Performance Analysis of IEEE 802.15.4 based Sensor Networks for Large Scale Tree Topology

Ziyad Khalaf Farej, PhD
Northern Technical University
Mosul, Iraq

Ali Maher Abdul-hameed
Northern Technical University
Mosul, Iraq

ABSTRACT
This paper evaluates the performance of IEEE 802.15.4 standard Wireless Sensor Network (WSN) in tree topology for large scale applications. The performance of the network is analyzed in terms of number of nodes, packet size and packet interval time (PIT) by using the discreet event OPNET (version 14.5) simulator. Performance investigation started with a packet size of 1408 bit and PIT of 1 sec in order to determine the best network performance, then based on the comparison which has been made among the network performance parameters, it is found that the network performance for tree topology is optimized at 90 nodes number with packet size of 4096 bits when PIT equals 1 sec.

Keywords
Wireless Sensor Network; IEEE 802.15.4; Network performance; Tree topology; OPNET; optimization.

1. INTRODUCTION
Wireless sensor networks (WSN) are an interesting research topic, both in military and civilian scenarios [1] [2]. WSNs are considered as very large systems comprised of small sized, low-power, low-cost sensor devices that collect detailed information about the physical environment. Each device has one or more sensors, embedded processors and low-power radios, and is normally battery operated [3]. The flexibility and self-organization, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of sensor networks create many new and exciting application areas for remote sensing. In the near future, this wide range of application areas will make sensor networks an integral part of life [4]. One of the latest standards for wireless sensor networking with low transmission rate and high energy efficiency has been proposed by the ZigBee Alliance [5].

The authors of [6] developed the ns2 support for 802.15.4 that is used in our study. They also performed simulation experiments to test beacon/non beacon transmission, association and tree formation, orphaning, and CSMA. They compared the results to the performance of IEEE 802.11 in the same scenarios. In [7], the performance of IEEE 802.15.4 is analyzed based on OPNET simulator. The simulation result indicates the influence of ACK mechanism and different network load on the system performance, i.e. end-to-end delay, packet reception ratio and throughput of node, which provides an important theoretical basis for the construction of actual network. In [8], authors compared non-beacon and beacon transmission modes in a realistic scenario with two IEEE 802.15.4 development boards through different performance metrics. The study concluded that beaconless networks perform better.

In [9], an investigation of the applicability of star, tree and mesh topology schemes for large scale Wireless Sensor Network (WSN) has been made. The main focus of this work is to evaluate the performance of such network through simulation. The simulation is carried out via the discrete event OPNET simulator (version 14.5). The performance metrics of interest include throughput, end to end delay and packet drop rates. It is concluded that the selection of topology scheme depends on the application context.

In [10], an evaluation of the performance of IEEE 802.15.4 standard Wireless Sensor Network (WSN) in star topology for large scale applications has been made. A comparison among different network performance parameters (number of nodes, packet size and PIT) is made in order to choose the best optimized network performances concerning throughput, end to end delay, and packet drop. Simulation result shows that the best performance is obtained at 230 nodes number with a packet size of 2048 bits and PIT equals 2s.

In [11], the performance of IEEE 802.15.4 standard Wireless Sensor Network (WSN) in mesh topology for large scale applications is evaluated. A deep comparison among different networks has been made and the simulation results show that the optimum network performance is obtained at 50 nodes number with a packet size of 1408 bits and PIT equals 3 sec.

In this paper, the impact of changing the number of nodes and packet size on the system performance is evaluated. In addition, the impact of the variation of the PIT duration is investigated. Finally, the behavior of the network is characterized. This is done by: first, increasing number of nodes and choosing the best performance, second, increasing packet size for further performance enhancement, third, changing PIT in order to reach the best optimized performance at which the throughput is at its maximum value.

This paper is organized as follows; Section 2, gives a brief overview about the IEEE 802.15.4. In section 3, the modeled network parameter and the setting that are used in the simulator are included. In section 4, the simulation results and graphs are given. Finally, section 5 presents the conclusion of this research.

2. ZIGBEE STANDARD OVERVIEW
The ZigBee standard is suited for the family of Low-Rate Wireless Personal Area Networks (LR-WPANs), allowing network creation, management, and data transmission over a wireless channel with the highest possible energy savings. There is three different types of nodes: coordinator, router, and end device. In the absence of a direct communication link from an end device to the coordinator, the router is employed...
to relay the packets towards the correct destination. The coordinator, in addition to being able to relay the packets itself, can also create the network, exchange the parameters used by the other nodes to communicate and send network management commands. The router and coordinator are referred to as Full Function Devices (FFDs), i.e., they can implement all the functions required by the ZigBee standard in order to set up and maintain communications. The end devices, which are also referred to as Reduced Function Devices (RFDs), can only collect data from sensors, insert these values into proper packets, and send them to destination nodes [12]. The ZigBee standard is based, at the first two layers of the ISO/OSI stack, on the IEEE 802.15.4 standard [13], which employs a non-persistent Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), Medium Access Control (MAC) protocol and operates in the 2.4 GHz band. In addition, the IEEE 802.15.4 standard provides an optional ACK message to confirm the correct delivery of a packet. In a scenario with transmission of ACK messages, the access mechanism of the non-persistent CSMA/CA MAC protocol is slightly modified. More precisely, after successful transmission of a data frame, a time interval, denoted as Short Inter Frame Spacing (SIFS), is reserved. The duration of this interval is longer than the duration of an ACK message and shorter than the ACK window duration. Therefore, the receiving node can send immediately an ACK message back, avoiding any collision. If the SIFS is too short, this mechanism may incur some problems in the presence of a router. In this case, in fact, the sum of the transmission times of the two ACK messages may be longer than the SIFS: therefore, the second ACK message may collide with other ongoing transmitted packets (from other nodes). This problematic behavior is exacerbated with two routers. We remark that the medium access mechanism in ZigBee wireless networks makes use of a back-off algorithm to reduce the number of packet collisions. A node, before transmitting a new packet, waits for a period randomly chosen in an interval defined during the network start-up phase. After this period has elapsed, the node tries to send its packet: if it detects a collision, it doubles the previously chosen interval and waits; if, instead, the channel is free, it transmits its packet. This procedure is repeated for five times, after which the waiting interval is maintained fixed to its maximum value. This back-off algorithm makes it likely, in the considered scenarios with low traffic loads that a node will eventually succeed in transmitting its packet [14].

3. OPNET NETWORK MODELS AND SIMULATION PARAMETERS

The Opnet modeler (version 14.5) is used to model and simulate different WSN tree topology scenarios. The simulations are carried out for different network loads and different number of nodes. It is worth to mention that the Opnet uses object modeling method and graphical editor to provide simulation environment for network modeling. Also it has three modeling mechanisms: the bottom is the process model, implementing the algorithm agreement; the middle is the node model which uses process model to implement the equipment function; the top mechanism is the network model which uses node model to make network topology structure. This model fully corresponds to the actual protocol, equipment and network, and completely corresponds to the network related features. The parameters that are used in the setting of the OPNET models are shown in Tables(1) as follows:

Table 1. Parameters Setting

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree</td>
<td></td>
</tr>
<tr>
<td>Payload (bits)</td>
<td>Variable</td>
</tr>
<tr>
<td></td>
<td>(1024,1408,2048,3072,4096,8192)</td>
</tr>
<tr>
<td>Max. children</td>
<td>260</td>
</tr>
<tr>
<td>Max. routers</td>
<td>10</td>
</tr>
<tr>
<td>Max. depth</td>
<td>10</td>
</tr>
<tr>
<td>Mesh routing</td>
<td>Disabled</td>
</tr>
<tr>
<td>Packet Interval</td>
<td>Variable</td>
</tr>
<tr>
<td>Time –PIT(sec)</td>
<td>(1 - 8)</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>0.1</td>
</tr>
<tr>
<td>(watt)</td>
<td></td>
</tr>
<tr>
<td>Channel Power</td>
<td>0.2</td>
</tr>
<tr>
<td>Sensing duration</td>
<td></td>
</tr>
<tr>
<td>(sec)</td>
<td></td>
</tr>
<tr>
<td>Packets reception power threshold (dbm)</td>
<td>-90</td>
</tr>
<tr>
<td>Simulation time</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>

The modeled networks are simulated under the following assumption:-

1- All system nodes distributed over 100X100 m² area.
2- ACK mechanism is not used.
3- Slotted CSMA/CA is not used.
4- All nodes are fixed.
5- Beacon-enabled mode is not used.
6- The addressing mechanism used in PANID is only 16bit.
7- The destination is randomly chosen from their neighbors.

4. SIMULATION RESULTS

The best performance of the IEEE 802.15.4 based WSN tree topology is evaluated by changing a number of different performance parameters: number of nodes, packet size and packet interval time. At the start a packet size of 1408 bit with PIT of 1 sec is chosen.

4.1 Number of Nodes

The best throughput is found at 90 nodes with packet size of 1408 bits and PIT equals 1 sec as shown in Figure (1).
The throughput increases gradually with increasing number of nodes until it reaches its peak at 90 nodes then it starts to decrease as the number of nodes increases. The reason behind that is the higher probability of packet collision upon increasing number of nodes which results in an increase in the end to end delay and that has a high impact on decreasing throughput as well as increasing the packets drop as illustrated in Figure (2) where the packet drop at 230 nodes is about 83 packets.

It is seen in Figure (3) that the delay of 100 nodes is less than 90 nodes delay but the packet drops is higher. The throughput of 90 nodes is better than 100 nodes throughput because there is no packet drops.

Figure (4) shows the average number of hops.

4.2 Packet Size
At PIT value of one, different packet sizes (1024, 1408, 2048, 3072, 4096 and 8192 bits) are used to evaluate the global throughput of the network. From Figure (5), it is found that increasing the packet size increases the global throughput up to packet size of 8192 bits where the degradation in the performance is seen, after the first three minutes of improvement, due to increased collisions and consequently packet drops, then the throughput improved gradually during the following minutes and that might be due to backoff mechanism which become less efficient for large (8192 bits) packet size.
4.3 Packet Interval Time (PIT)

Changing the PIT for the best network performance at packet sizes of 4069 and 8109 bits is made in order to evaluate the best performance with PIT values. Figures (6 and 7) show that increasing PIT decreases throughput at any value, but the decrease in the case of 8192 bits is less than 4096 bits which is normal because the increased time is used more efficiently by the larger packet size. Also the performance of 8192 bits with PIT equals 5 is more stable.

The network performances, for the best packet size (4096 and 8109 bits) is investigated for different PIT, and it is found that for 4096 bits the throughput performance for PIT=1 is higher than the PIT=3 by (16%). The reason behind that is when increasing PIT, the time required between a transmission of a packet and other increases, which means giving enough time for the packet to be transmitted but on account of speed (i.e. increasing PIT decreases data rate and consequently the throughput).

Figure (8) shows a comparison for the best network performances, and it is seen that the best performance for tree topology is gained at the 90 nodes with packet size of 4096 bits and PIT equals 1 sec.
5. CONCLUSION
In this paper, the performance of IEEE 802.15.4 based WSN tree topology is evaluated by changing the following parameters: number of nodes, packet size and packet interval time. Network performance is evaluated by changing the number of nodes from 30-260 nodes and it is found that the peak throughput value is acquired at 90 nodes. Also it is found that increasing the packet size increases the global throughput up to packet size of 8192 bits. Finally, it is found that for 4096 bits packet size, the throughput performance for PIT=1 is higher than that at the PIT=3 by (16%) and it can be concluded that the best network performance for tree topology is obtained at 90 nodes with packet size of 4096 bits when the PIT equals 1 sec.

6. REFERENCES