without Agg and Dup layers is 0.07 initially and increases steeply to stabilize at 0.36 at simulation time of 14 sec. However, in case of the MR protocol with Agg and Dup layers (Fig. 10 (b)), the loss rate is 0.06 initially and increases to 0.36 at simulation time of 14 sec after which it stabilizes. For the BR protocol with and without Agg and Dup layers the loss rate is remains constant thereafter. For the BbR protocol without Agg and Dup layers the loss rate is 0 initially and then increases sharply to 0.32 at simulation time of 5 sec after which it reduces to stabilize at 0.2 at simulation time of 13 sec. For the BbR protocol with Agg and Dup layers the loss rate is 0 initially and thereafter fluctuates to stabilize at 0.26 at simulation time of 13 sec.

For the AT protocol without Agg and Dup layers the loss rate is 0.09 initially and stabilizes at 0.13 at simulation time of 13 sec. However, in case of the AT protocol with Agg and Dup layers the loss rate is 0.04 initially which increase to stabilize at 0.11 at simulation time of 18 sec. Thus, in case of RMSINR, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest loss rate. However, the MR protocol with and without Agg and Dup layers indicates highest loss rate.

Fig. 11 (a) depicts that the energy consumption of the MR protocol without Agg and Dup layers is 290 initially which then increases sharply to 750 till simulation time of 19 sec and stabilizes thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 11 (b)), the energy consumption is 150 initially which then increases steeply till simulation time of 19 sec and stabilizes at 620. For the BR protocol without Agg and Dup layers the energy consumption is 80 initially which then rise to 230 at simulation time of 19 sec and stabilizes. However, in case of the BR protocol with Agg and Dup layers, the energy consumption is 40 initially and later on increases to stabilize at 280 at simulation time of 19 sec.



(a)



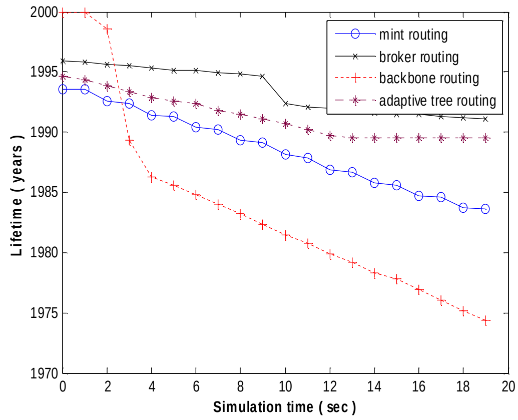
(b)

Figure 11. Average energy of sensor nodes for different routing algorithms in case of radio channel with SINR (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

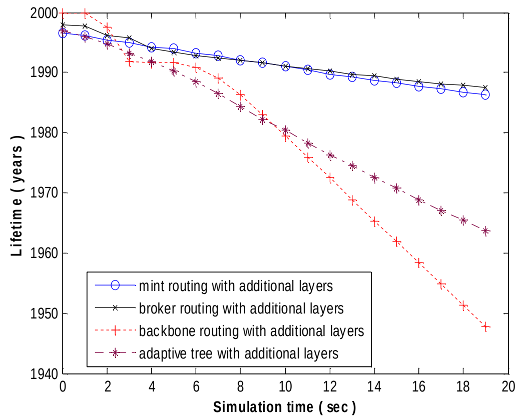
For the BbR protocol without Agg and Dup layers the energy consumption is 0 initially which then rise to 790 at simulation time of 19 sec and stabilizes thereafter. However, in case of the BbR protocol with Agg and Dup layers, the energy consumption is 0 initially and later on increases to stabilize at 730 at simulation time of 19 sec. For the AT protocol without Agg and Dup layers the energy consumption is 150 initially and stabilizes at 240 at simulation time of 13 sec. However, in case of the AT protocol with Agg and Dup layers, the energy consumption is 40 initially which increases to stabilize at 620 at simulation time of 19 sec. Thus, in case of RMSINR, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest energy consumption while the BbR protocol with and without Agg and Dup layers indicates the highest energy consumption.

Fig. 12 (a) indicates that the lifetime of the MR protocol without Agg and Dup layers is 1994 years initially and decreases to 1984 years till simulation time 18 sec after which it stabilizes. However, in case of the MR protocol with Agg and Dup layers (Fig. 12 (b)), the lifetime is 1996 years initially which then decreases steeply till simulation time of 18 sec and stabilizes at 1986 years. For the BR protocol without Agg and Dup layers the lifetime is 1996 years initially which then decrease to 1991 years at simulation time of 18 sec stabilizing thereafter. However, in case of the BR protocol with Agg and Dup layers, the lifetime is 1998 years initially and later on decreases to stabilize at 1988 years at simulation time of 19 sec. For the BbR protocol without Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1974 years. On the other hand, in case of the BbR protocol with Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1947 years. For the AT protocol without Agg and Dup layers the lifetime is 1995 years initially and stabilizes at 1990 years at simulation time of 13 sec.

However, in case of the AT protocol with Agg and Dup layers, the lifetime is 1997 years initially which decreases to stabilize to 1964 years at simulation time of 19 sec. Thus, in case of RMSINR, it has been concluded that the BbR protocol with and without Agg and Dup layers shows the lowest lifetime while the BR protocol with and without Agg and Dup layers indicates the highest lifetime.



(a)

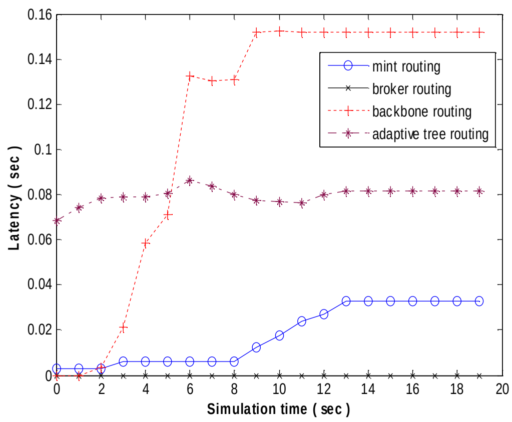


(b)

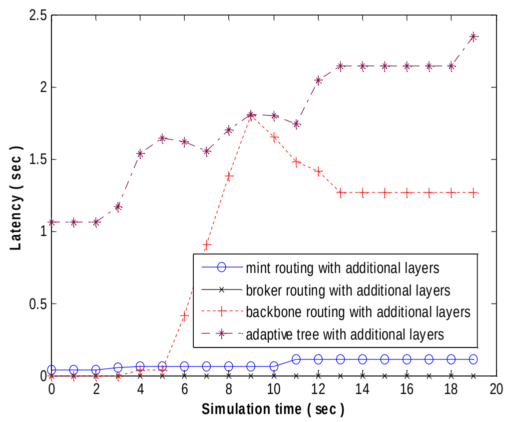
Figure 12. Average lifetime of sensor nodes for different routing algorithms in case of radio channel with SINR (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

C. CASE 3: Radio Model with Rayleigh Fading

We observe that the latency of the MR protocol without Agg and Dup layers Fig. 13 (a) is 0.005 sec initially which then increases to 0.03 sec at simulation time of 13 sec and stabilizes thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 13 (b)) the latency of the MR protocol is 0.005 sec initially which then increases till simulation time of 11 sec and stabilizes at 0.1 sec. For the BR protocol without and with Agg and Dup layers the latency is remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the latency is 0 sec initially and stabilizes at 0.15 sec at simulation time of 9 sec. However, in case of the BbR protocol with Agg and Dup layers, the latency is 0 sec initially which increases sharply and then decreases to stabilize at 1.2 sec at simulation time of 13 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the latency is 0.07 sec initially and then increases to 0.08 sec at simulation time of 13 sec stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the latency is 1.1 sec which then increases to 2.4 sec at simulation time of 19 sec after which it stabilizes.



(a)

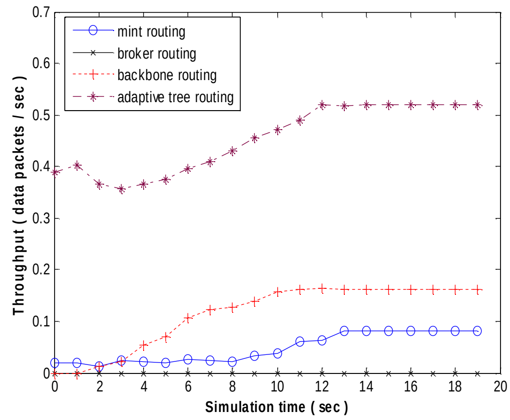


(b)

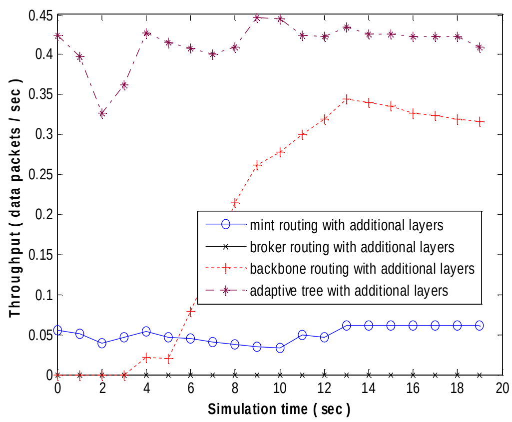
Figure 13. Average latency of sensor nodes for different routing algorithms in case of radio channel with Rayleigh fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

Thus, in case of RMRYF, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest latency whereas the BbR protocol without Agg and Dup layers indicates the highest latency whereas the AT protocol with Agg and Dup layers depicts highest latency.

Fig. 14 (a) shows that the throughput of the MR protocol without Agg and Dup layers is 0.02 data packets/sec initially which then increases to 0.08 data packets/sec at simulation time of 13 sec and stabilizes thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 14 (b)) the throughput of the MR protocol is 0.05 data packets/sec initially which then increases till simulation time of 13 sec and stabilizes at 0.06 data packets/sec. For the BR protocol without and with Agg and Dup layers the throughput remains constant for the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the throughput is 0 data packets/sec initially and stabilizes at 0.15 data packets/sec at simulation time of 11 sec. However, in case of the BbR protocol with Agg and Dup layers, the throughput is 0 data packets/sec initially which increases sharply and then decreases to stabilize at 0.32 data packets/sec at simulation time of 19 sec.



(a)



(b)

Figure 14. Average throughput of sensor nodes for different routing algorithms in case of radio channel with Rayleigh fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

Moreover, in case of the AT protocol without Agg and Dup layers, the throughput is 0.39 data packets/sec initially and then fluctuates till 0.51 data packets/sec at simulation time of 13 sec stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the throughput is 0.42 data packets/sec which then varies till 0.40 data packets/sec at simulation time of 19 sec after which it stabilizes. Thus, in case of RMRYF, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest throughput while the AT protocol with and without Agg and Dup layers depicts highest throughput.

We find that the loss rate of the MR protocol without Agg and Dup layers Fig. 15 (a) is 0.08 initially and increases steeply to stabilize at 0.6 at simulation time of 13 sec. However, in case of the MR protocol with Agg and Dup layers (Fig. 15 (b)), the loss rate is 0.13 initially and increases to 0.48 at simulation time of 13 sec after which it stabilizes. For the BR protocol with and without Agg and Dup layers the loss rate remains constant thereafter for the rest of the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the loss rate is 0 initially and then increases to stabilize at 0.19 at simulation time of 13 sec.

For the BbR protocol with Agg and Dup layers the loss rate is 0 initially and thereby increases to stabilize at 0.26 at simulation time of 13 sec. For the AT protocol without Agg and Dup layers the loss rate is 0.14 initially and stabilizes at 0.23 at simulation time of 13 sec. However, in case of the AT protocol with Agg and Dup layers the loss rate is 0.26 initially which decrease to stabilize at 0.31 at simulation time of 19 sec. Thus, in case of RMRYF, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest loss rate. However, the MR protocol with and without Agg and Dup layers indicates highest loss rate.

We observe that the energy consumption of the MR protocol without Agg and Dup layers Fig. 16 (a) is 290 initially which then increases sharply to 750 till simulation time of 19 sec stabilizing thereafter. However, in case of the MR protocol with Agg and Dup layers (Fig. 16 (b)), the energy consumption is 150 initially which then increases steeply till simulation time of 19 sec and stabilizes at 620. For the BR protocol without Agg and Dup layers the energy consumption remains the same for the remaining of the simulation time of 20 sec. For the BR protocol with Agg and Dup layers the energy

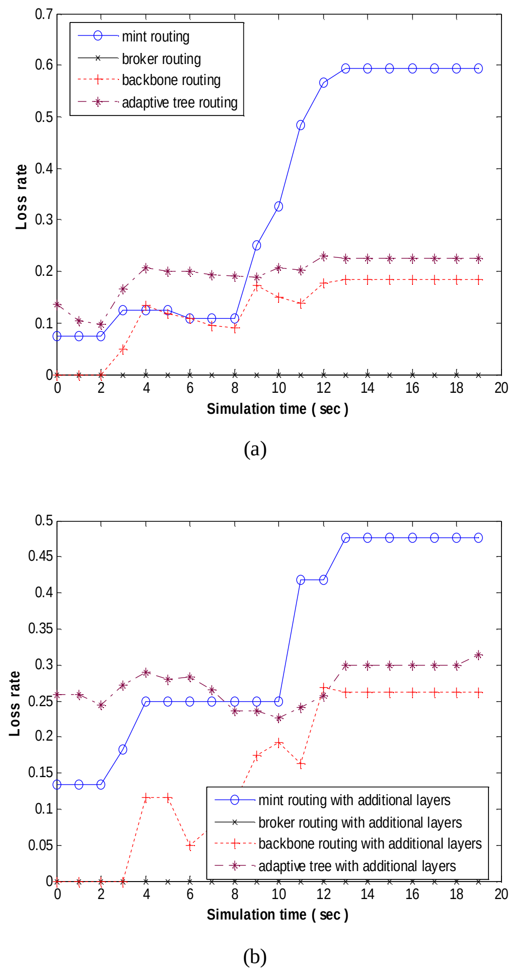


Figure 15. Average loss rate of sensor nodes for different routing algorithms in case of radio channel with Rayleigh fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

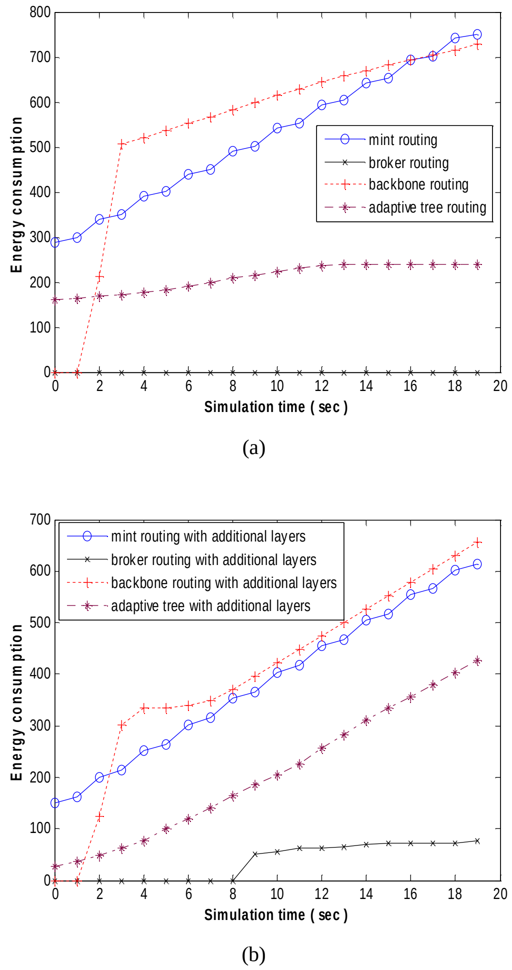


Figure 16. Average energy of sensor nodes for different routing algorithms in case of radio channel with Rayleigh fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

consumption is 0 initially and increases to 170 s at simulation time of 14 sec and stabilizes. For the BbR protocol without Agg and Dup layers the energy consumption is 0 initially which then rise to 730 at simulation time of 19 sec and stabilizes thereafter. However, in case of the BbR protocol with Agg and Dup layers, the energy consumption is 0 initially and later on increases to stabilize at 650 at simulation time of 19 sec. For the AT protocol without Agg and Dup layers the energy consumption is 160 initially and stabilizes at 240 at simulation time of 14 sec. However, in case of the AT protocol with Agg and Dup layers, the energy consumption is 30 initially which increases to stabilize at 430 at simulation time of 19 sec. Thus, in case of RMRYF, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest energy consumption whereas the BbR protocol with and without Agg and Dup layers indicates the highest energy consumption.

We find that the lifetime of the MR protocol without Agg and Dup layers Fig. 17 (a) is 1994 years initially and decreases to 1984 years till simulation time of 19 sec after which it stabilizes.

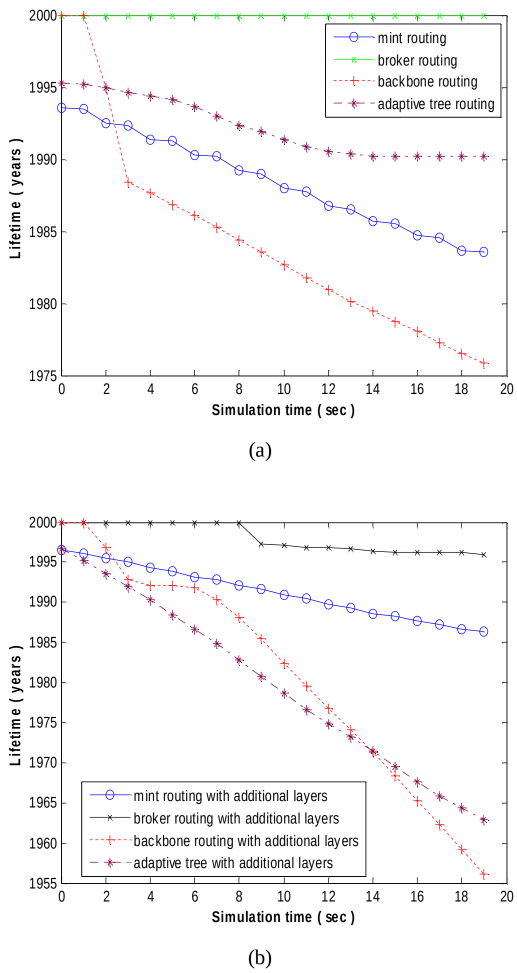
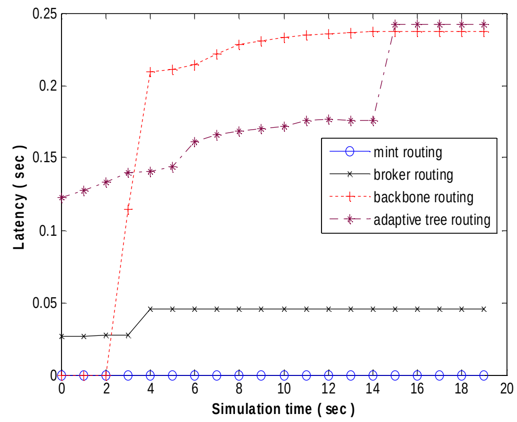


Figure 17. Average lifetime of sensor nodes for different routing algorithms in case of radio channel with Rayleigh fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

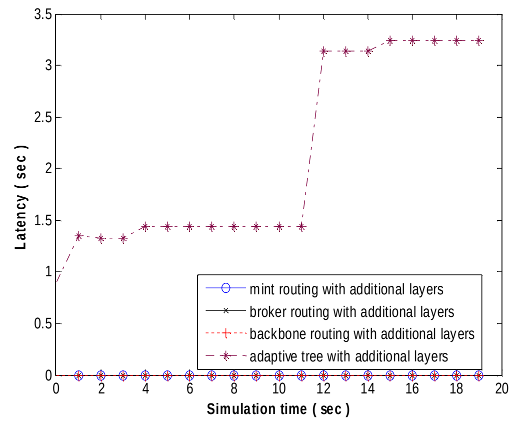
However, in case of the MR protocol with Agg and Dup layers (Fig. 17 (b)), the lifetime is 1997 years initially which then decreases steeply till simulation time of 19 sec and stabilizes at 1987 years. For the BR protocol without Agg and Dup layers the lifetime is 2000 years initially and remains constant for the rest of the simulation time of 20 sec. However, in case of the BR protocol with Agg and Dup layers, the lifetime is 2000 years initially and later on decreases to stabilize at 1996 years at simulation time of 19 sec. For the BbR protocol without Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1976 years. On the other hand, in case of the BbR protocol with Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1956 years. For the AT protocol without Agg and Dup layers the lifetime is 1995 years initially and stabilizes at 1990 years at simulation time of 14 sec. However, in case of the AT protocol with Agg and Dup layers, the lifetime is 1997 years initially which decreases to stabilize at 1963 years at simulation time of 19 sec. Thus, in case of RMRYF, it has been concluded that the BbR protocol with and without Agg and Dup layers shows the lowest lifetime whereas the BR protocol with and without Agg and Dup layers indicates the highest lifetime.

D. CASE 4: Radio Model with Rician Fading

Fig. 18 (a&b) shows that the latency of the MR protocol with and without Agg and Dup layers is 0 sec initially and remains constant for the rest of the simulation time of 20 sec. For the BR protocol without Agg and Dup layers the latency is 0.02 sec initially and thereby increases to 0.05 sec till simulation time of 4 sec and stabilizes thereafter. For the BR protocol with Agg and Dup layers the latency is 0 sec initially and remains constant for the remaining of the simulation time 0f 20 sec. For the BbR protocol without Agg and Dup layers the latency is 0 sec initially and stabilizes at 0.24 sec at simulation time of 14 sec. However, in case of the BbR protocol with Agg and Dup layers, the latency and remains zero for the simulation time of 20 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the latency is 0.12 sec initially and then increases to 0.24 sec at simulation time of 15 sec stabilizing thereafter. Further, in case of the AT protocol with Agg and Dup layers, the latency is 0.9 sec which then increases to 3.2 sec at simulation time of 15 sec and stabilizes. Thus, in case of RMRCF, it has been concluded that the MR protocol with and without Agg and Dup layers as well as BbR and BR protocol with Agg and Dup layers show the lowest latency while the AT protocol with and without Agg and Dup layers indicates the highest latency indicates the highest latency.

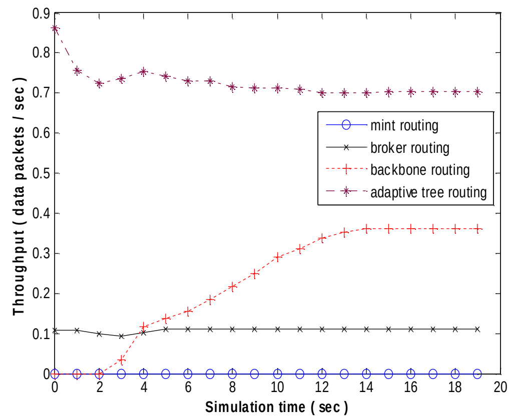


(a)

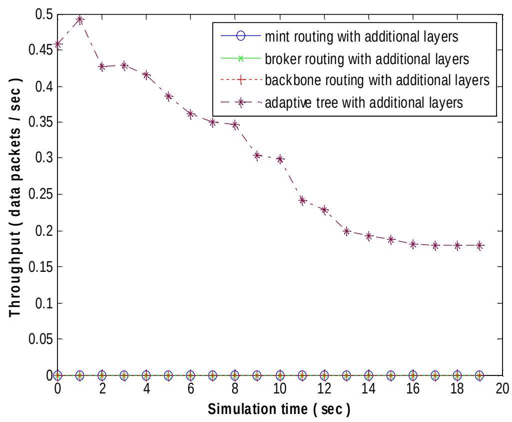


(b)

Figure 18. Average latency of sensor nodes for different routing algorithms in case of radio channel with Rician fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers



(a)



(b)

Figure 19. Average throughput of sensor nodes for different routing algorithms in case of radio channel with Rician fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

We observe that the throughput of the MR protocol with and without Agg and Dup layers Fig. 19 (a&b) remains constant for the simulation time of 20 sec. For the BR protocol without Agg and Dup layers the throughput is 0.1 data packets/sec initially and then rises slightly till 0.11 data packets/sec at simulation time of 5 sec stabilizing thereafter. For the BR protocol with Agg and Dup layers the throughput is 0 data packets/sec initially and remains the same throughout the remaining simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the throughput is 0 data packets/sec initially and stabilizes at 0.35 data packets/sec at simulation time of 14 sec. However, in case of the BbR protocol with Agg and Dup layers, the throughput is 0 data packets/sec initially and remains constant for the rest of the simulation time of 20 sec. Moreover, in case of the AT protocol without Agg and Dup layers, the throughput is 0.88 data packets/sec initially and then decreases to 0.70 data packets/sec at simulation time of 12 sec and stabilizes. Further, in case of the AT protocol with Agg and Dup layers, the throughput is 0.46 data packets/sec which then decreases to 0.18 data packets/sec at simulation time of 16 sec and stabilizes thereafter. Thus, in case of RMRCF, it has been concluded that the MR protocol with and without Agg and Dup layers as well as the BR and the BbR protocols with without Agg and Dup layers show the lowest throughput whereas the AT protocol with and without Agg and Dup layers depicts highest throughput.

Fig. 20 (a&b) depicts that the loss rate of the MR protocol with and without Agg and Dup layers remains zero for the simulation time of 20 sec. For the BR protocol without Agg and Dup layers the loss rate is 0.03 initially and remains constant thereafter for the remaining of the simulation time of 20 sec. For the BR protocol with Agg and Dup layers the loss rate is 0 initially and remains the same for the remaining of the simulation time of 20 sec. For the BbR protocol without Agg and Dup layers the loss rate is 0 initially and then increases sharply to 0.49 at simulation time of 4 sec after which it reduces to stabilize at 0.25 at simulation time of 14 sec. For the BbR protocol with Agg and Dup layers the loss rate is 0 initially and remains constant for the remaining simulation time of 20 sec. For the AT protocol without Agg and Dup layers the loss rate is 0.02 initially and stabilizes at 0.12 at simulation time of 15 sec. However, in case of the AT protocol with Agg and Dup layers the loss rate is 0.05 initially and remains the same for the rest

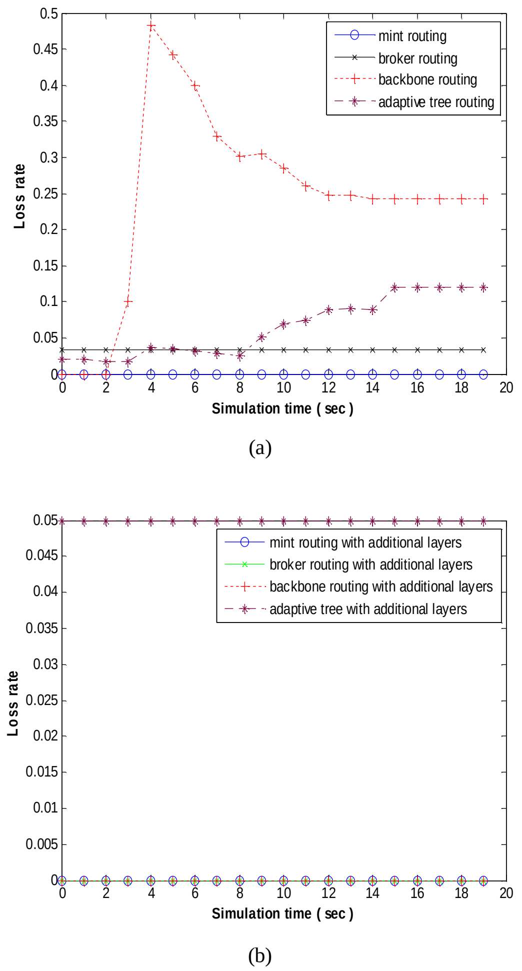


Figure 20. Average loss rate of sensor nodes for different routing algorithms in case of radio channel with Rician fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

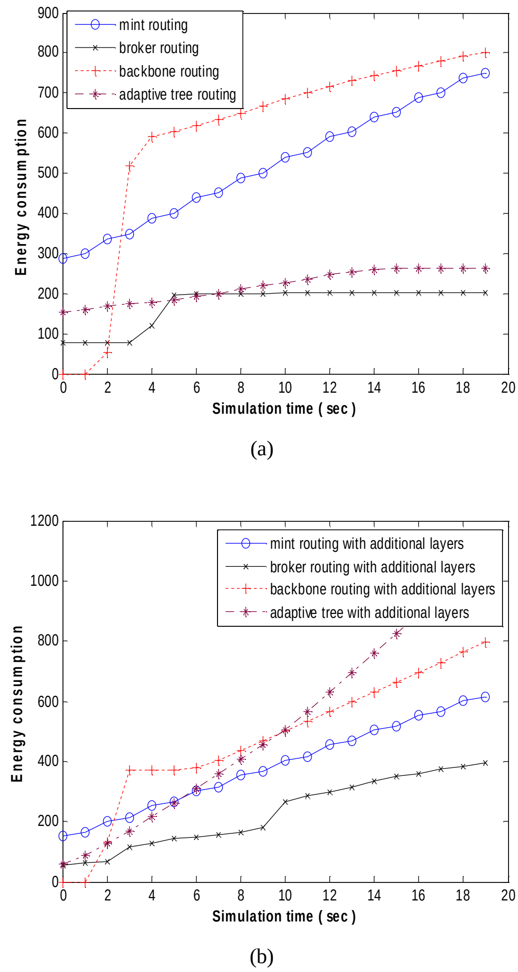


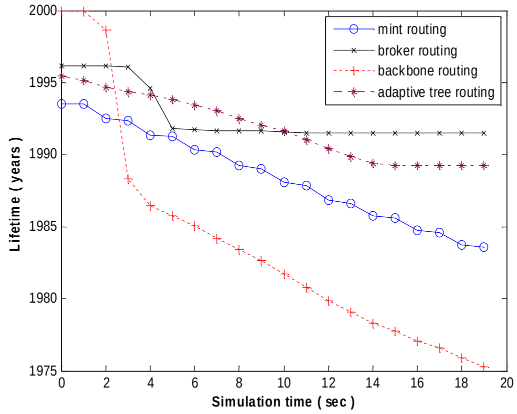
Figure 21. Average energy of sensor nodes for different routing algorithms in case of radio channel with Rician fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

of the simulation time of 20 sec. Thus, in case of RMRCF, it has been concluded that the MR protocol without Agg and Dup layers and the MR, the BR and the BbR protocols with Agg and Dup layers shows the lowest loss rate. However, the BbR protocol without Agg and Dup layers and the AT protocol with Agg and Dup layers indicates highest loss rate.

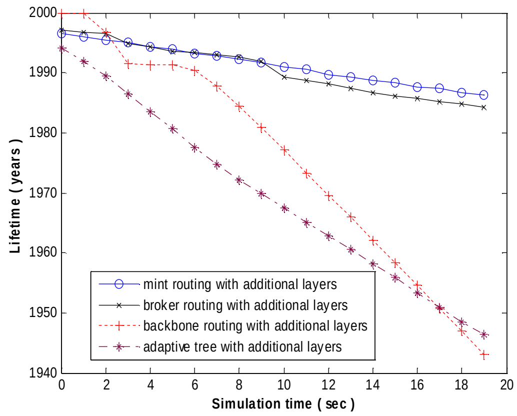
Fig. 21 (a) indicates that the energy consumption of the MR protocol without Agg and Dup layers is 290 initially which then increases sharply to 750 till simulation time of 19 sec and stabilizes thereafter. However, in case of the MR protocol with Agg and Dup layers Fig. 21 (b), the energy consumption is 160 initially which then increases steeply till simulation time of 19 sec and stabilizes at 620. For the BR protocol without Agg and Dup layers the energy consumption is 80 initially which then rise to 200 at simulation time of 12 sec stabilizing thereafter. However, in case of the BR protocol with Agg and Dup layers, the energy consumption is 50 initially and later on increases to stabilize at 400 at simulation time of 19 sec. For the BbR protocol without Agg and Dup layers the energy consumption is 0 initially which then rise to 800 at simulation time of 19 sec and stabilizes. However, in case of the BbR protocol with Agg and Dup layers, the energy consumption is 0 initially and later on increases to stabilize at 800 at simulation time of 19 sec. For the AT protocol without Agg and Dup layers the energy consumption is 150 initially and stabilizes at 260 at simulation time of 14 sec. However, in case of the AT protocol with Agg and Dup layers, the energy consumption is 50 initially which increases to stabilize at 1000 at simulation time of 19 sec.

Thus, in case of RMRCF, it has been concluded that the BR protocol with and without Agg and Dup layers shows the lowest energy consumption whereas the BbR protocol without Agg and Dup layers and the AT protocol with Agg and Dup layers indicates the highest energy consumption.

Fig. 22 (a) shows that the lifetime of the MR protocol without Agg and Dup layers is 1994 years initially and decreases to 1984 years at simulation time of 19 sec after which it stabilizes. However, in case of the MR protocol with Agg and Dup layers (Fig. 22 (b)), the lifetime is 1997 years initially which then decreases steeply till simulation time of 18 sec and stabilizes at 1987 years. For the BR protocol without Agg and Dup layers the lifetime is 1996 years initially which then decrease to 1992 years at simulation time of 12 sec stabilizing thereafter.



(a)



(b)

Figure 22. Average lifetime of sensor nodes for different routing algorithms in case of radio channel with Rician fading (a) without addition of agg. & dup. layers (b) with addition of agg. & dup. layers

However, in case of the BR protocol with Agg and Dup layers, the lifetime is 1998 years initially and later on decreases to stabilize at 1984 years at simulation time of 19 sec. For the BbR protocol without Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1975 years. On the other hand, in case of the BbR protocol with Agg and Dup layers the lifetime is 2000 years initially which then decrease steeply till simulation time of 19 sec and stabilizes at 1943 years. For the AT protocol without Agg and Dup layers the lifetime is 1995 years initially and stabilizes at 1989 years at simulation time of 14 sec. However, in case of the AT protocol with Agg and Dup layers, the lifetime is 1995 years initially which decreases to stabilize at 1946 years at simulation time of 19 sec. Thus, in case of RMRCF, it has been concluded that the BbR protocol with and without Agg and Dup layers shows the lowest lifetime while the BR protocol without Agg and Dup layers and the MR protocol with Agg and Dup layers indicates the highest lifetime.

IV. Conclusion

Using the layered architecture, we integrated Agg and Dup routing components in the above stated tree-based WSN protocols. The simulation results indicate that the adaptive tree protocol with and without additional layers has low energy consumption, less success rate and high throughput for all the radio models. However, the broker routing protocol with and without additional layers shows a slightly enhanced lifetime than the adaptive tree protocol with and without additional layers for all the radio models except NRM. Further, for the NRM, the adaptive tree protocol with and without additional layers depicts a better lifetime than broker, mint and backbone routing protocols with and without additional layers. Thus, it has been concluded that the addition of the Agg and Dup layer reduces energy consumption and enhances the lifetime of sensor network. These networks are being used in healthcare, environmental, ubiquitous computing fields and have many more applications related to IT and these applications can be used for wireless sensor networks. The wireless sensor networks are, thus, spearheading what the future of computing is going to look alike establishing the fact that any improvement in the WSN technology will lead to advances in IT.

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