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Evaluating Quasi Random Deployment in Zigbee Based Wireless Sensor Networks

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Abstract

Among the various parameters and constraints considered that are affected by optimal deployments, performance as per the mac layer has attained limited attention. This article is aimed at two things. Firstly, it aims to understand the packet delivery parameters for convergecast communication pattern ideal for Zigbee based wireless sensor networks. It also compares the mac layer metrics for the corresponding deterministic and random deployment patterns under the same set of network conditions. Secondly, it aims to suggest enhancements through proposing a quasi based deployment pattern, that may help boost the performance to acceptable levels. We simulate and observe the packet based statistics at the mac layers employing different protocols like AODV, DSR. As the choice of routes and the inherent topology construction is usually based on the shortest path constraint and maximum connectivity, respectively, protocols are subject to two separate cases for this analysis. This paper is also an effort to suggest the use of 'Quasi based deployment strategy' comparable to the existing random and deterministic methods. The inferences obtained are for zigbee networks encorporating both peer to peer (using a tree based topology) and star (using a graph based topology) WSN architectures. A quasi based deployment pattern offers scope for improvement of the reliability metrics which is the sole accountability of the mac layer, irrespective to the protocol employed at the higher levels or the backbone structure for communication.

Keywords: *wireless sensor networks, tree architectures, delay and throughput, Quasi-random, deployment strategies*

1. Introduction

Sensor network deployments are foreseen to be done in large scales where each network consists of hundreds or even thousands of sensor nodes. The method of deployment depends on the suitability to the application requirements. The quality parameters that have acquired due attention are energy constraints, coverage and connectivity issues, lifetime enhancements and robust communication. All these constraints cannot be met with one solution. From the current literatures we can isolate different types of deployment for different applications. In deployments for environmental monitoring or anomaly detection type; as human configuration of each sensor node is not feasible, self configuration of the nodes becomes a prerequisite. The other critical issue is energy efficiency as batteries cannot be replaced. The other class of applications is home automation or machine and structural monitoring where battery replacement may be possible but still requires minimizing the maintenance costs. Moreover the main criterion for such applications is the complete coverage and connectivity with the minimum number of nodes. Such constraints require solutions that cater to real time autonomous deployment of sensor nodes only in the terrain of interest, optimizing the deployment procedure [1], stochastic deployments, intelligent deployments based on AHP. Redeployment of extra nodes, spare nodes or relay nodes claim to achieve longer lifetime or are used for load sharing [2, 3]. Most literatures on deployment methodology focus on the energy conservation and propose balanced energy consumption results [4, 5]. Some focus on minimizing the total energy cost of gathering data through optimally deploying storage nodes to reduce the heavy load of transmitting through archiving and reducing the communication cost. There are works related to effects of placement errors and random failures on the density of the nodes needed for full coverage. All these approaches usually base upon simulation evaluation and comparison of deterministic and random placement methodologies [6-9].

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None of the researches, as far as our knowledge, discuss the effect of deployment on the robustness of communication in terms of the packet delivery based statistics at the mac layer. Considering packet loss in choosing the best communication path has a significant impact on reducing the energy consumption of the network as well as increasing network throughput [10]. As per the available research it is clear that the mac layer has primarily two factors that affect the packet delivery performance. First, the application workload (in case of sensor networks it is the sensed environment) determines the traffic generated by the nodes and hence the efficacy of the channel access. The second factor is the topology (or equivalently the spatial relation between the nodes) affects how many nodes might potentially contend for the channel at a given point of time [11].

Our paper presents a quasi based deployment method (employed for topology variation) that compares the performance of zigbee networks (used for traffic generation) for both graph (Ad hoc) and tree (Backbone assisted) based wsn architectures with respect to the typically followed deterministic and random deployments. This paper introduces quasi-random sequences to generate location coordinates for two cases; backbone assisted and adhoc architectures. The factors affecting the performance of the network is the number of hops from the node to base station, and the parent's residual energy, link quality, or the length of routing path to base station. A minimum spanning tree is used to generate the required communication backbone. We observe performance metrics for different deployments, namely: deterministic, random and quasi random. Quasi random sequences which have low discrepancy (a measure of uniformity for the distribution of the points) have been widely employed in Quasi Monte Carlo simulations [12]. Performance of the network is evaluated in terms of the number of packets dropped, retransmitted and delay based statistics at the MAC layer for different existing protocols employed in diverse application of WSNs. For analysis we use ZigBee and IEEE 802.15.4 which are standard based protocols that provide the network infrastructure required for wireless sensor network applications. 802.15.4 defines the physical and mac layers, and ZigBee defines the network and application layers. Section 2 discusses the system requirements while the system model is outlined in section 3 followed by results in section 4 and conclusion.

2. Preliminaries

IEEE 802.15.4 can manage two types of networks, i.e., star topology or the peer-to-peer topology. The network performance metric is based on the packet delivery performance and the packet latency. At the mac layer interfering transmissions are the cause of poor packet delivery performance. The packet loss probability (λ) can be modeled by sampling and communication parameters affecting the communication load over the network.

$$\lambda = 1-e^{-0.01f/(150e\ exp(-M/15)+5)} \quad (1)$$

Where, *'M'* is the number of source nodes and *'f'* is the sampling frequency of the source node in samples/sec.

For estimating the total number of source nodes in a network, the probability of having exactly '*K*' source nodes within a given interval of the sensing range can be given by:

$$Prob\ (k) = e^{-\alpha R}\ (\alpha R)^k\ /k! \quad (2)$$

Where, α is the density of nodes deployed and R is the constant transmission range.

The packet delay is estimated according to the MAC Layer statistics given by:

$$Delay(x) = T_{BO} + T_{frame}\ (x) + T_{TA} + T_{ack} + T_{IFS}(x) \quad (3)$$

Where,

T_{BO} = Back-off periods in seconds.
$T_{frame}(x)$ = Transmission time for a payload of x bytes.
T_{TA} = Turnaround time.
T_{ACK} = Transmission time for an acknowledgement.
T_{IFS} = IFS time.

We consider CSMA based communication as it is used mostly by wireless LAN's. Also, it is more suited for network protocols like TCP/IP with a variable traffic and is robust against interference. The main problem with CSMA /CA is that the transmitter cannot detect collisions on the medium. To hold back this situation, mac layer protocols implement positive acknowledgements to avoid losing packets. Hence, mac level retransmissions can be used to solve the problem of packet losses due to errors and collision in wireless networks.

Since sensor networks are based on multi hop links, they suffer from packet losses due to error prone wireless channels, mac layer contention and route breakages. Our approach tries to measure and compare the total number of packet losses incurred by the deployed scenarios in terms of the packet losses, the number of retransmissions needed and the number of times transmission fails due to the channel congestion in the mentioned scenarios.

3. System Model

We consider a terrain of size 50 X 50 deployed with 15, 25 and 50 homogeneous nodes in three phases. Phase 1 places the nodes in square grid pattern while phase 2 arranges the nodes in a quasi sequence. Phase 3 deploys nodes in random manner. All the three phases are analyzed for a set of protocols for both graph and tree based structures. The analysis is based on performance of the mac Layer. We analyze whether the quasi method improves the packet dropping rate due to collisions and congestion. For generating the quasi random sequence we apply "halton" [12] sequence as it is known to achieve asymptotically optimal discrepancy and is easy to construct. Moreover it is a reasonably good sampling-point generator. In this article we consider a star based network that can be comparable to a tree based network similar to a parent child association. We place a simple star topology with a single sink in three different deployment strategies and study the efficacy of packet delivery under tree and graph based architectures. The first FFD (full function device) that is activated may establish its own network and become a Personal Area Network (PAN) coordinator. Then both FFD and RFD (reduced function device) devices can connect to the PAN coordinator. In Case 1 we construct an MST from the points generated by the halton sequence and the pan coordinator serves as the root node or the sink the non-child nodes forward the aggregated message to the pan co-ordinator. The idea behind tree-based communication architectures is simple. A spanning tree is first constructed with the root node being the sink node; following the tree generation algorithm mentioned in 3.1. The list of notations used in the algorithm are defined in Table 1. Each node transmits its value to its own parent. At each non-leaf node, the value of each of its child nodes, in addition to its own value, is processed before transmitting the result up the tree. In case 2 the pan coordinator establishes a zigbee connection in a star topology wherein nodes communicate through the wireless medium in an adhoc manner communicating with the PAN Coordinator that acts as the sink.

3.1. Algorithm Used

```
/* Deployment of nodes*/
begin procedure N_deploy (n, bi; where (bi є smallest prime number set)).
For i: n repeat
Compute coordinate: call (halton (i, bi)).
end procedure.

/* Tree generation*/
begin procedure N_tree (Si, (Xi, Yi); where (Si є set of nodes)).
initialize i: =0, j: =1, range of each node: = range.
while (i < n) do
        while (j < n) do
                if (j ≠ i and i. parent ≠ NULL) then calculate ED (i, j)
                        if(ED (i, j) < = i. range) then
                                if (j. parent = NULL) then
                                 Compute MST to assign parent to node
                        else store in route_table.
                end if.
        end if.
```

14: end while.
15: end while.
16: end procedure.

Table 1. Notations

n	Total number of nodes deployed
Si	Set of all nodes deployed
(Xi, Yi)	Coordinates of ith node
NODE_ID	Unique identification of each node
Ti	Tree generated using node communication
i.level	Level of 'i' in tree hierarchy
i.parent_distance	Distance of i from its parent
EDi	Euclidean distance between i and j

3.2. Scenario Generated

Figures 1, 2 and 3 depict the qualnet simulation scenarios generated for deterministic, random and quasi random node positions respectively. The area deployed varies from 50 X 50 to 100 X 100 m. The links between communicating parent and child in the "MST" are depicted by dashed lines in blue colour while the green lines denote the data transmission. Figure 4 represents the graph based communication for quasi random sequences generated by the algorithm employed for 50 nodes. Similar figures result for both deterministic and randomly deployed nodes when the transmission power or the node density is varied and have not been included for fear of redundancy.

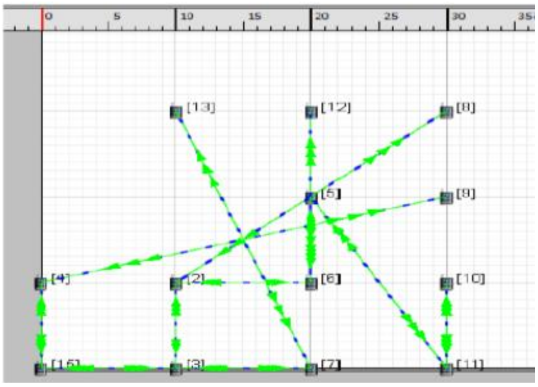

Figure 1. Deterministic deployment (15 nodes, tree based communication)

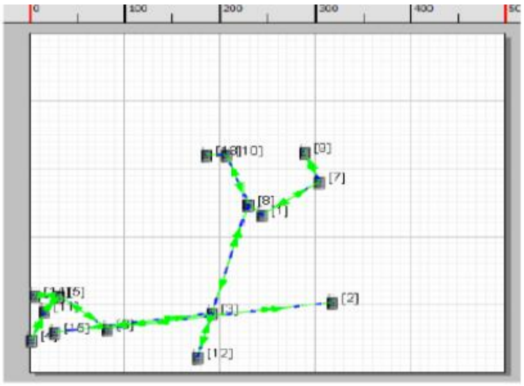

Figure 2. Random deployment (15 nodes, tree based Communication)

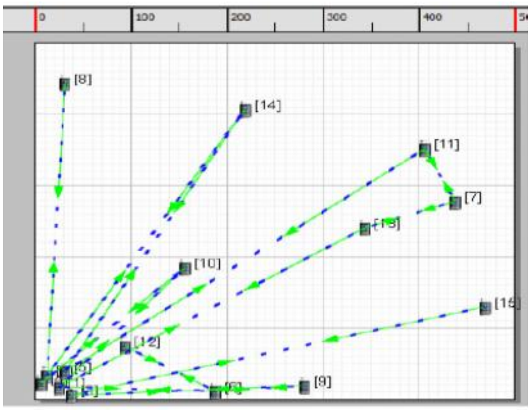

Figure 3. Quasi random deployment (15 nodes, Tree based communication)

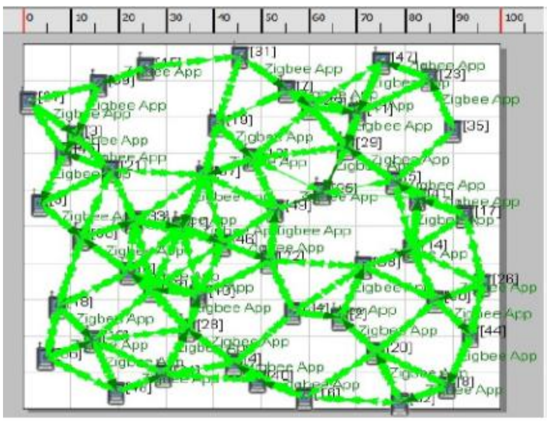

Figure 4. Quasi random deployment (50 nodes, Graph based communication)

Figures 1, 2 and 3 observe the network statistics in case of tree based communication backbone where the communication occus only through the enforced wireless links between the nodes. Figure 4 depicts the complete mesh based communication pattern followed by typical wireless networks communicating in an adhoc manner.

4. Results and Analysis

The results are analysed for mac protocols which traditionally manage power saving as they are designed to be application aware to a degree.The following graphs display the performance evaluation of the two cases: Case 1 (Tree) and Case 2 (Graph) for deterministic, Quasi and Random deployment strategies for a set of protocols namely; AODV, DSR, Dymo, Fisheye and Bellman-ford.The simulation parameters are as follows:

Table 2. Simulation Parameters

Parameters	Values
Radio type	802.15.4
Transmission power	3.0 dbm
Number of nodes	15,25,50 nodes
Packet reception model	PHY 802.15.4 Reception model
Modulation scheme	O-QPSK
CCA Mode	Carrier sense
Noise factor	10.0
Energy model	Linear gradient model
Node Type	MICAZ motes

4.1. Performance Comparison

We collect and compare the mac layer statistics of quasi based deployment strategy with respect to deterministic and random on the basis of Case 1 (Tree) and Case 2 (Graph) for the same set of protocols. Also, the total energy consumption is discussed for the tree and graph based scenarios.

4.1.1. Ad hoc On Demand Routing (AODV)

The average number of packet drops, collectively, due to channel congestion, and unattainable acknowledgement have been analysed for networks employing backbone or operating in an ad hoc manner.the statistics depicted in Figure 5, 6, 7, 8 and 9 relate to a network of 50 nodes for deterministic, random and quasi random deployment strategies for the mentioned protocols.

We observe lesser number of packet drops for quasi random based deployments and is consistent for nearly all the protocols considered. Also, the difference in the packet drops is impervious by the presence or absence of the underlying backbone structure. On the contrary, considering bellman ford algorithm, random based deployments outperform quasi random deployment for ad hoc mode of operation. This discrepancy is, however, attributed to the inherent quality of shortest path availability search mechanism adopted by the Bellman Ford algorithm. Similarly, in case of Fisheye routing protocol, as the protocol restricts the search space of probable forwarding neighbors, the performance of deterministic deployments appears better. However, it is worth mentioning that in the above two diverse cases, the performance of quasi random deployments is either better than deterministic or random deployments. It can be seen that the packets dropped in quasi strategy is significantly less than random and deterministic strategies for case 2 i.e graph and nearly equal when considering tree based architecture (case 1).

Energy efficiency can be seen as the number of packets that can be transmitted successfully using a unit of energy, packet collision at the MAC layer, the routing overhead, packet loss and packet retransmission reduce the energy efficiency. Packet drops in quasi deployment for the considered protocols is quite less than the other two strategies and hence offer better energy saving options with smaller delay in end to end communication and can be used for time critical real time applications. Hence, we consider the overall energy consumption for the cases considered to confirm that quasi random deployments outperform the other deployment schemes.

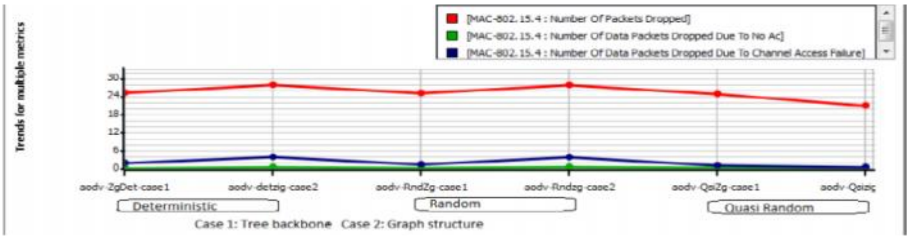

Figure 5. MAC layer statistics for AODV protocol for deterministic, random and quasi random scenarios

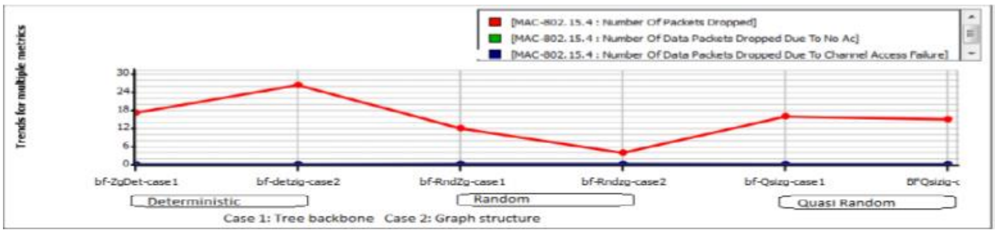

Figure 6. MAC layer statistics for Bellman Ford algorithm for deterministic, random and quasi random scenarios

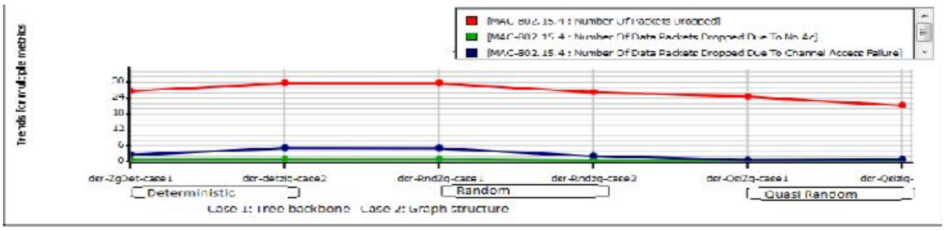

Figure 7. MAC layer statistics for DSR protocol for deterministic, random and quasi random scenarios

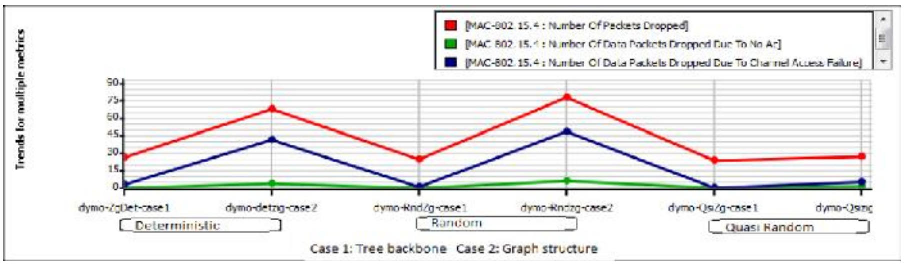

Figure 8. MAC layer statistics for DYMO protocol for deterministic, random and quasi random scenarios

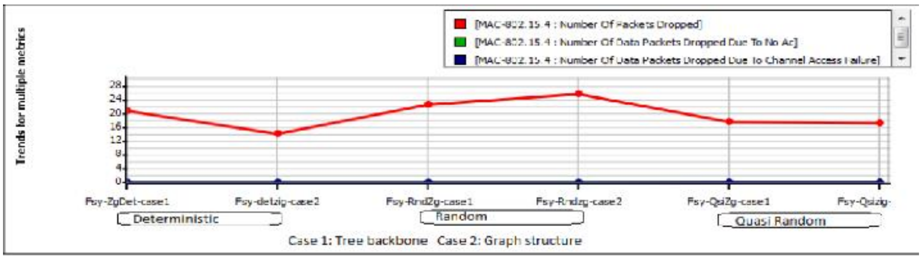

Figure 9. MAC layer statistics for Fisheye protocol for deterministic, random and quasi random scenarios

It is seen from Figure 10, 11, 12 ,13and 14 that, though the energy consumed in transmit mode is nearly equal for all the deployment schemes irrespective of the employed backbone structure, for all the protocols considered; the energy consumed in idle mode and reception mode is significantly less for quasi based deployment. This shows the impact of number of retransmissions and packet forwarding that needs to be done for successful packet delivery.

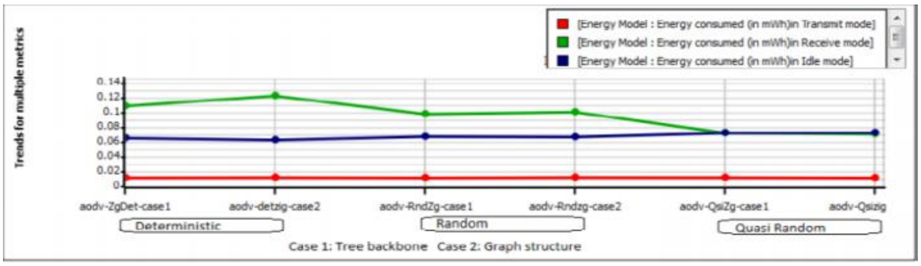

Figure 10. Energy consumption for AODV protocol for deterministic, random and quasi random scenarios

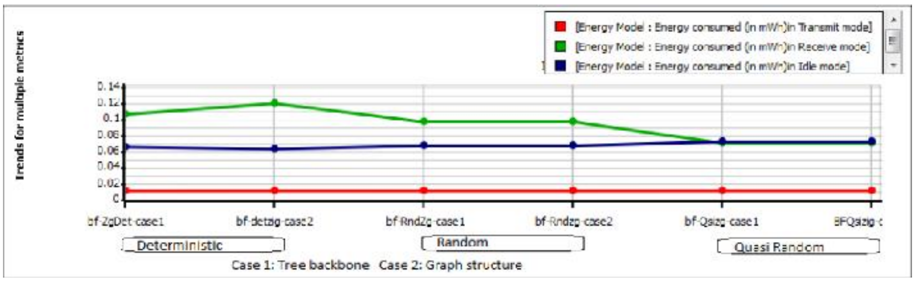

Figure 11. Energy consumption for Bellman Ford algorithm for deterministic, random and quasi random scenarios

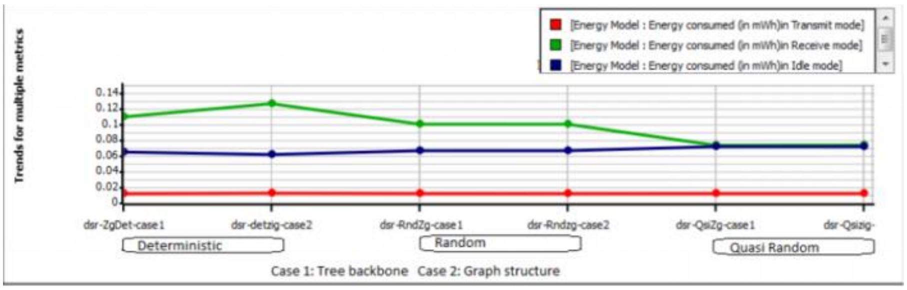

Figure 12. Energy consumption for DSR protocol for deterministic, random and quasi random scenarios

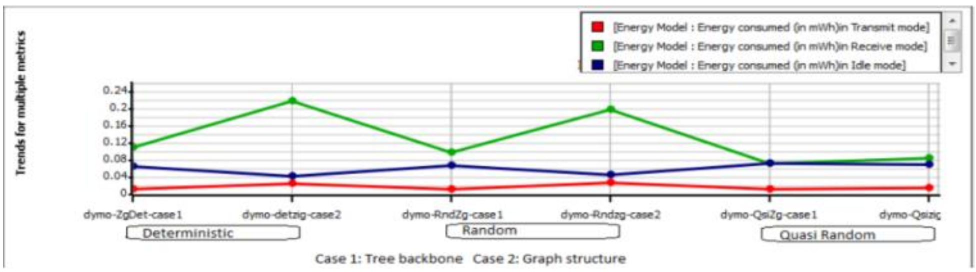

Figure 13. Energy consumption for DYMO protocol for deterministic, random and quasi random scenarios

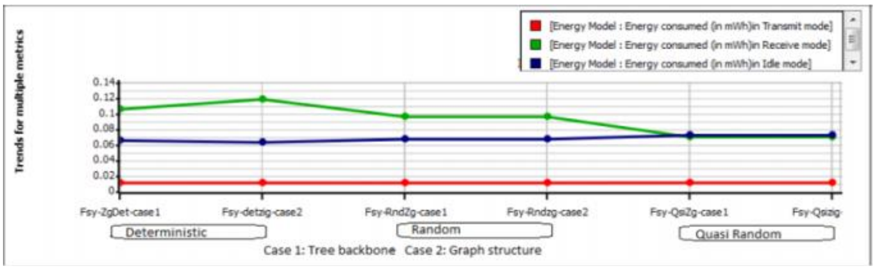

Figure 14. Energy consumption for Fisheye protocol for deterministic, random and quasi random scenarios

4.2. Effect of Varying Transmission Power on the Performanace of Quasi Based Networks

As it was observed that with increase of the transmission range more number of nodes was able to connect to the communication backbone in case of a random deployment, we varied the transmission power of the nodes. Since the Bellman ford algorithm is based on the shortest path selection, that is employed when we construct the minimum spanning tree connections for the network, we adopt it for our further analysis. By a change in the transmission power, the connection backbone changed and restructured the tree for the above mentioned scenarios. By this strategy we tried to reduce the total number of packet drops due to no route or the loss of acknowledgement.

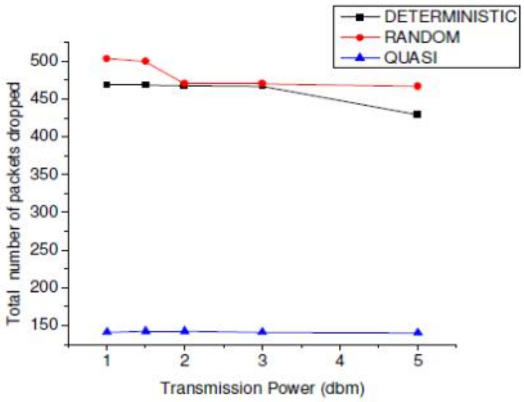

Figure 13. Average number of packet drops

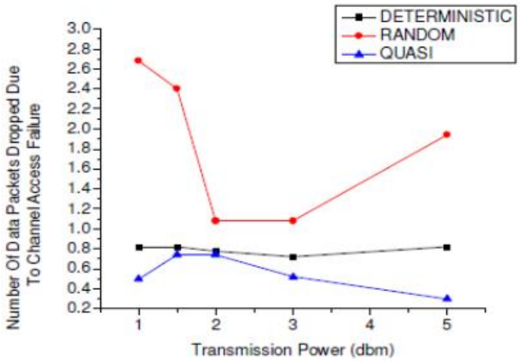

Figure 14. Packet drops due to channel acess failure

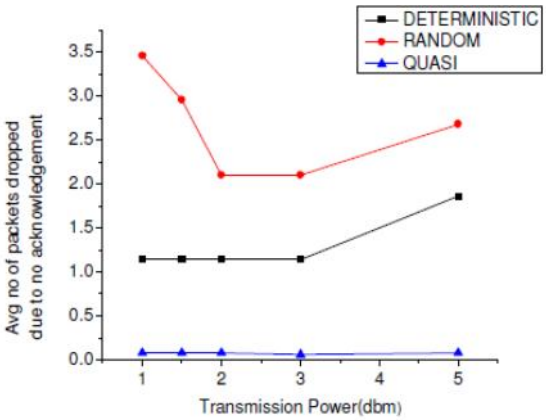

Figure 15. Packet drops due to no acknowledgement

The following Figure13 shows that the total number of losses in case of quasi strategy is always less than both the deterministic and random deployments. Hence we can infer that by using quasi based deployment we can ensure a robust communication with fewer losses. In Figure 14 and 15 we see that the number of packet drops due to congestion or collision is drastically lesser than random strategy and almost equal to the deterministic method. Moreover for the same traffic load there is lesser number of retransmissions at the mac level as depicted in figure.

5. Conclusion

This paper is a study on the effect of varying deployment on the required transmission parameters. It is observed that for a sensor network there is no stringent requirement for maximizing the throughput as most of the application domains incorporate redundant transmission of the data. It is the effective data delivery that is more important; be it in terms of optimal energy or in terms of reduced latency. These parameters are associated with the energy wastage and the delay in transmission when retransmissions are required at the different layers of the network stack. Quasi based deployment strategy offers the reduction in delay and the energy loss through efficient placement of sensors.

As quasi random deployment strategy performs better than both deterministic and random deployments, we can infer that there is a substantial saving in the energy due to retransmissions and congestion. Hence we can suggest that for applications that require robust communication or where the network is protocol specific quasirandom can be used as a deployment strategy to achieve the claimed quality of service. We advocate a strategy that can be adopted for further research, a method that can be used with the existing standard literate works to enhance and optimize the quality of service criteria of sensor networks.

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