Performance Analysis of Quasi-Random Deployment Strategy in Sensor Networks

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Abstract— This article evaluates the performance of a quasi random deployment strategy for wireless sensor networks on the basis of the application invoked for tree based communication networks. The quasi random deployment strategy tries to combine the benefits of both random and deterministic approaches for effective coverage and connectivity. We adopt Halton sequence to generate the node placement co-ordinates and study the features and effects on the network traffic, the total carried load, the amount of delay incurred and the energy consumption under the IEEE 802.15.4 standard. Our analysis suggests the need to revisit currently used models of deployment in such networks. This paper also tries to suggest adoption of quasi based deployment on the basis of the simulation results. It shows that quasi random deployment strategy is better than deterministic deployment which is difficult to maintain and better than random deployment scheme that is expensive in terms of coverage, and network constraints.

Keyword- Wireless Sensor networks, Minimum Spanning Tree architectures, Delay, Throughput, Quasi-random deployment, Zigbee networks

I. INTRODUCTION

The quality of service metric in a wireless sensor is evaluated on the basis of energy efficiency, lifetime, delay, coverage and the robustness against transient load. However, there is a fair share of how the nodes are arranged in the region of interest. Deployment methods may force an early depletion of nodes irrespective of the efficiency of the routing protocol unless there is a guarantee to self adjustment or self organization among the nodes. Not many algorithms focus on the readjustment of the node positions and many algorithms assume a deterministic deployment with static nodes. In such scenarios, the initial deployment method of the nodes or their readjustment plays an important role in achieving the desired quality of metrics, as per the application specified; be it a simple monitoring application, or a real time environment like disaster control. This requirement compels us to analyse the performance of a network under the different strategies of deployment. The available deployment strategies are shown in Fig. 1.

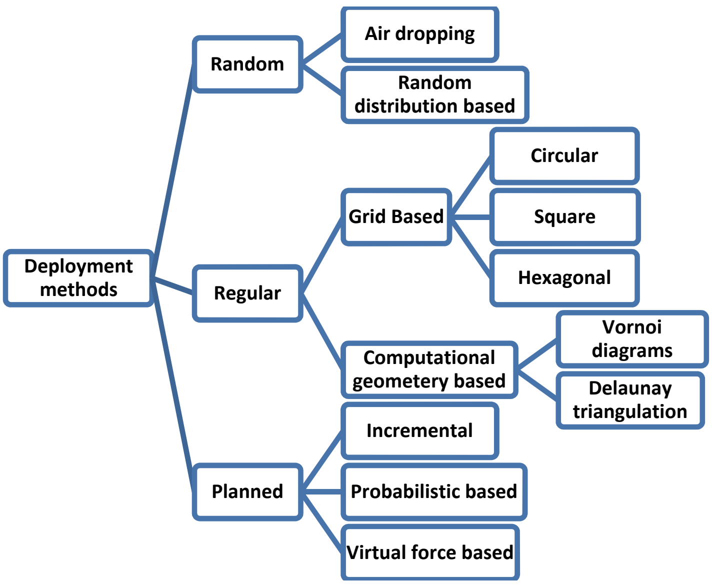

Fig.1. Existing deployment methods

The deployment methods are usually suited for both flat and hierarchy based communication architectures. In contrast to Flat or clustered networks, a hierarchy based architecture requires more in-network data processing or data aggregation. Moreover, the parent nodes are prone to early failures due to extra data relaying and computation. Still, there are ample works that advocate the use of tree based structure for achieving the quality of service metrics for wireless sensor networks. In most cases we can infer that use of single paths to connect each node to the base station has been preferred as opposed to using the multiple paths at the same time due to the duplication of the same packet.[1] Moreover, on analysis of the performance of cluster-based and tree-based topologies, it is found that cluster-based topology is more energy efficient for aggregation than tree-based topology; but in the case of acquisition, tree-based topology is more energy efficient than cluster-based topology. Other similar works like Tree-based routing protocols are aimed to construct the best route from a node to base station [2]. Protocols like HTECRP [3] claim to manage congestion and perform fairness on the network by assigning privileges to the traffic. ViTAMin [4] offers a hierarchical backbone tree algorithm for energy efficiency and sufficient network lifetime. While Localized area spanning tree (LAST) protocols for wireless short range sensor networks optimizes the energy cost and the interference imposed by the structure [5], a BFS based tree rooted at the base station offers shortest path traversal for each data message which utilizes the sensor resources efficiently by employing a local repairing approach for the crashing nodes thereby increasing the lifetime [6]. CTP is a routing protocol implemented in TinyOS-2.x, offers 90-99.9% packet delivery in highly dynamic environments while sending up to 73% fewer control packets than existing approaches ([7]-[9]). Tree based strategies reduce the burden of retransmissions and hence can be used for congestion management [3]. Thus, it can be believed that a tree structure is popular in wireless sensor network structure, for most applications having one sink and too many sender nodes. But does the node placement which affects the tree formation affect the communication as well?

Our approach tries to answer this question. To the best of our knowledge, there has been no systematic experimental study that analyses how underlying deployment strategies manifest themselves for tree based network characteristics for the different classes of protocols. We provide a systematic analysis of factors influencing the network behaviour by separating them out each primary level: the network layer, medium access layer, and application layer. Our work considers a tree based topology constructed for a quasi random deployment scenario under the specific application like Zigbee for a number of routing protocols. Typically, a parent node is selected based on two parameters. One is the number of hops from the node to base station, and the other is one of the following: parent's residual energy, link quality, or the length of routing path to base station. We use an MST to generate the required communication backbone based on the shortest path characteristics. We observe the performance metrics for the different deployments, namely: Deterministic, Random and Quasi Random. Section 2 discusses the system requirements while results are analysed in section 3 followed by conclusion in section 4.

II. SYSTEM MODEL

We consider a terrain of size100 X 100 deployed with 50 homogeneous nodes in three phases. The network is modeled as a graph *G = (N, L)* where '*N'* is the set of nodes and '*L'* is the set of links between the nodes. Among the '*N*' nodes there is a special device or pan coordinator that we consider to be the initiator of the connection procedure. To deal with the necessary connection establishment and maintenance, we adopt a unit disk model constraint where any two nodes can communicate if their distance is smaller than or equal to *'R'* where *'R'* is the transmission range.

Phase 1 places the nodes in a square grid pattern while phase 2 arranges the nodes in a random manner. Phase 3 deploys nodes in a quasi sequence. These deployment schemes then connect to the sink in the form of a tree. The idea behind tree-based communication architecture is simple. A spanning tree is first constructed, with the root node being the sink node. 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. This message passing can be considered similar to a star based network with one parent and '*n'* non-leaf nodes. The emphasis is not on the best tree structure, but whether the different deployment methods have different performance of the identical tree structure mechanism. 'Zigbee' application is used for the traffic generation for a set of 50 nodes deployed deterministically, quasi-random and randomly. The next step generates the MST for the deployed nodes as shown in fig. 1, 2 and 3; which are analyzed for Distance vector based, Ad Hoc and link based protocols.

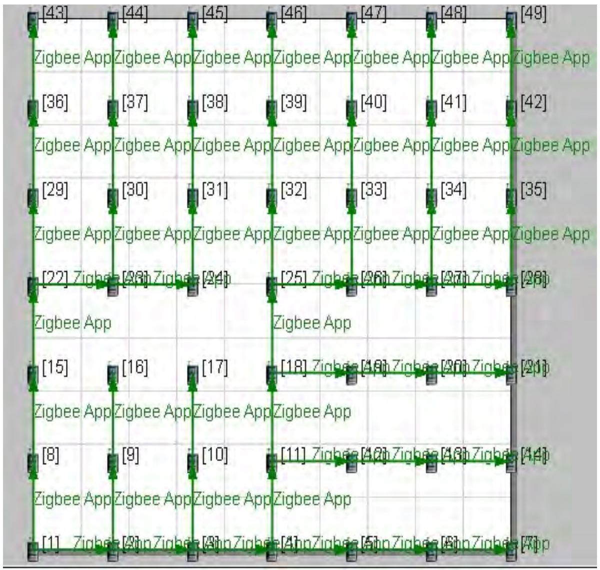

Fig. 2. Deterministic Deployment

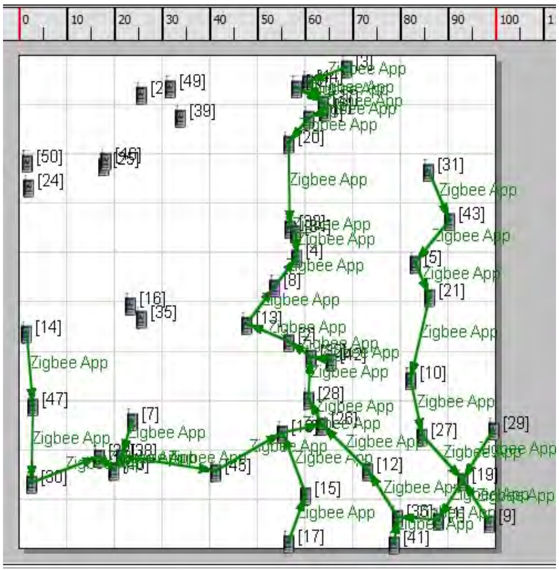

Fig. 3. Random deployment

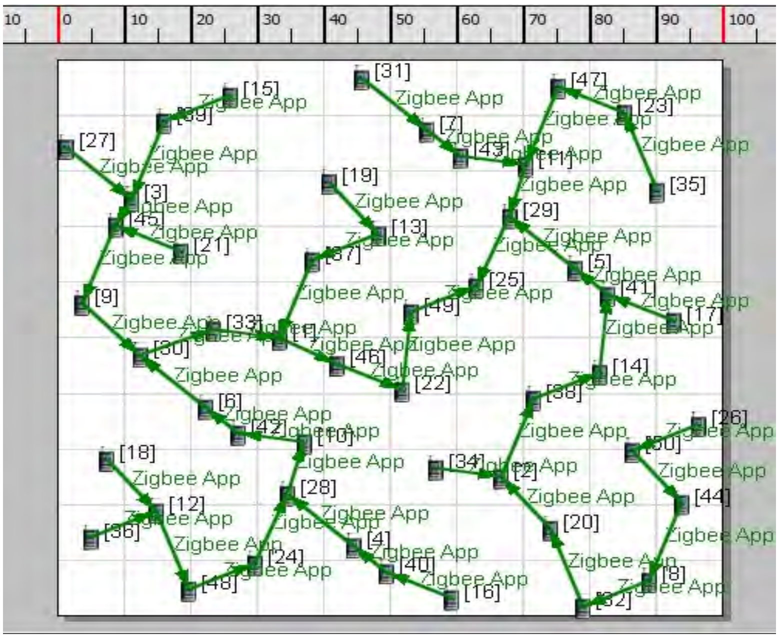

Fig. 4. Quasi Random Deployment

A. Assumptions

- All Sensor nodes are homogeneous in nature and are location aware.
- Sink is responsible for forwarding the data to the base station.
- The parent nodes forward their data from the leaf nodes in addition to their collected data.
- Only the nodes within the transmission radius of other nodes are a part of the communication structure but there is no spanning forest formation.
- The simulation parameters considered for analysis are given in table 1.

Table I
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

III.RESULTS AND DISCUSSIONS

The results are analysed for the network and MAC layer as the MAC layer protocols that traditionally manage power saving are designed to be application aware to some degree, for example they provide service differentiation for data, query and management packets. The parameters that are considered for comparison under the following set of protocols are:

1) Total carried load: is indicative of the throughput of the network. Since we consider TCP/IP for our analysis the throughput decrease is indicative of the TCP's counterbalance for packet drops. The number of packets dropped at the Mac layer is due to link failure or congestion or collisions. The throughput is directly affected by the number of packets dropped in the MAC layer and hence those statistics are also included.

Throughput can be calculated as: Total bytes sent or received * 8 / (Total time allotted for communication - time first packet is sent or received).

2) Average delay: at the network layer is crucial, in case of real time applications. The average delay is computed as follows:

Avg. End to end delay = Total transmission delays of all the received packets / No of packets received Where,

The transmission delay of a packet = Total time when a packet is received at the server - Time when a packet is transmitted at the client.

The comparison of the deployment schemes in Fig. 5, show that the number of successful deliveries of the packets is better in case of quasi based deployment as compared to both random and deterministic deployments for all the protocols considered. It is also observed from Fig. 6 and 7 that as a consequence the 'TTL sum of in-deliveries' and the throughput is more for quasi based network rather than the other two deployment schemes. By observing Fig. 7 we see that in case of AODV, DYMO and Fisheye, the carried load is remarkably high for quasi based deployment scheme. In case of Bellman ford algorithm (BF), the carried load in case of deterministic and random deployment is slightly more than 'quasi' which is attributed to its proactiveness in route selection. This is also the reason that delay is more in case of a quasi deployed network than the other two deployment cases for DYMO and AODV as depicted in Fig. 8. The delay is nearly equal for Bellman ford and fisheye protocols for all the three deployment strategies. In Fig. 9, in case of average jitter, 'quasi based deployment' shows a better performance and is always lesser than random based deployments. The feature that is significant is that, as compared to the corresponding carried load, the incurred delay is comparatively lesser or equal in case of quasi based deployment.

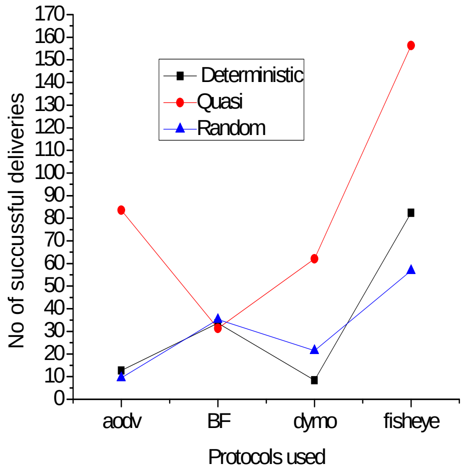

Fig. 5. IP Indelivers for different protocols

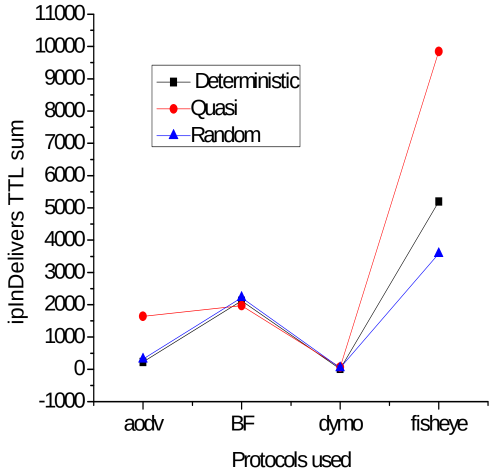

Fig. 6. TTL Sum of packets at the network layer

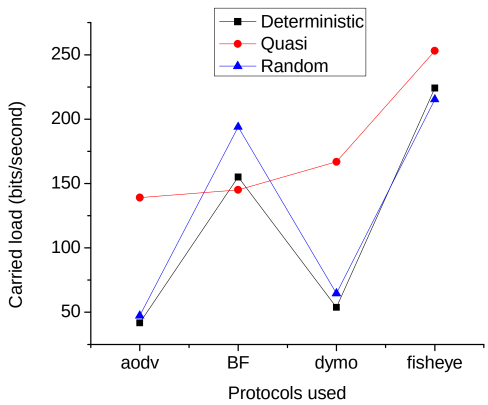

Fig. 7. Average carried load by nodes

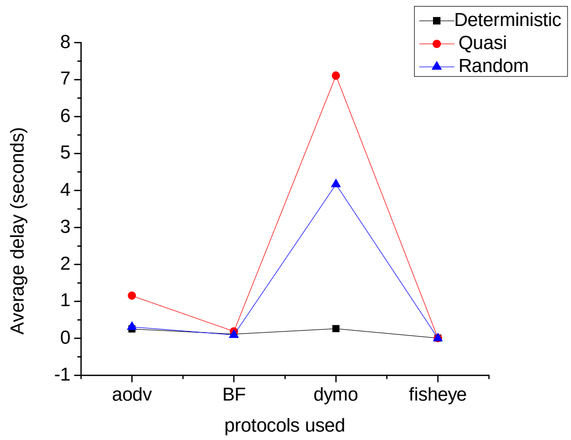

Fig. 8. Average delay of nodes

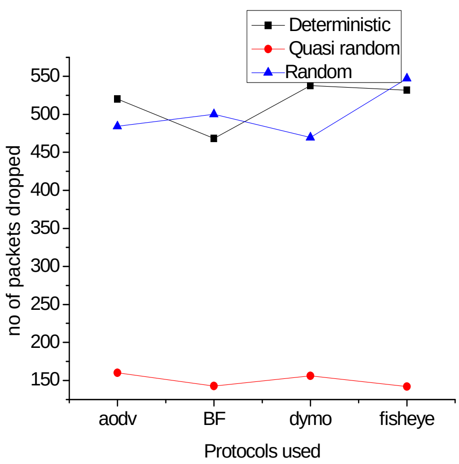

Fig.9. Average number of packets dropped

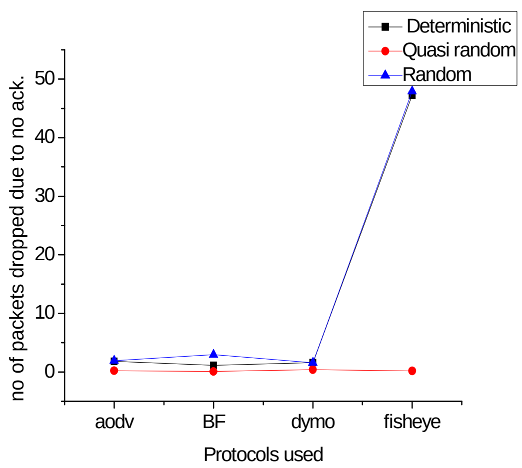

Fig.10. Number of packets dropped due to no acknowledgement

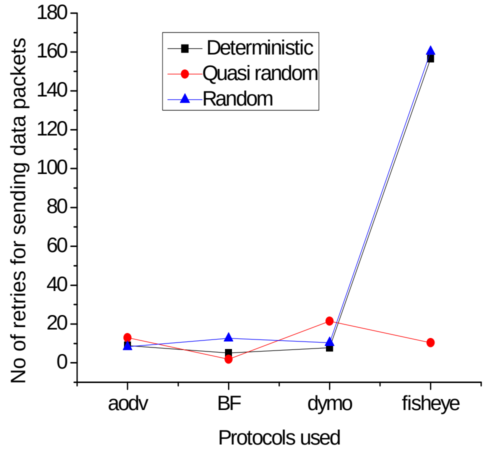

Fig.11. No of retries made to send packets

The figures 9, 10 and 11 are the statistics collected as per the MAC layer where we see that the number of packets dropped and the number of retries for packet resending in quasi based deployments is significantly lesser than the other two strategies. Hence, we confirm that the Quasi based strategy has a better payoff in case of congestion and collision in the channel.

IV. ANALYSIS FOR IMPROVED PERFORMANCE

Quasi based deployment strategy aims to bridge the gap between the performance of deterministic and random deployments. Hence, we further analyze our scheme to study the impact of varying AODV based constraints on the performance of the quasi based network. We put quasi based AODV statistics for analysis in the following section as AODV is the default protocol used for Zigbee networks. This section analyses the variance in the performance of the protocol when subject to varied network conditions.

1) *Case 1: By varying the traffic load*

By defining the total number of packets to send, it was observed that there was not much variation on the traffic load due to change in deployment as they depended more on the protocol involved.

2) *Case 2: By varying the transmission power of the nodes*

Though the throughput performance of the network significantly increases by increasing the transmission power, the number of packet drops also increase due to the increase in contention and collision of the packets transmission. Since the increase in transmission power requires antenna size modifications, which is not a possibility in case of sensor networks due to the small size of the nodes employed. Hence, we do not include these results.

3) *Case 3: On the basis of varying the hop counts of the AODV protocols*

The transmission power required by any node 'i' to transmit data to node 'j' is dependent on the distance between the nodes d_{ij} ,the rate of transmission 'r' in bits/sec and the path loss index. We relate this distance d_{ij} to the number of hops required for successful data delivery to the sink. In networking, the hop count represents the total number of devices a given piece of data (packet) passes through. The more the number of hops the data must traverse to reach their destination, the greater the transmission delay. Moreover, the devices receiving the packets compare the hop count against a predetermined limit and discard the packet if the hop count is too high. Hence increasing the hop count limit reduces the chances of packet dropping at the MAC layer. Since AODV uses max hop counts to limit the endless bouncing of packets around the network due to routing errors, on changing the maximum hop count, the network performance improves. Therefore, we vary the maximum hop counts from the ideal 35 hops to 10, 15, 25 and 45 to study the effect on the overall network performance of the different deployments. The observed results are presented henceforth.

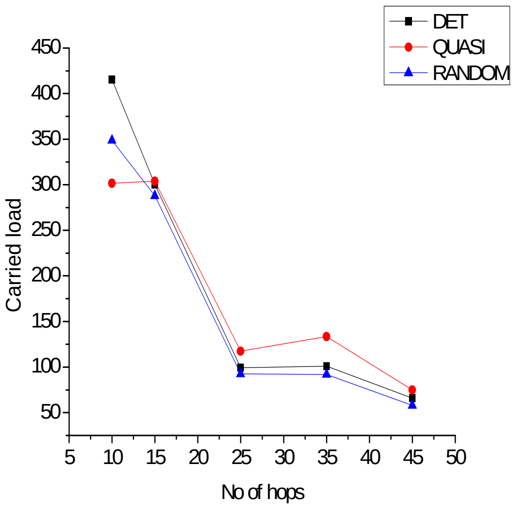

Fig. 12. Average carried load

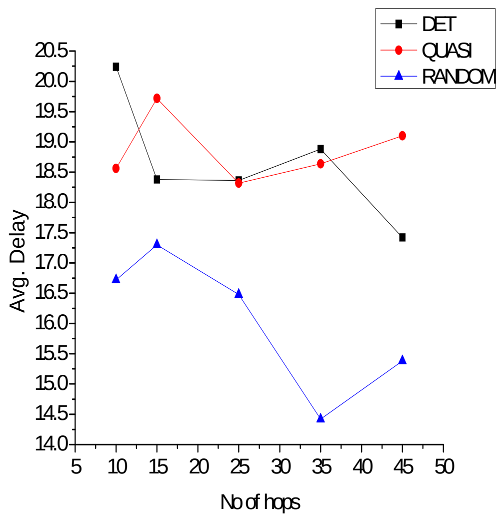

Fig. 13. Average Delay

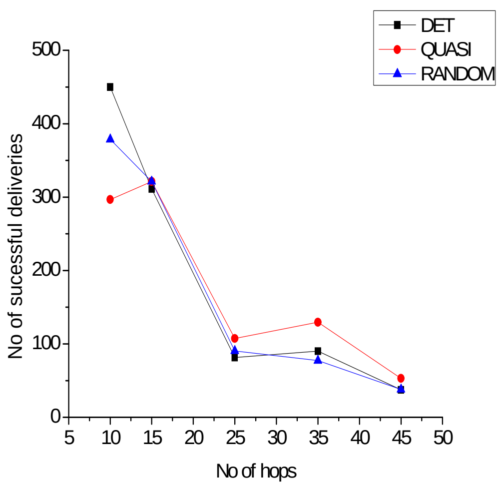

Fig. 14. Number of successful packet deliveries

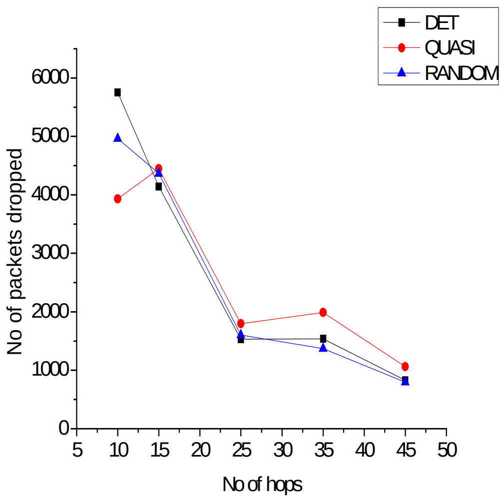

Fig. 15. Number of packets dropped

From the above figures it is observed that the average number of hops, a packet needs to travel, for successful delivery, increases with increase in the max number of hops as shown in Fig. 12, and the delay is more than random deployments in case of quasi based deployment as shown in Fig.13. But all the three deployments exhibit almost the same pattern of change with respect to the change in the maximum number of hops as shown in Fig. 14 and 15 respectively. It can further be noticed that the variation in the network parameters in case of quasi deployed network is lesser than the other two deployment schemes and hence quasi depicts a more stable network performance against the changes in given routing protocol parameters.

V. CONCLUSION

This article analyses the quasi based strategy prospects in the deployment of sensor networks. On observation of the performance parameters like carried load and successful deliveries, we find that the statistics are better for a quasi based network than both (deterministic and random deployment) or at least one of the existing strategies employed usually for deployment in sensor networks. The saving is not much when considering delay but there is a significant reduction in the number of packet drops due to channel congestion or no acknowledgement. Also, on varying the maximum hop counts we see that, the variation in network parameters is smoother in Quasi based networks as compared to both random and deterministic based networks. Hence, we can infer than employing Quasi based strategy in deployment guarantee a better network performance and can be adopted for further investigation.

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