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Application of Swarm Intelligence Based Routingprotocols for Wireless Adhoc Sensor Network

Mrutyunjaya PANDA
Department of Electronics and Communication Engineering
Gandhi Institute for Technological Advancement, Bhubaneswar
Odisha, India
E-mail: mrutyunjaya.2007@rediffmail.com

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Abstract: The enormous growth of wireless sensor network (WSN) research has opined challenges about their ease in implementation and performance evaluation. Efficient swarm intelligence based routing protocols that can be used to obtain the application specific service guarantee are the key design issues in designing a WSN model. In this paper, an experimental testbed is designed with 100 sensor nodes deployed in a dense environment to address the scalability and performance issues of WSN. In this paper, we use Flooded Piggyback (FP) and SC-MCBR ant colony based routing along with AODV and MCBR Tree in order to design an efficient WSN model. Finally, simulation results are presented with various performance measures to understand the efficacy of the proposed WSN design. *Copyright © 2011 IFSA.*

Keywords: Wireless sensor network, Ant-colony, Swarm intelligence, Energy, Latency, Throughput.

1. Introduction

Wireless Sensor Network (WSN) consists of large number of small nodes with sensing, computation and communication capabilities [1] which are deployed in such a manner that they can satisfy the phenomena of interest [2]. Recent developments in wireless communication networks and with the invent of MEMS (Micro Electro Mechanical Systems) technology [3] make it possible to obtain tiny sensors with low power consumption and short range communication capabilities with less production costs for a wide range of applications. The areas of application behind the WSN research are military, medical, intrusion detection and environmental applications.

The main working principle of the sensor node (also called as motes) is to sense and collect the valuable information from the domain of interest, process them and then finally transmit it to the sink for necessary application at the end. So, various routing protocols are designed for the efficient data managements amongst the various sensor nodes deployed in an environment with maximum energy efficiency and to incur minimum connection errors [4]. To move in this line, various social insect colonies based WSN protocols are proposed in [5-6]. The main motivation of this paper is to design and implement various sensor network protocols based on Ant colonies and power aware routing protocols are proposed in the experimental testbed. A generalized framework for the wireless sensor network is shown in Fig. 1.

It can be seen from the Fig. 1 that the sensor nodes are deployed largely in a network for its low cost and can communicate with each other either directly or through other nodes and thus form an autonomous intelligent network. The information gathered by the sensor nodes must be transmitted to a control center called the Base Station (BS) either directly or through other sensor nodes. The base station is fixed and located far away from the sensors. The base station can then communicate with the end users either directly or through the existing wired network.

The rest of the paper is organized as follows. Section 2 discusses about the literature review in this area of research followed by the factors of the routing protocol design in Section 3. Section 4 discusses about our experimental testbed with various proposed routing protocols. The experimental results with discussion are provided in Section 5. Finally, we conclude with future scope in Section 6.

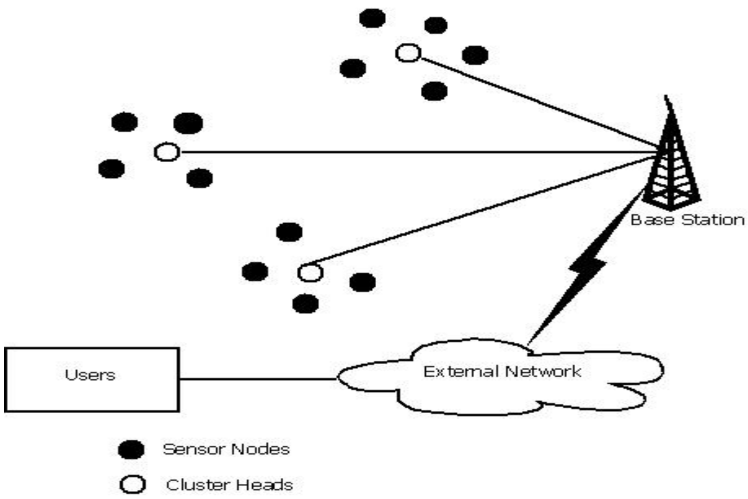


Fig. 1. Wireless sensor network architecture [7].

2. Literature Search

In this section, we provide a brief overview of the literature available in WSN research.

The authors have evaluated the performance of various routing protocols in NS-2 environment using AODV, DSR, DSDV, and TORA [8]. A modified routing algorithm for reducing congestion in wireless sensor network is proposed in [9]. In [10], the authors presented a novel routing protocol based on ant colony optimization to design a WSN and discuss its effectiveness to achieve a dynamic and adaptive routing in order to compensate the nodes power consumption and increase the network life time as far as possible. Performance evaluation of CSMA-MAC based WSN by considering various radio channels are discussed in [11]. The authors presented a cross layer design based self-optimized ant colony routing protocol for WSN in order to improve the overall data delivery ratio [12].

In [13], the authors analyze the performance of distributed energy efficient clustering protocol in context to network life time, and energy balancing. In [7], a new power aware, adaptive, hierarchical and chain based protocol (CCPAR) is proposed for ensuring the power dissipation evenly amongst all the nodes.

3. Design Factors for Routing Protocols

Since a distributed network has multiple nodes and services many messages, and each node is a shared resource, many decisions must be made. The following are some of the important factors affected by routing protocols that should be considered with great attention for an efficient WSN design.

3.1. Latency

Latency of a packet is a measure of the time delay of the packet to reach the base station (sink node) from its source node. For any sink, latency is obtained after arrival of n packets as $\sum_i \frac{d_i}{n}$, where d_i is the latency of the ith packet and the latency of the network is then averaged by the total number of sinks. We use latency rather than the number of hops as the metric because of its relation not only with the number of hops traversed, but also with the length of the transmission queues and delays introduced randomly at the MAC layer including delays that is introduced to minimize the collision errors thereof.

3.2. Energy Consumption

It is defined as sum of energy of all nodes, where the energy used for a node is the sum total of the energy used for the communication, that includes transmitting, receiving and idling [14]. As sensor nodes are having the limited energy, routing strategies need to be processed dynamically for obtaining the highest efficiency of the sensor nodes.

3.3. Throughput

Throughput is used to measure the number of data packets received at the sink node per second [15]. This counts only the desired data packets for obtaining the effectiveness of the WSN model.

3.4. Scalability

Scalability depends upon the total number of sensor nodes that are deployed in a wireless sensor network, in terms of hundreds and thousands etc. Hence, it is desirable that the proposed routing algorithms must be scalable enough to respond all the events for efficient data handling in such a dense environment.

3.5. Quality of Service (QoS)

The quality of service is a measure of excellence while designing a particular application in terms of network life span, energy efficiency, collaborative processing and location awareness that are highly affected by the proper selection of the routing protocols [16].

3.6. Success Rate

The success rate is obtained by looking at the total number of packets received at all the destinations vs. the total number of packets sent from all the sources.

3.7. Loss Rate

It is defined as the number of lost packets vs. the total expected number of packets for that destination.

4. Methodologies and Experimental Setup

In this section, we discuss about the proposed routing protocols followed by the experimental set up for WSN design. We use swarm intelligence based routing protocols for WSN that falls under three categories. First one is Ant-Colony based (ACO) consists of SC-ant, FF-ant and FP-ant routing; secondly bee colony based (for example beesensor routing) and third one slim mold based.

4.1. Flooded Piggybacked Ant Routing (FP Routing)

Flooded piggybacked routing approach provides a new ant species to forward ants such as data ants carrying the forward list, where as control of the flooded forward ants are treated same as in case of flooded forward ant routing [17]. This is found suitable in designing a complex, dynamic and highly distributed wireless sensor network. Single path routing tends to have high loss rates, due to dynamic and asymmetric properties of sensor networks. Multi-path routing such as flooding is very robust and has high success rate. In FP, we combine forward ants and data ants, using constrained flooding in the previous algorithm to route the data and to discover good paths at the same time.

4.2. MCBR Tree Routing

The term MCBR is used to indicate the term message-initiated Constrained based Routing for routing mechanism with constraint-based destinations and objectives specified in messages [18]. One advantage of the MCBR routing is its accurate initial objective estimate based on its specifications. The objective functions are used to estimate the minimum cost along the path, while the destination constraints are basically used to estimate the minimum number of hops to the destinations. With the separation of routing specification from routing strategies, general purpose Meta routing strategies can be thought of for MCBR routing tree implementation with QoS support, in comparison to the most existing ad-hoc routing strategies, which do not support QoS to their account.

4.3. Sensor-driven and Cost-aware Ant Routing (SC)

One of the problems of the basic ant-routing algorithm is that the forward ants normally take a long time to find the destination, even when a Tabu list is used (i.e., no repeating nodes if possible). That happens because ants initially have no idea where the destination is. Only after one ant finds the destination and traverses back along the links will the link probabilities of those links change. In SC, we assume that ants have sensors so that they can smell where the food is even at the beginning [19]. That is not an unrealistic assumption for sensor networks, since feature-based routing dominates address-based routing in that space. Some features, such as geographic location, have a natural potential. If the destination does not have a clear hint, pre-building the feature potential is sometimes still efficient. Cost awareness generalizes the objective of shortest path length so that ants can apply other routing metrics as well, e.g., energy-aware routing.

4.4. AODV Routing

The AODV (Adhoc on-demand distance vector routing) [20] is a reactive routing protocol, where routes are determined only on demand. AODV avoids problems similar to count-to-infinity. For this, AODV uses a technique of assigning sequence numbers to all the updates. AODV is also found suitable in restrictive environments because of its ability to intercommunicate with the end points which cannot be accessed directly. It finds the route through which the message can be forwarded and also find the shortest path to the end point.

4.5. Experimental Setup

We implemented several routing protocols simulation using Prowler [21] and Rmase [22] in MATLAB 7.0 environment to evaluate the performance of the wireless sensor network.

In this, we used a square sensor field of 10 x 10 square unit areas. Initially, all the nodes are placed in a grid placed uniformly, where the coordinates of each node were shifted by a uniform random distribution with range [-0.5, +0.5]. In this, a node which is closest to the center of the sensor field was referred to as the base station.

4.6. Radio Channel Modeling

The radio model used by Prowler provides a radio propagation model with CSMA –MAC protocol using MICA motes. In this, we use a simple deterministic radio channel, where a packet is received successfully only when the received signal strength is greater than a pre-defined threshold limit. In situations, when two simultaneous transmission are received with signal strength satisfy the above conditions at one node of consideration, collision occurs. A packet is lost only when there is some collision occurs. In all our simulations, the data rate of wireless links is set to be 40 Kbps with maximum length of a packet as 960 bits.

4.6.1. Propagation and Fading Models

The current implementation uses a basic model for radio propagation with two different fading models. In both cases the signal propagation is modeled by an ideal propagation function, and disturbing components. The ideal propagation function defines the signal strength vs. the distance between the transmitter and receiver. The disturbance components model the fading effect. The f(x) is the ideal propagation function. The ideal received signal strength is P_rec_id =P_transmit*f(x), where x is the distance.

4.6.2. Fading Model 1 (Line of Sight)

This model describes scenarios where the motes have direct line of sight. The fading is modeled by adding noise components to the ideal received signal strength .The received signal strength is: P_rec=P_rec_id*(1+alpha(x))*(1+beta (t)), where alpha and beta are random variables with normal distributions N(0, s_alpha) and N(0, s_beta), respectively. Here, P_rec is forced to be non-negative. In this, alpha models location-dependent effects, while beta models time-dependent effects. The magnitude of the fading effect modeled by alpha remains constant during the simulation (unless location of the node changes, when it is recalculated), while the magnitude of the effect modeled by beta changes in time.

4.6.3. Fading Model 2 (Rayleigh Fading)

This model describes scenarios where the motes do not have direct line of sight. The fading is modeled by randomly modulating P_rec_id: P_rec=P_rec_id*R, where R is a random variable with exponential distribution (mean = 1). There is a consistency time parameter (tau) defining the time while the fading can be considered constant. P_rec is recalculated for every transmitter mote in every tau time period. If the position of a mote changes, the corresponding P_rec values are recalculated. An additional transmission error p_error is defined for both models. It models all other sources/effects that may lead to an unsuccessful transmission.

4.6.4. Radio Channel Models

The simulator contains two different models to describe radio transmissions, receptions, and collision avoidance.

Channel Model 1 (simple)
This simple model is fast, although not very accurate. Transmitters check the channel before starting transmission. The channel is considered idle if MRP<RECEPTION_LIMIT, where MRP is the maximum received power at the time of the idle check.

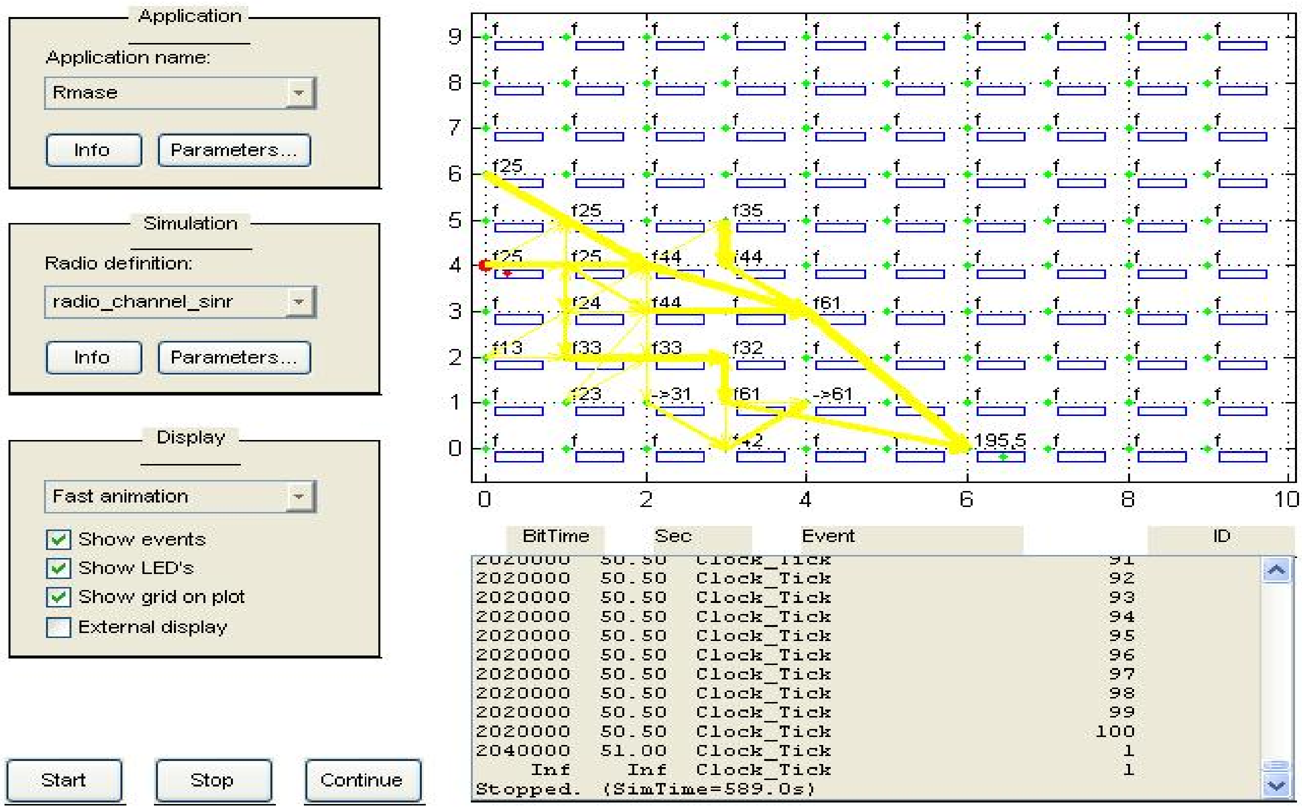
Channel Model 2 (more detailed)
This model provides more accurate results at a somewhat slower speed. The Signal to Noise and Interference Ratio (SINR) is defined by SINR=P_rec/(P_noise+P_int), where P_rec is the power of the received (useful) signal, P_noise is the receiver's noise variance (RNV), and P_int is the total (summed) interference from all the undesired transmitters. The signal is successfully received if SINR > SINR_LIMIT, during the time of the reception. Transmitters check the channel before starting transmission. The channel is considered idle if TRP < P_noise * IDLE_LIMIT_CONSTANT, where TRP is the total received power (TRP) at the time of the idle check.

5. Experimental Results and Discussion

We perform all our simulations with a simulation time of 50 seconds. The radio connectivity obtained from different routing protocols and radio channel under our investigation are presented in Fig. 3 below, in order to have an understanding about the simulation environment. Fig. 2 (a) shows the radio connectivity for MCBR ant routing with Rayleigh fading followed by the MCBR ant routing with SINR in Fig. 2 (b). Further, Fig. 2 (c) and Fig. 2 (d) presents the radio connectivity scenario for FP based ant routing with SINR and Rayleigh fading taken into consideration.

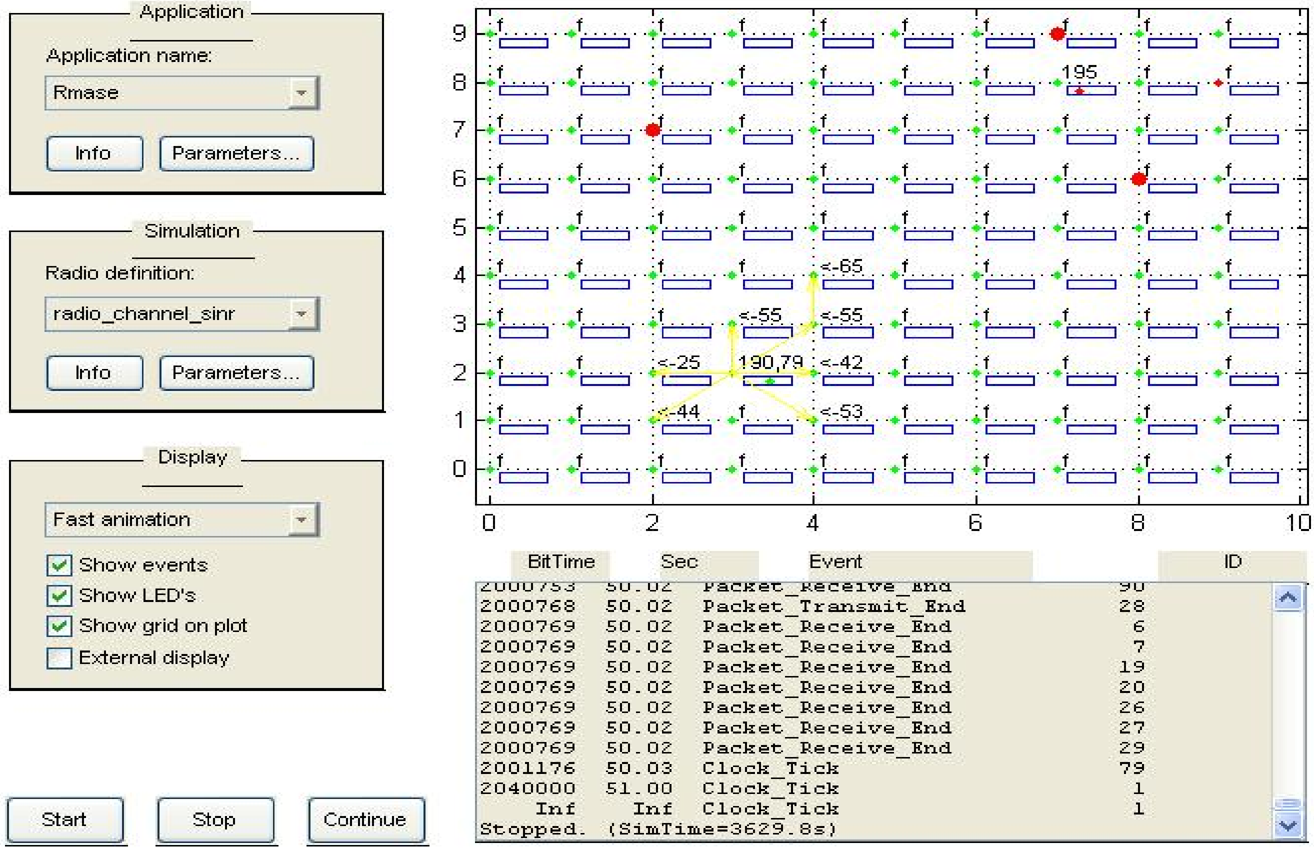
Various performance evaluations such as Latency, energy and throughput with respect to simulation time in seconds for the proposed routing protocols are obtained and presented in Fig. 3, Fig. 4, and Fig. 5 respectively. From Fig. 3(a), it can be observed that MCBR tree routing provides better latency in comparison to others; where as in all other case as is evident from Fig. 3 (b) and Fig. 3 (c) that Flooded piggybacked routing (FP) performs better and AODV routing is at the bottom, need some enhancement for a suitable WSN design.

(a) Radio connectivity for SC-MCBR Ant routing with Rayleigh Fading.

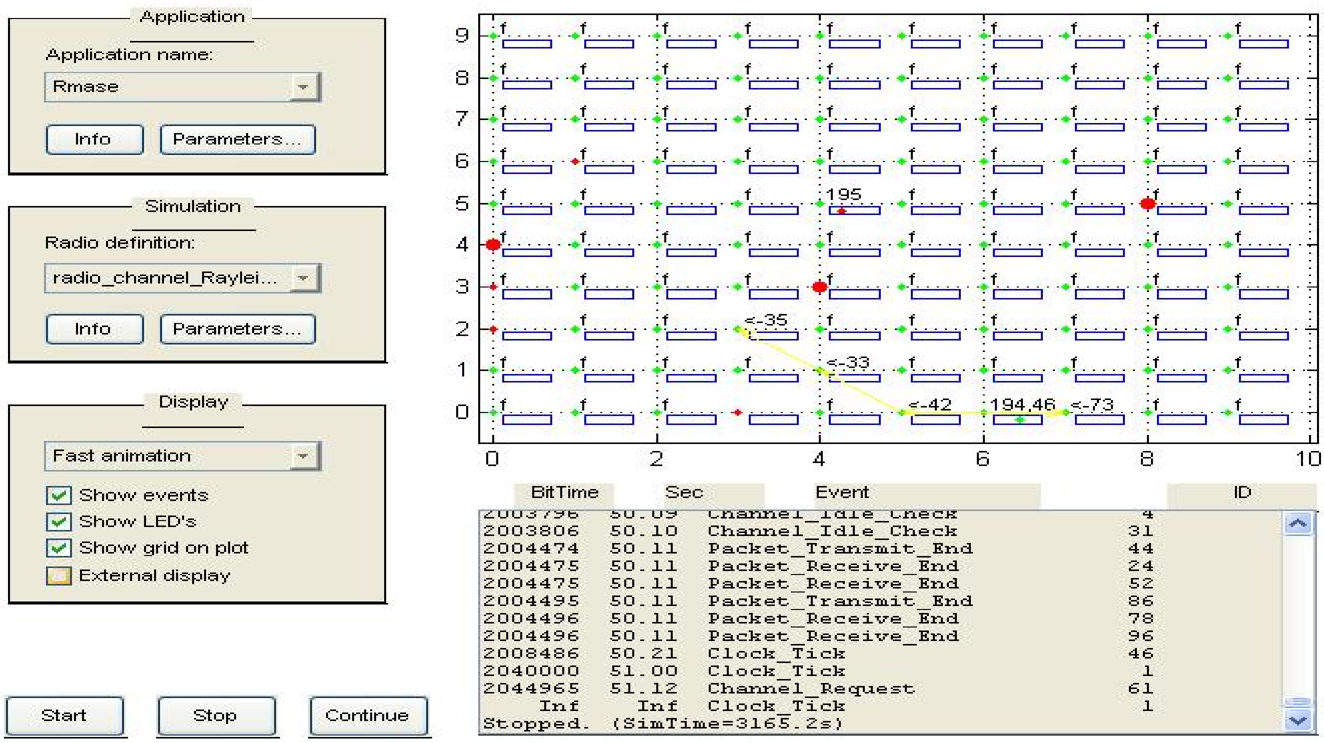


(b) Radio connectivity for SC-MCBR Ant routing with SINR.

Fig. 2 (a-b). Instances of radio connectivity for swarm based routing with fading.

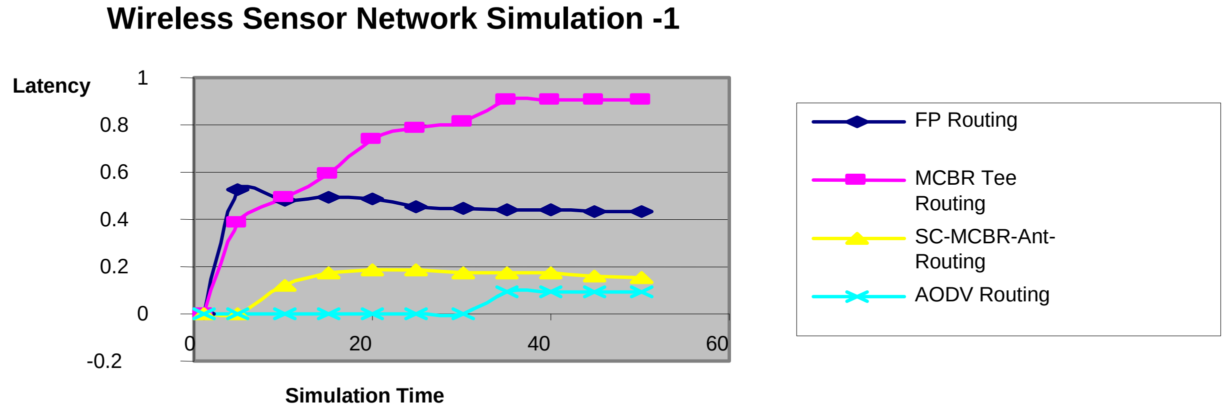


(c) Radio connectivity for FP Ant routing with SINR.

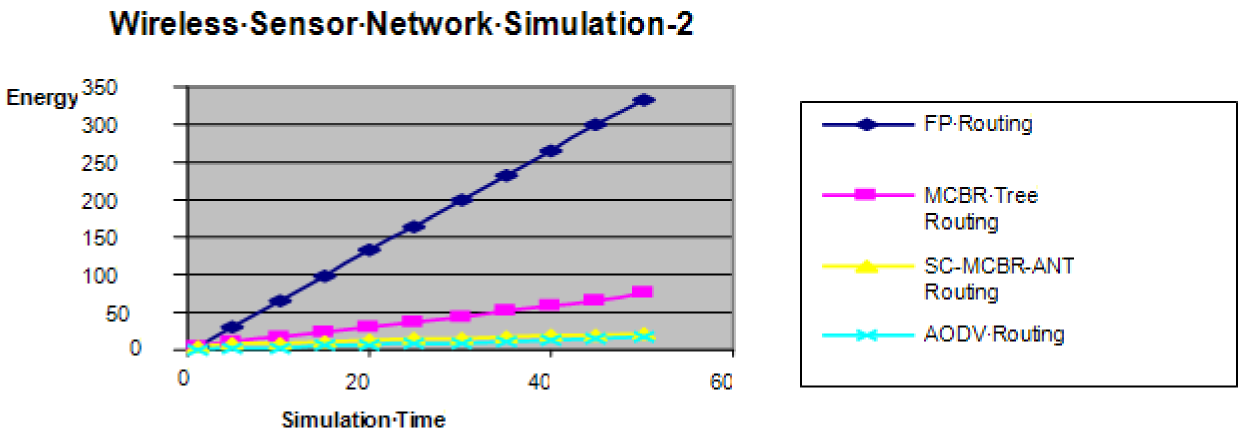


(d) Radio connectivity for FP Ant routing with Rayleigh Fading.

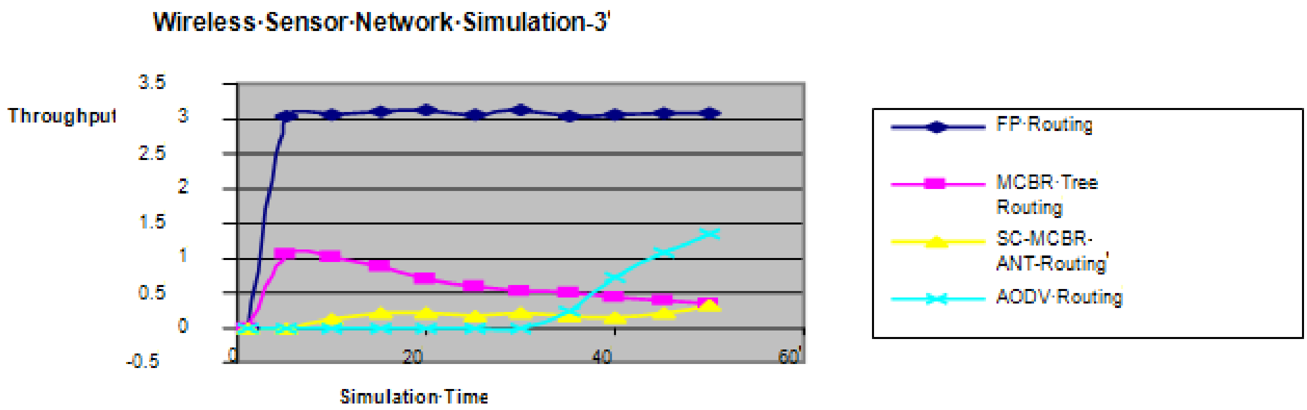
Fig. 2 (c-d). Instances of radio connectivity for swarm based routing with fading.



(a) Comparison of latency.



(b) Energy consumption comparison.



(c) Throughput Analysis.

Fig. 3. Comparison of different routing algorithms in case of a normal radio channel.

From Fig. 4, it can be observed that MCBR tree with Rayleigh fading has high latency in comparison to categories. It suddenly rises from zero to 1.0256 and then reduced to 0.751 for many and then finally settled at 0.7719 seconds. However, in case of MCBR ant routing with SINR, the constant latency achieved.

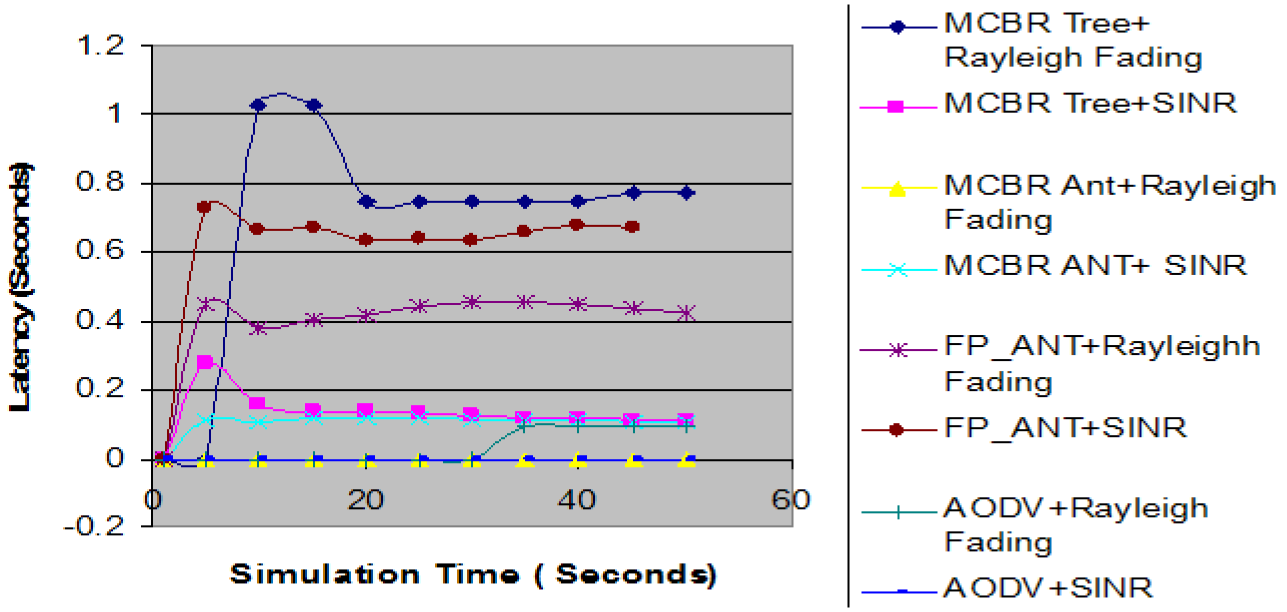


Fig. 4. Latency comparison in channel fading environment.

In is quite evident from Fig. 5 that MCBR ant routing with Rayleigh fading consumes more energy in Joules per packet in comparison to all other types. It consumes 3.456 joules per packet initially and then finally consumes 48.864 joules per packet at the simulation time of 50 seconds. However, AODV routing with Rayleigh fading and with SINR provides lowest energy consumption varying from 0 joules per packet to 15.072 and 11.88 joules per packet respectively.

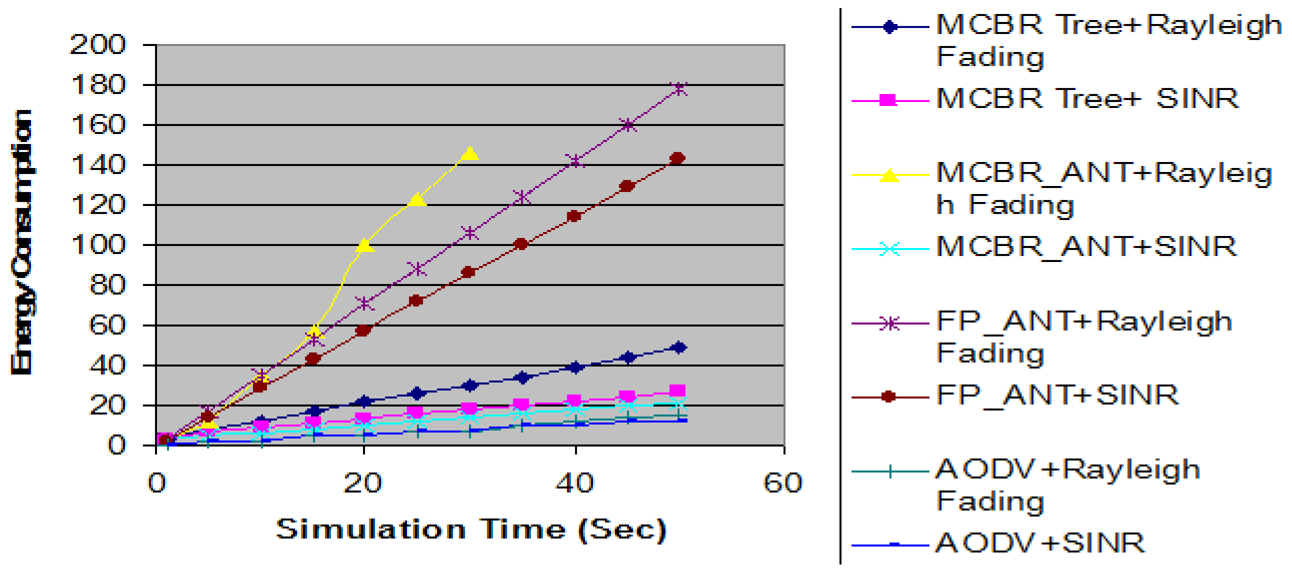


Fig. 5. Energy consumption.

Fig. 6 shows that in case of MCBR ant routing with Rayleigh fading, throughput remains unchanged throughout the simulation period, where as on case of MCBR tree with SINR, it rises from 0 to 2.9467 data packets per seconds. The FP ant routing with both Rayleigh fading and SINR cases, provides better throughput finally of 1.5529 and 1.1874 respectively.

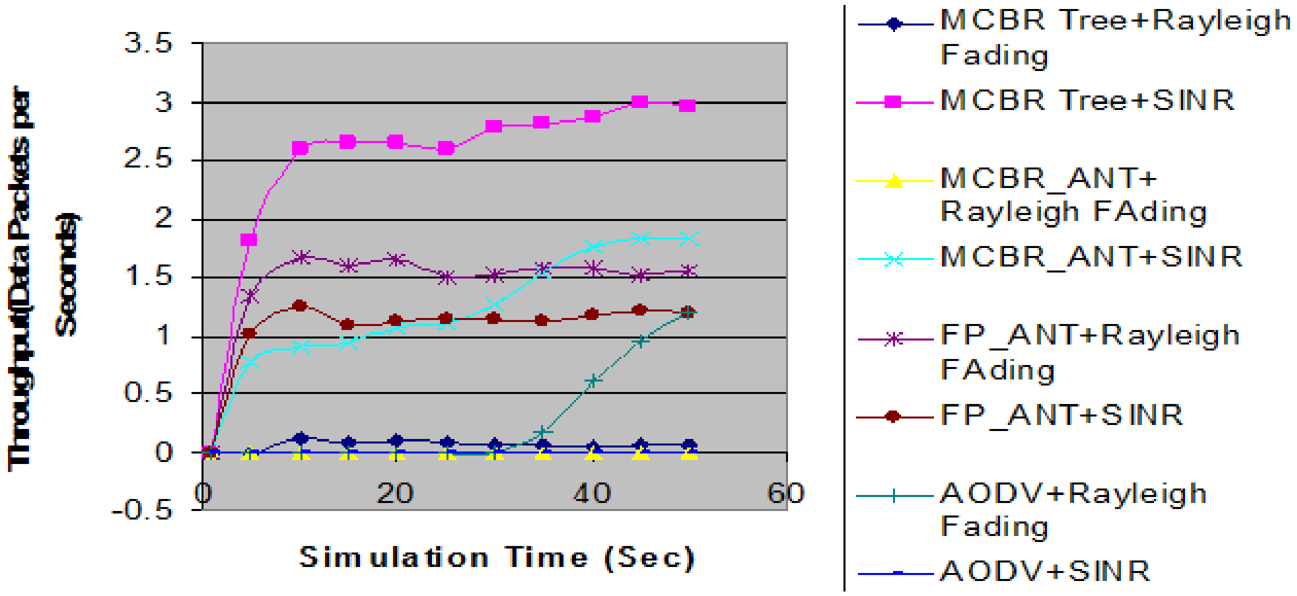


Fig. 6. Throughput.

As can be seen from Fig. 7, loss rate in case of MCBR tree with Rayleigh fading is high, ranges from 0 to 0.9807 through 0.9718. However, in case of MCBR ant routing with Rayleigh fading and AODV routing with SINR maintains the constant loss rate. FP ant routing with Rayleigh fading and SINR provides loss rate ranging from 0 to 0.610 and 0 to 0.696 respectively.

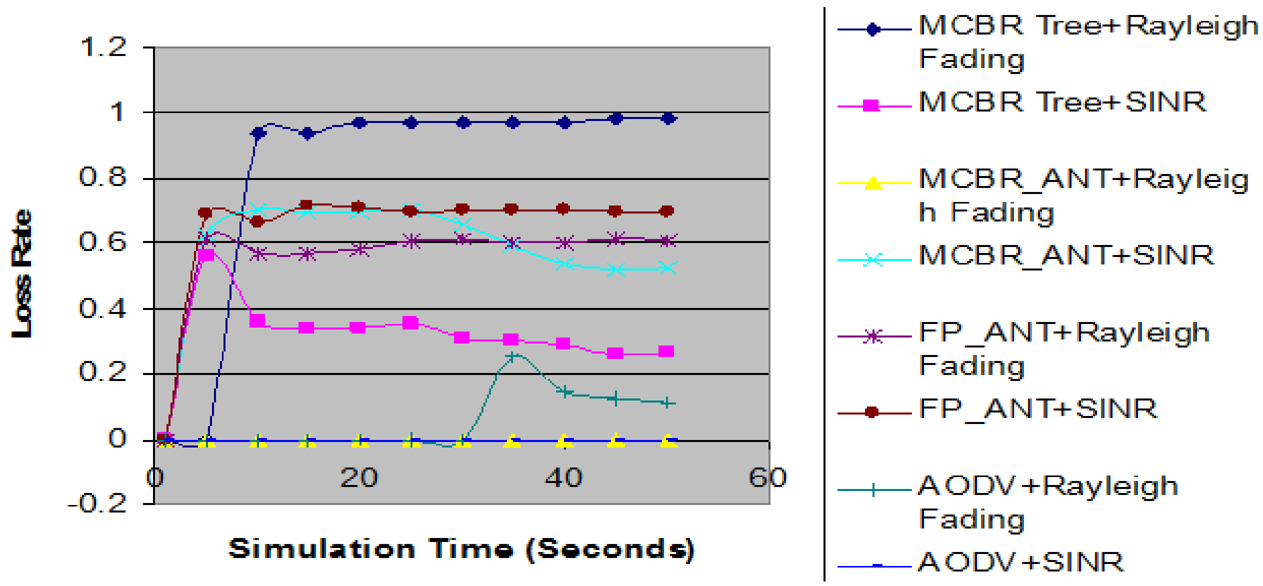


Fig. 7. Loss rate.

The success rate for MCBR tree with SINR is the highest among all ranging starting 0 to 0.7347 finally, as can be seen from Fig. 8. Further, this shows that AODV with SINR and MCBR ant routing with Rayleigh fading provides the constant success rate. In this case, FP ant routing with Rayleigh fading rises from 0 to 0.4167 and then finally settled at 0.3877. Similarly FP ant routing with SINR provides success rate varying from 0 during first simulation time to 0.301 at 45th simulation time and finally at 0.296 in 50th simulation time.

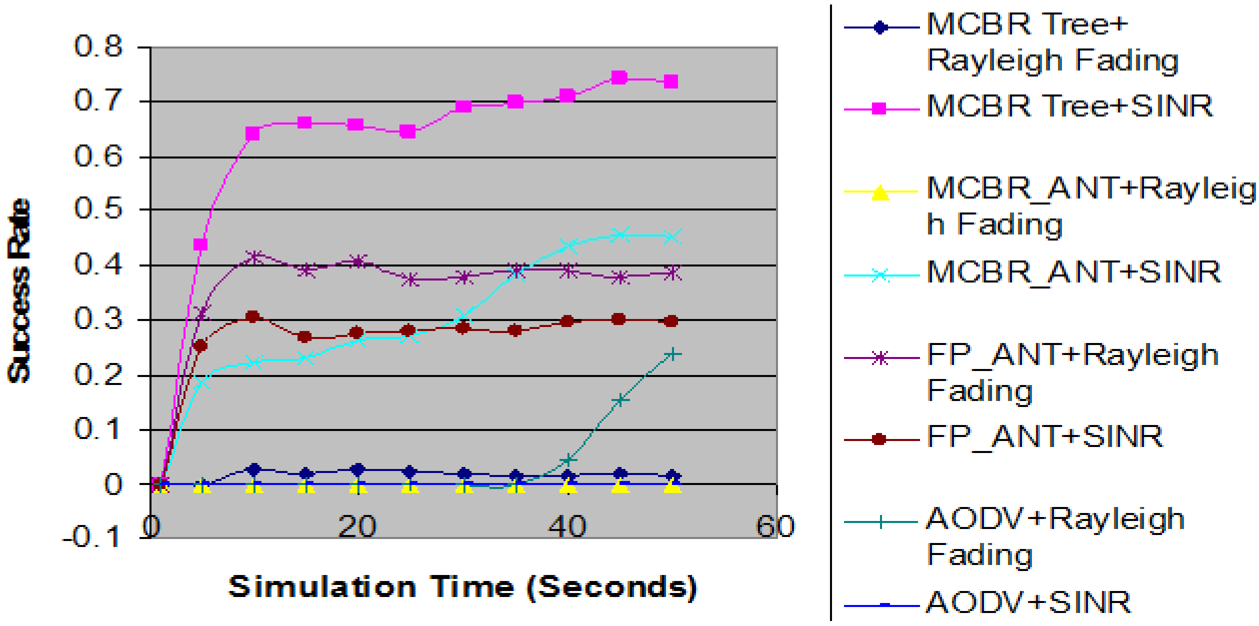


Fig. 8. Success rate.

5. Conclusion and Future Scope

Wireless sensor networks are an emerging area of research that finds many applications in every walk of life. Researches are going on to either developing the new or enhance the existing technologies for making the WSN application more viable to the people. However, before implementation and actual production, all these techniques are to be properly tested and verified. As the real world implementation and test-beds are some what difficult to obtain, the modeling and simulation is the only solution to achieve such a WSN design.

In this paper, we have concentrated on to implement various routing protocols based on ant routing and power aware routing in order to model an efficient wireless sensor network in terms of their latency, energy consumption, throughput, loss rate and success rate. Through the simulation experiments conducted in this research, we conclude that in case of normal radio channel, power aware routing MCBR tree is better in case of latency comparison to ant based routing where as in case of the other scenarios; the reverse has been true for designing a WSN. Similarly, while considering radio channels with Rayleigh fading and SINR for WSN design, MCBR tree with Rayleigh fading provides high latency, MCBR ant routing with Rayleigh fading consumes more energy, MCBR tree with SINR with highest throughput, loss rate in case of MCBR tree with Rayleigh fading is high and finally MCBR tree with SINR has the highest success rate, in comparison to all others. Our future work is to define some new protocols for efficient WSN design and then to formulate an anomaly detection framework.

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