Impact of Coordinator Mobility on the throughput in a Zigbee Mesh Networks

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***Abstract*— Zigbee (IEEE 802.15.4) standard interconnects simple, low power and low processing capability wireless devices. The Zigbee devices facilitate numerous applications such as pervasive computing, national security, monitoring and control etc. An effective positioning of nodes in a ZigBee network is particularly important in improving the performance (e.g., throughput) of ZigBee networks. In the wireless sensor network (WSN) literature, the use of a mobile sink is often recommended as an effective defense against the so-called hot-spot phenomenon. But the effects of mobile coordinator on the performance of the network are not given due consideration. In this paper, we perform extensive evaluation, using OPNET Modeler, to study the impact of coordinator mobility on ZigBee mesh network. The results show that the ZigBee mesh routing algorithm exhibits significant performance difference when the router are placed at different locations and the trajectories of coordinator are varied. We also show that the status of ACK in the packet also plays a critical role in deciding network performances.**

Keywords-Sensor Networks; Zigbee; Mobile Coordinator

I. INTRODUCTION

The conventional wireless sensor network (WSN) architecture consists of a large number of devices (wireless sensor nodes) at the bottommost layer. On top of these devices there is a subsystem which supports the routing of the data from the node to the gateway. The wireless sensor nodes are miniature battery powered devices with very less power consumption rates making them appropriate for use in the remote areas. These sensor nodes are distributed randomly in area and connected to the outside world through a gateway. A sensor can act as a Full Functional Device (FFD) or a Reduced Functional Device (RFD) [8], with at least one FFD acting as a Coordinator. The primary goal of the RFDs (end devices) is to gather the data from the surrounding environment and route it to the coordinator which has superior computing capabilities and serves as gateway for the entire network. This type of setup with multiple nodes sending data to a single processing unit are termed as many-to-one systems as shown in Figure 1.

One of the major issues in the wireless sensor networks is the hot-spot [3,6]. The FFDs in the vicinity of the coordinator need to send the data to coordinator on behalf of the other distant nodes. So these nodes tend to dissipate more power as compared to other nodes and hence die out much earlier leaving the coordinator unconnected from rest of the network.

Figure 1. Many-to-one Systems

A considerable number of studies [1,2,4,5,9,10,11] on the mobile coordinator in WSNs have been published and most of them proposed that the mobile coordinator is better option to reduce the formation of hot spots in the network. But none of them concentrated on the change in the throughput due to the mobility of the coordinator. The goal of this paper is to study the effect of mobility of coordinator on the throughput of the network.

This paper is organized as: Section II gives a brief overview of the IEEE 802.15.4, Section III discusses the arrangement of nodes in the network and the trajectories for the coordinator motion, Section IV analyzes the simulations performed and Section V concludes the paper giving the results.

II. OVERVIEW OF IEEE 802.15.4 (ZIGBEE)

The IEEE 802.15.4 / ZigBee suite of standards [11] is considered the ‘technology of choice’ for applications involving sensor networks, due to the reliability they provide. Other reasons for their success is the low-power and cost-effective communication they provide. In recent years, the technology has been gaining use in industrial and commercial acceptance, this is clear from the wide spread use in defense, monitoring and control, commercial use etc. As shown in Figure 2 Zigbee architecture comprises of 4 layers – Physical Layer, MAC Layer, Network and Security Layer and Application Layer. Physical and MAC Layer are defined as IEEE 802.15.4 standards while the higher layers follow standards set by Zigbee Alliance.

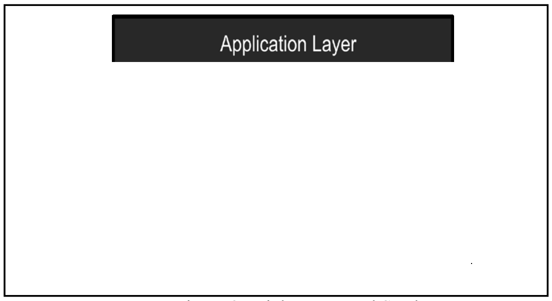

Figure 2. Zigbee Protocol Stack

There are three types of devices defined by the Zigbee standards [11] - coordinators, routers and end-devices. Zigbee coordinator is responsible for setting up all the network parameters such as topology, packet size etc. It is a node with superior computing capabilities as compared to routers and end-devices. It is a gateway for the outside world to interact with the network. This role is generally assigned to the sink node. ZigBee routers are the intermediate devices in a network which route the data from the source to the destination. These devices route the data as well as sense the data from their surrounding environment. ZigBee end-devices are devices with least computing capabilities. They are only capable of sensing data and completely depend on their parents (routers/coordinators) for routing their packets.

The ZigBee standard also defines 3 possible types of network Topology [8]: star, cluster-tree and peer-to-peer (mesh). In the star topology, direct communication link is established between devices and a single central controller, called the PAN coordinator. In cluster-tree topology, there is a parent child relationship between the nodes. Each node passes its packet to this parent and it then passes it further. In mesh topology, each device not only transmits to its parent but also to all the neighboring devices as long as they are in range. It works on a proactive routing mechanism in which each node broadcasts a message and finds the shortest path on the basis of the replies from the routers. It is better than other topologies due to its powerful routing mechanism.

III. NETWORK ASSUMPTIONS

The network setup consists of a network field within which the end devices are present, which sense the data and transmit via the routers (or directly) to the coordinator (sink).

- The network field is a square shaped region.
- The end-devices are distributed in a complete random manner.
- The routers are arrangement in either one of the two configurations – square and hexagon.
- The coordinator can be static (at the center of the network field) or mobile.

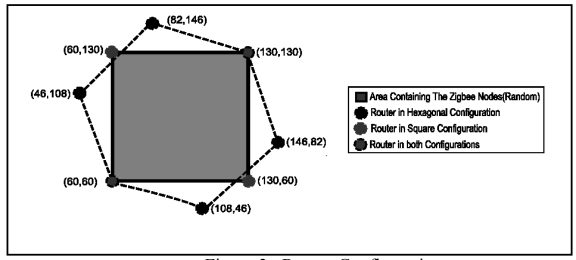

Figure 3. Router Configurations

- The path of the mobile coordinator can be one of the following- outer periphery, inner periphery, along principal diagonal, circular and random trajectory.
- The effect of external interferences is considered zero.

A. Arrangement of Routers:

To avoid the deviation in the results due to random arrangement of routers, two specific router configurations are used as shown in Figure 3.

1) Square Configuration: In this configuration, routers are arranged on the corners of a network field. The position of routers is such as to cover the entire network field. The routers are not in the radio range of each other.

2) Hexagonal Configuration: In this configuration, routers are arranged so as to cover the entire network field and forming a hexagon. The vertices of the hexagon represent the routers. The routers are within the radio range of two adjacent routers.

B. Coordinator Trajectories: There are two different sink mobility models – random sink mobility model and fixed sink mobility model [6].

1) Random Sink Mobility Model: In this model the trajectory of the sink movement comprises of the random sequence of segments distributed through the network.

2) Fixed Sink Mobility Model: In this model, the trajectory of the sink movement is along a fixed path, and during the entire simulation duration the sink keeps on moving on the same path.

- Outer Periphery: In this path, the coordinator moves outside the network field on the boundary forming a square.
- Inner Periphery: In this path, the coordinator moves inside the network field at some distance from the boundary generally half the distance from the center forming a square.
- Circle: In this path, the coordinator moves on almost a circular path.
- Along Principal Diagonal: in this path, the coordinator will have a to and fro motion along the diagonal.

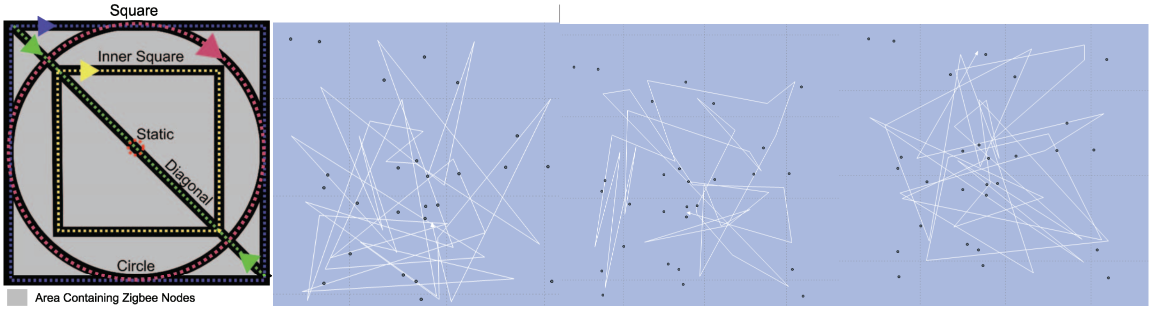

Figure 4. Coordinator Trajectories

IV. Analysis of Network Simulations

A. Simulation Parameters: The simlations analysed in this section are performed on the OPNET Modeler v 14.5 [7]. The network field is of size 70m X 70m. The simulations are performed on two different network sizes – 25 end-devices and 50 end-devices.The topology used is Peer-to-Peer (Mesh) Topology. In the simultion, the distribution of end-devices is random. The simulations are performed for 3 different seeds in both network sizes on all configurations. The coordinator moves at a constant speed of 10m/sec. The overall simulation time is 3600 sec with the measurements taken been aggregated at every 36 sec. The simulation parameters which are used for simulation are sumarized in the Table 1.

TABLE I. SIMULATION PARAMETERS

Network Parameter	Parameter Value
Transmission Range	60 m
Packet Size	1024 bits
GTS	Disabled
CSMA-CA minimum backoff exponent	3
CSMA-CA maximum number of backoffs	4
Channel sensing Duration	0.1 sec
Beacon Order	6
Super Frame Order	0
Maximum Children	30
Maximum Routers	6
Maximum Depth	7
Beacon	Disabled
Frequency Band	2.45 GHz
Packet Inter-Arrival Time	36 sec
Packet Inter-Arrival Time (Router)	120 sec
Packet Inter-Arrival Time(Coordinator)	10 sec
Route Discovery Timeout	10 sec
Packet Destination	Coordinator

Throughput represents the total number of bits (in bits/sec) forwarded from 802.15.4 MAC to upper layers in all WPAN nodes of the network while Load is the total load (bits/sec) submitted to 802.15.4 MAC by upper layers in all WPAN nodes. The seed values used for simulation are- 1, 15000 and 98765 for square router configuration while for hexagonal router configuration they are taken as 1099951566, 143302913 and 121150608.

B. Analysis

In the analysis we will consider the throughput for different coordinator trajectories, effect of ACK on throughput and the throughput to load ratio for different router configurations.

1) Square Configuration of Routers:

a) Throughput for different coordinator trajectories: Simulation results for the throughput based on the trajectory of the coordinator are shown in Figure 5 and Figure 6. Figure 5 gives a timed relationship between various trajectories for 50 end-devices. The results of Figure 5 shows that the maximum throughput is achieved keeping the coordinator static. When the trajectory is changed to circle or inner square, the throughput reduces and it is almost equal. The throughput is minimum for the square or diagonal trajectories both being almost equal. When the ACK is enabled, there is a decrease in the throughput for all the trajectories with static being the highest and diagonal being the lowest. The results of Figure 6 shows the effect of density of nodes on the performance of the network. Figure 5 shows that the results are almost similar but for the fact that the configurations show less deviations for each other except for the inside square confiuration which is left behind. On disabling ACK it mimics the curve with 50 nodes with inside square improving performance as the diagonal and square configurations fall low. There are repetitive peaks at around 120s due to routers' increased participation, which die out in configurations like the square and the diagonal when the throughputs become low.

*b) Effect of Acknowledgement on throughput:*As shown in Figure 7, enabling and disabling ACK have a huge impact on the throughput of the system. Whereas in case of 50 nodes with static sink, the disabling of ACK gives better results, the results are opposite when the density gets lower. The results are consistent in 25 node scenario with other configurations, while in case of 50 nodes, the deviations of ACK and without ACK are marginal. At higher densities, i.e. at higher traffic conditions other factors seem to limit the throughput whereas the increased traffic shows its impact in low densities.

c) Throughput Load Ratio: Another parameter for the analysis and measurement of the network performance is the

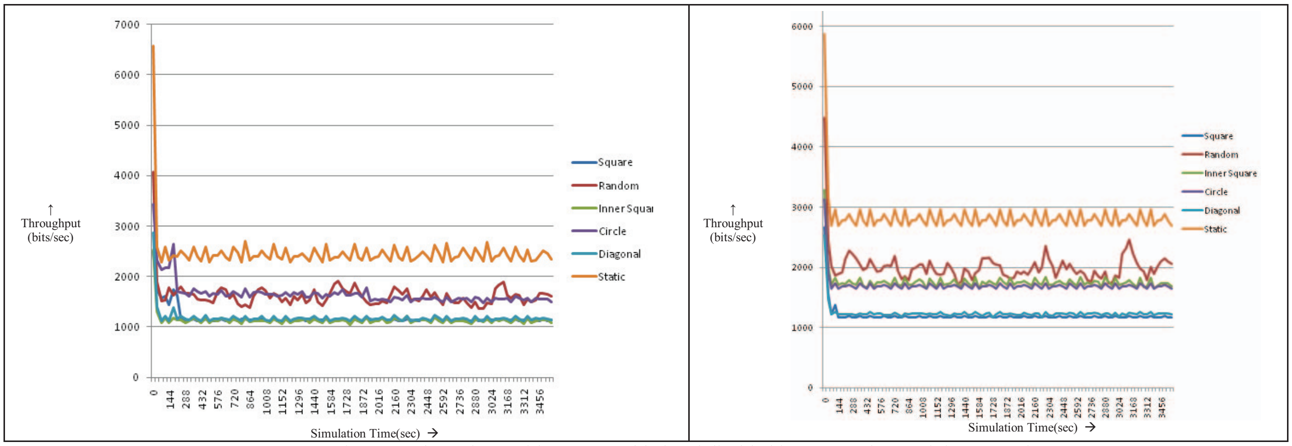

Figure 5. Throughput with ACK enabled and disabled in a network containing 50 nodes.

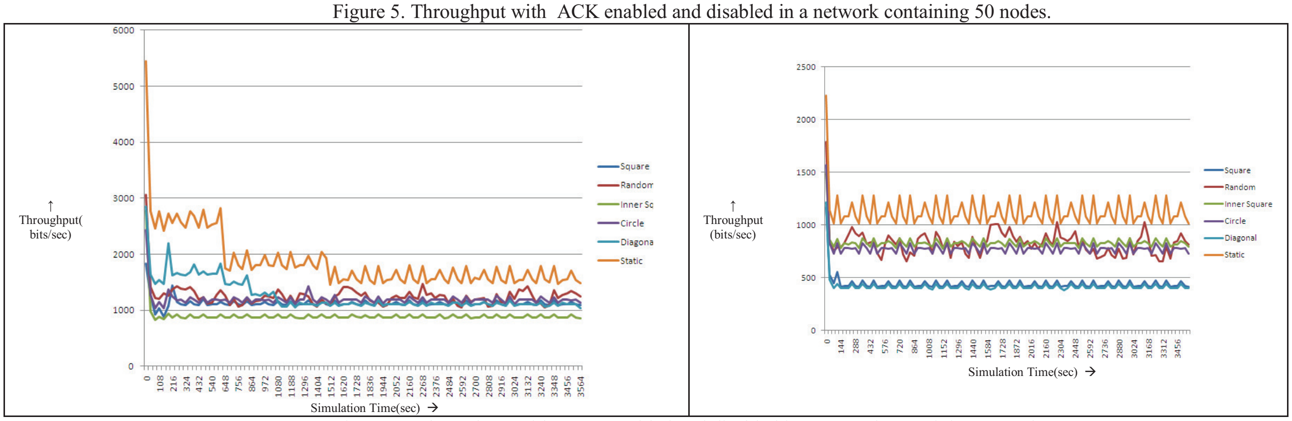

Figure 6. Throughput with ACK enabled and disabled in a network containing 25 nodes

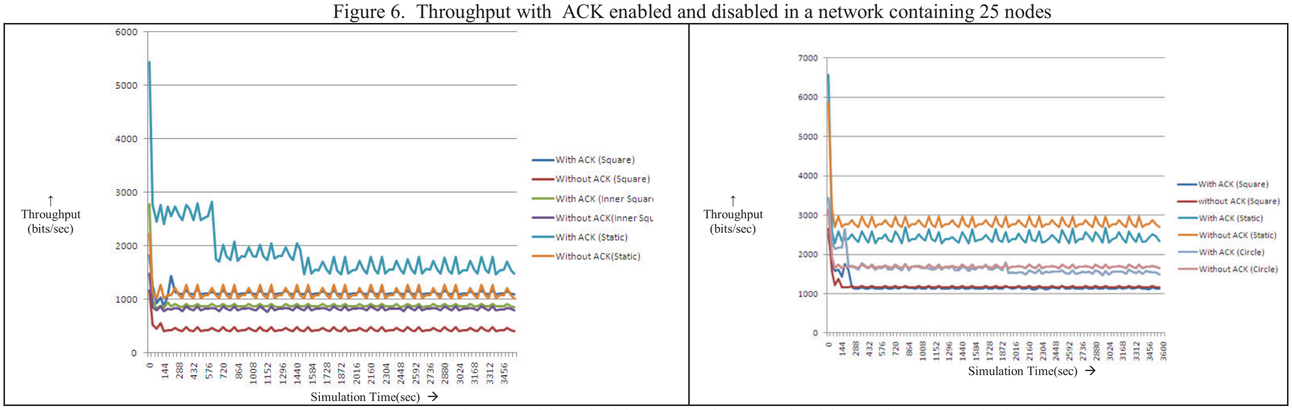

Figure 7. Comparison of with and without ACK in network with two different node densities

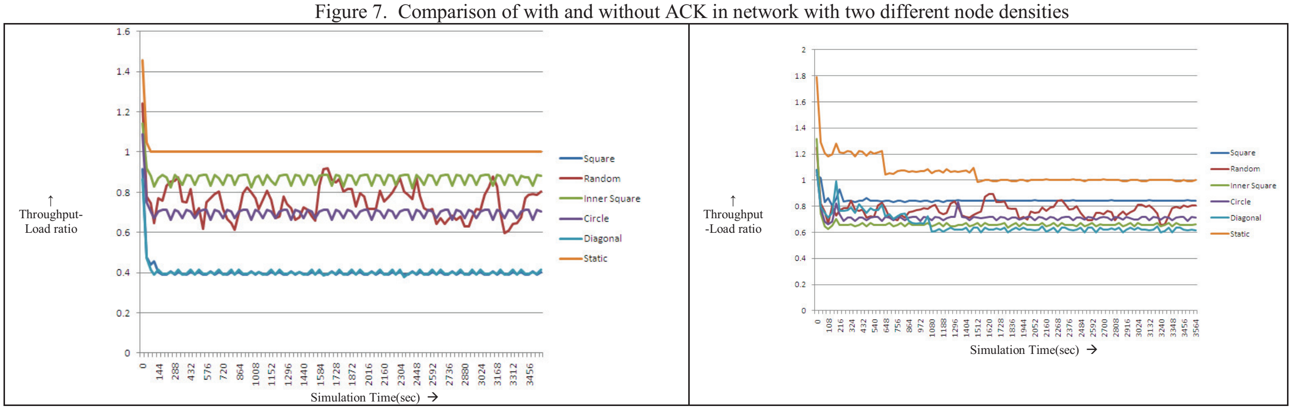

Figure 8. Throughput load ratio for a network containing 25 nodes without ACK enabled and disabled.

deviations imply loss of packets while transmision. Figure 8 show the ratios for various configurations. The static sink configuration has a near perfect ratio, with a higher than one ratio for 25 nodes due to two devices reading and forwarding the same packet(directly to sink and via router). Diagonal again has the worst performance due to inability to get packets from the opposite end routers most of the time, while it varies between 0.6 to 0.9 for others with ACK improving performances of diagonal and square considerably.

2) Hexagonal Configuration of Routers:

a) Throughput for different coordinator trajectories: Figure 9 and Figure 10 show the results obtained for the hexagonal configuration. The results show that the arrangement of routers has a considerable effect on the performance of the network. Figure 9 shows that network achieves maximum throughput when the coordinator is static and throughput being minimum when trajectory is diagonal. But in all the trajections, the peaks are observed at the same time interval. When ACK is enabled, the overall statistics remain the same but the overall throughput of the network increases. When the density of the network is decreased, there is no change in the nature of any of the trajectories as shown in Figure 10.

b) Effect of Acknowledgement on throughput: Simulation results of Figure 11 are similar to the those in Figure 8. It shows that ACK has no effect on the comparitive behaviour of the different trajectories but the net throughput of the system can vary with huge margins.

c) Throughput Load ratio: Figure 12 show the ratios for various configurations. The static sink configuration has a exactly perfect ratio for lower densities while for higher densities it deviates. Diagonal again has the worst performance due to inability to get packets from the opposite end routers most of the time. It varies between 0.4 to 0.5 for lower densities and increases subsequently to 0.6 to 0.8 for higher densities.

C. Conclusion

The simulations indicate that keeping the sink static gives the best performance. If a trajectory has to be chosen for other reasons, then the trajectory should give a considerable amount of time to each route that is the link route for a segment of the network. Otherwise(as in the case of Diagonal trajectory), the throughput is very low. The type of the trajectory along with the node density and the traffic are also major factors that decide the sysem performance. Choosing a random topology is among the means possible to prevent exceptionally low throughput. Having the routers placed within range for effective meshing gives sharper curves which are closer but even in this case, it is better to keep the sink static at a location from where each route has an access to the sink possible with minimum hops. In circumstances sink movement is necessary, clever selection of the trajectory is essenial for best throughput.

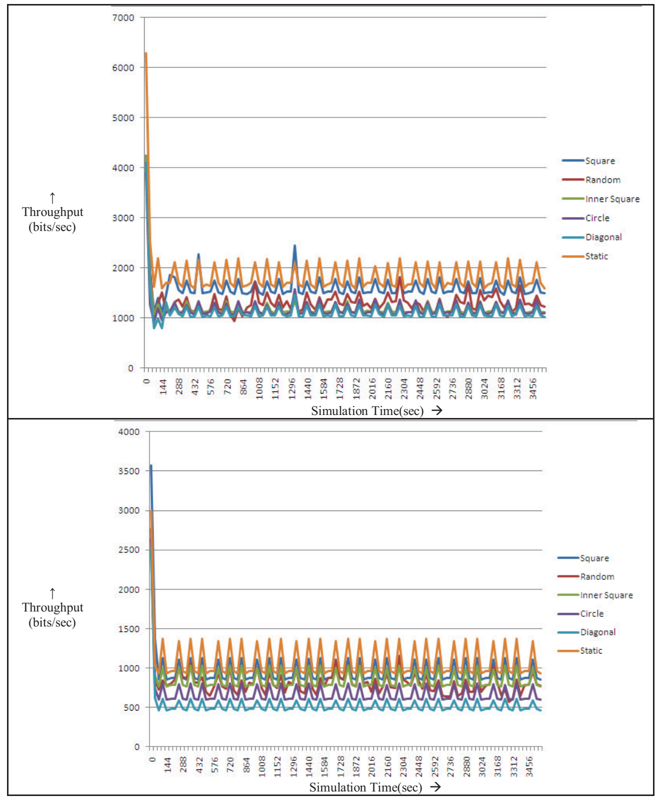

Figure 9. Throughput for Hexagonal Configuration with 25 nodes and ACK enabled and disabled

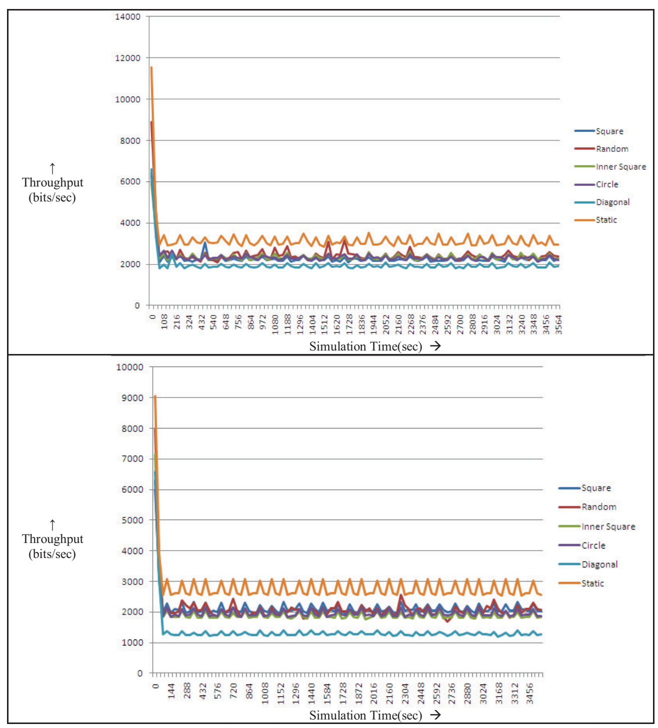

Figure 10. Throughput for Hexagonal Configuration with 50 nodes and ACK enabled and disabled

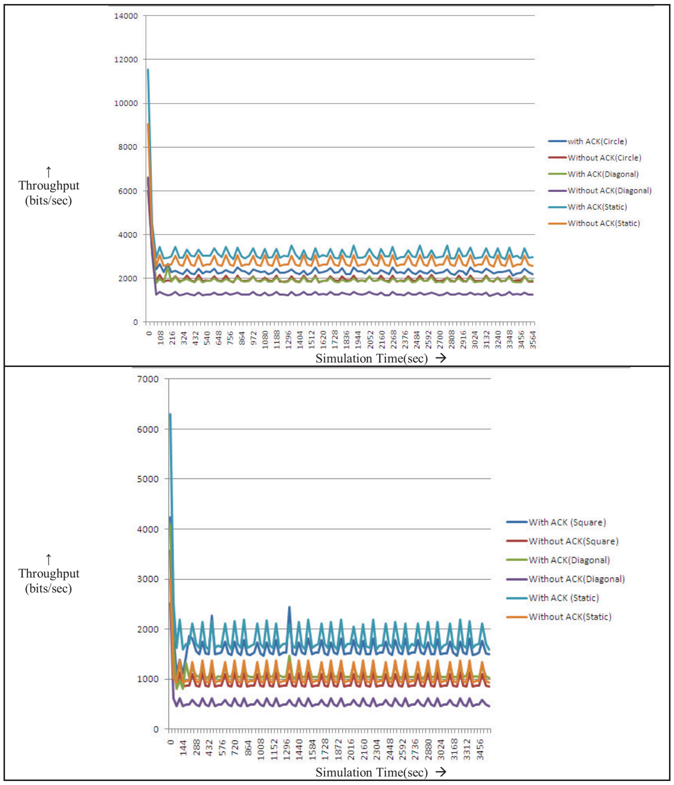

Figure 11. Throughput for Hexagonal Configuration with ACK enabled and disabled for higher and lower node densities

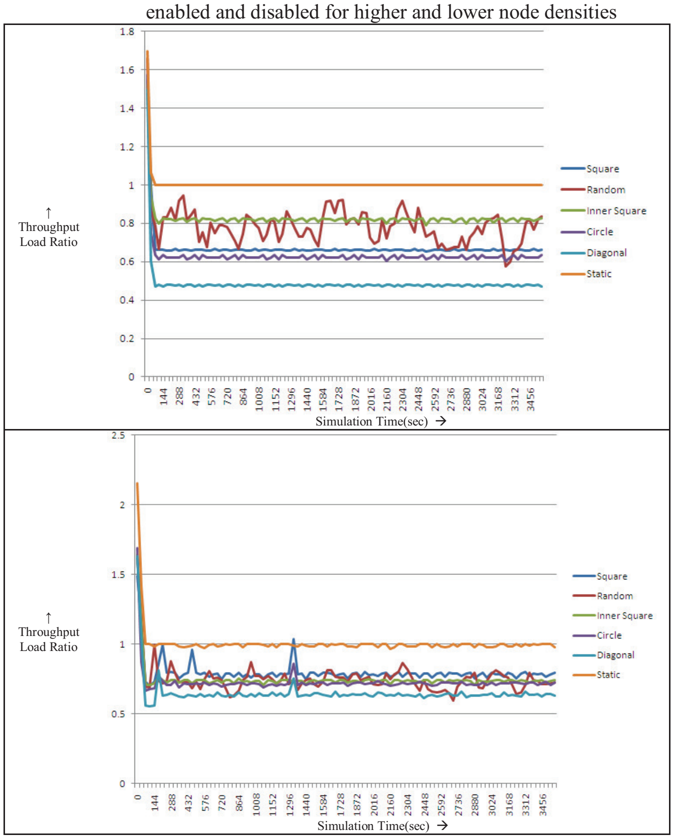

Figure 12. Throughput Load Ratio for Hexagonal Configuration for lower and higher node densities

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