DE GRUYTER OPEN

Print ISSN: 1312-2622; Online ISSN: 2367-5357
DOI: 10.1515/itc-2017-0003

Simulation Framework for Realization of Priority-based ZigBee Network

V. Aleksieva

Key Words: *ZigBee; wireless network; WPAN.*

Abstract. *ZigBee is a wireless technology, which provides low power consumption of devices in personal area network (WPAN) for low data rate applications that require long battery life and secure networking. ZigBee gives effective ways of supporting of QoS (Quality of Service), functionality and manageability, because ZigBee devices can transmit data over long distances (more than 100 meters) by passing data through a mesh network of intermediate devices to reach more distant ones. In this paper is proposed a simulation framework for ZigBee technology. It implements modified algorithm for the construction of a priority-based and energy-balanced WPAN network and visualize the method of transmission. The results of the conducted experiments are given.*

Introduction

The developed Wireless technology ZigBee by ZigBee Alliance, Developed by ZigBee Alliance Wireless technology ZigBee, complying with standard IEEE 802.15.4 [1], is designed to create a wireless network, based on devices with low power in the area of wireless control and monitoring. The ZigBee specification is publicly available for non-commercial purposes. The membership in the ZigBee Alliance at primary level (Adopter), provides access to unpublished specifications and gives permission to create a commercial market products, using these specifications.

ZigBee protocols apply to embedded systems with low power consumption and requiring low transmission speeds. The resulting network of devices is also very low energy intensive, as each device must have a battery life of at least two years to pass ZigBee certification. Typical applications are home entertainment systems, management and control systems (lighting, temperature control, connection between devices, security, music and video applications – QIVICON), wireless sensor networks (Telosb/Tmote and Iris), production control, built-in sensor systems, fire detection systems, security system, buildings automated systems, etc.

In a large-scale IEEE 802.15.4/ZigBee networks with their beacon-enabled mode achieve flexibility, but in the standard some imperfections are observed when the formation of a balanced network is created and collisions occur during transmission. Especially clear this problem has reflected in a tree architecture with several coordinators, where devices generate the beacons, to provide local synchronization of connected components (children), because in this architecture the possibility of occurence of beacon collisions – direct and indirect is increased. IEEE 802.15.4 standard does not support mechanism to avoid them, but IEEE 802.15.4b Task Group offer some solutions and improvements [2]. These suggestions are basic approaches, which are not very well detailed yet. Other approaches [1,3,4] partitialy avoid the problems with direct and indirect collisions. A simulation environment for the study of such approaches is offered based on OPNET [5], but from 2012 it became part of Riverbed and provides a paid version [6]. The lack of widely available simulation environment requires developing of custom solutions for research and testing approaches to solving the problem of direct and indirect collisions in ZigBee technology.

Nature of the ZigBee Technology

ZigBee technology works on the physical layer of the network and the MAC sublayer of the link layer defined in the standard IEEE 802.15.4. It is for wireless networks with low speed. The specification includes four additional key components: the network layer, application layer, ZigBee device objects (ZDOs), and application objects defined by a particular manufacturer that allow customization and integration. ZDOs are responsible for a range of tasks such as monitoring roles, manage requests for inclusion in the network, visibility of devices and security functions.

The ZigBee network is realized with three types of devices:

- ZigBee coordinator – it forms the root of the network tree and it can be a bridge to other networks. In the ZigBee network there is only one coordinator, as this is the device which initiates the network. The coordinator stores information about the network, including working as the center of defense responsible for spreading the protective keys. ZigBee LightLink specification allows the operation of the ZigBee network in case without coordinator, especially in consumer products for the home ZigBee network.
- ZigBee router – it can serve working application and it transmits data across networks and devices.
- ZigBee end device – it communicates with parent node, but it cannot transfer data from other devices.

The basic topology of ZigBee networks are presented in the standard IEEE 802.15.4 and they are a star (*figure 1*) and peer-to-peer.

Third topology – cluster-tree topology (*figure 3*) could be considered as a special case of peer-to-peer topology. The tree and mesh networks (*figure 2*) allow the use of specialized routers to expand the topology of the network layer.

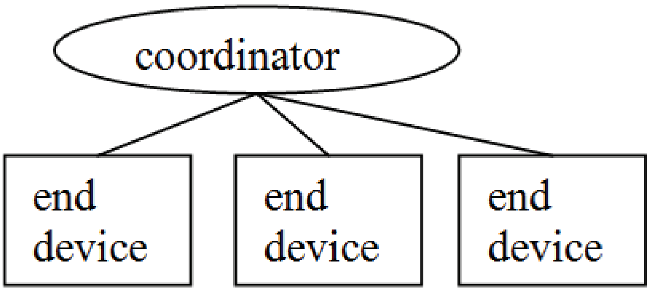


Figure 1. ZigBee star network

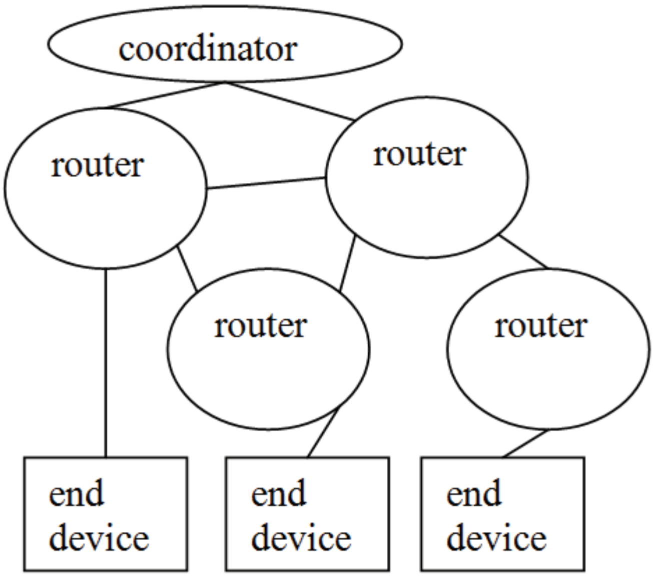


Figure 2. ZigBee mesh network

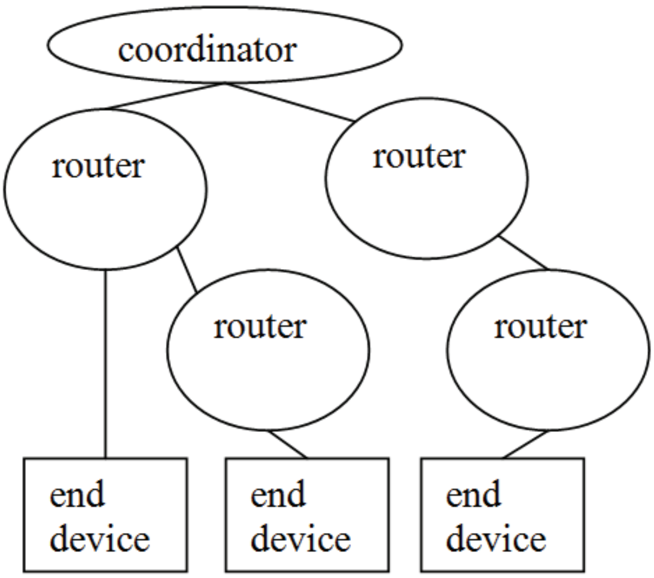


Figure 3. ZigBee cluster tree network

In this approach is investigate only this complicated topology – cluster-tree topology.

Related Works

One approach to solving the problem of direct collision is Time-Division approach [1], in which each coordinator selects the start time Beacon_Tx_Offset to transmit their beacon frames and Superframe duration during the sleeping period of rest coordinators. Before sending of beacon frames, the coordinator must obtain Beacon_Tx_Offset from their neighbors and their parents and then choose different from them. The limitation of this approach is that it requires short cycles of operation and direct communication between similar devices is not possible. Moreover this method requires each coordinator to wake up in your own active period and the active period of its parent.

Another approach is the Beacon-Only Period, presented in [7], where Superframe structure for each coordinator begins with Beacon-Only-Period, where the beacon frames of different coordinators sent it without conflict. Each coordinator selects sending time offset- Contention-Free Time Slot. Thus beacon frames do not compete with those of neighbor devices. In this case, all the active periods start at the same time, which allows the communication between non-terminal devices from different nodes. Also, unlike previous decision, there is no limit for working cycles. The main limitation of this approach is the lack of implementation presented in detail to make it practical easy to implement. Another difficulty is how to measure Beacon-Only Period.

Proposals to solve the problem of indirect collision are presented in [3]. One of them is Reactive method which is easy to implement. The coordinator does not apply any special procedures to avoid indirect conflict for associative stage. If such collision is detected, the device attempts to resolve it. In this method it has much time to resume normal operation. But Proactive approach deals with collisions during associative stage. During the connection, the coordinator seeks to avoid indirect collision, gathering specific data to characterize the transmission of beacon frames of its neighbors. In this method each device (router or end device) must have the ability to transmit time information for beacon frames from its parent to its neighbors. This approach is complicated to sort table from neighbor coordinators, because they need frequent updates, but it eliminates the possibility of developing an indirect collision.

Modified Algorithm for ZigBee Priority Based and Energy Balanced Network

If the network is formed in order of inclusion of devices without considering the priority or level of energy, an example topology will look as shown in *figure 4*, where routers are presented as a circle. Their priorities are as follows: Router 4 is with low level of energy, and Router 1, Router 3, Router 6 and Router 7 are with high level of energy. The end devices are presented as square. Their

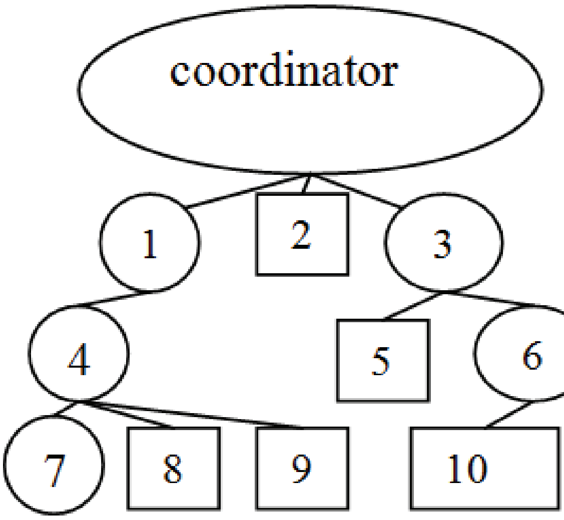


Figure 4. Connecting the ZigBee network in order of their inclusion

priorities are as follows: Device 5 is with high priority, and Device 2, Device 8, Device 9, Device 10 are with low priorities.

The current aproach offers a modification of algorithm proposed in [4]. To be implemented and evaluated the proposed algorithm is designed a simulation environment. The basis of the proposed algorithm stands method of pricing based on which builds effective energy-balanced prioritized tree structure of ZigBee devices.

In this method it is assumed that routers only serve to build the topology and do not work as end devices. Each device (end device or router) has a field *payment* (paying ability). This field in the end device keeps a priority and in the router this field keeps its energy level. Coordinator and routers also have field for cost (charging rate). Other devices pay this cost to connect to them. Therefore, when the current paying ability of the end device is higher, then it has higher priority. When this device is router, the higher value of paying ability means the higher energy. According to this fact, this router must be attached to a lower level in the network tree because it will be able to serve more devices.

When the end device has a larger current paying ability than the paying ability of its parent candidate, it binds to it, changing the paying ability using formulae (1).

$$(1)\; p(t+1) = p(t) + \frac{1}{(k+1)(m_{en} - p(t))}$$

where p(t +1) is new paying ability, p(t) – old paying ability, k – number of children- end devices in step t, m_{en} – cost.

In this modified algorithm first connect routers in the network tree to be able to build a network, then the end devices connect to them. When connecting the router to router, or router to the coordinator, the cost of the parent does not change. In the case when the device is with a sufficient current paying ability, it is connected to the router who has the smallest number of children. The proposed algorithm for sorting of devices in ZigBee network is presented in *figure 5*.

Then after the implementation of the proposed algorithm for the same devices in *figure 4*, ZigBee network changes as shown in *figure 6*.

Implementation

In this approach a simulation environment was established for implementation and exploration of the proposed algorithm. Used software tool is Visual Basic 2010. A database for storing data from individual experiments for each coordinator and its connected devices is created.

Thus, the input of data for each device starts from initial parameters for the coordinator. This is represented in the example of *figure 7*. Another coordinator (the next in the order) receives serial number. After that the user must type the number of ZigBee devices that will participate in the network of this coordinator, according to the limits imposed by the standard. The choice of bandwidth (868 MHz, 915 MHz or 2,4 GHz) sets limits in the cell radius of the coordinator and the transmission speed (bandwidth).

The tabular presentation of coordinators and the information for devices (*figure 8*) is suitable for displaying of multi aspected information that can be edited (*figure 9*).

Information about the devices and their location after applying of the algorithm for prioritization and established tree topology is displayed in tabular form (*figure 10*).

According to Beacon-Only-Period approach with collisions avoidance, the construction of the tree topology of ZigBee network Parents and children are determined by comparing of their active periods (SuperframeDuration). If a child has higher priority than parent, it gets parent's active period. The timeline visualizes the transmission of packets with Beacon-Only-Period method to avoid direct collisions. The diagram (*figure 11*) shows the number of active periods required from end devices to send the entered number of packages. For this purpose, it is taking into account the transmission rate of the coordinator, the size of the active period and the number of packets of the end device, and then it is calculated the time required for transmission. This time is divided by the duration of the active period of the device and provides the number of active periods required for the transmission of the requests of individual devices.

Experimental Results

The performance evaluation of the proposed algorithm is made based on a comparison with the evidence presented in [7] results for traditional building topology of ZigBee network. To infer the number of collisions occurred it is monitored average speed of transmission of packets of varying lengths of transmission via ZigBee network created by the classical method and the method of pricing. In both cases the ZigBee network consists from the same devices

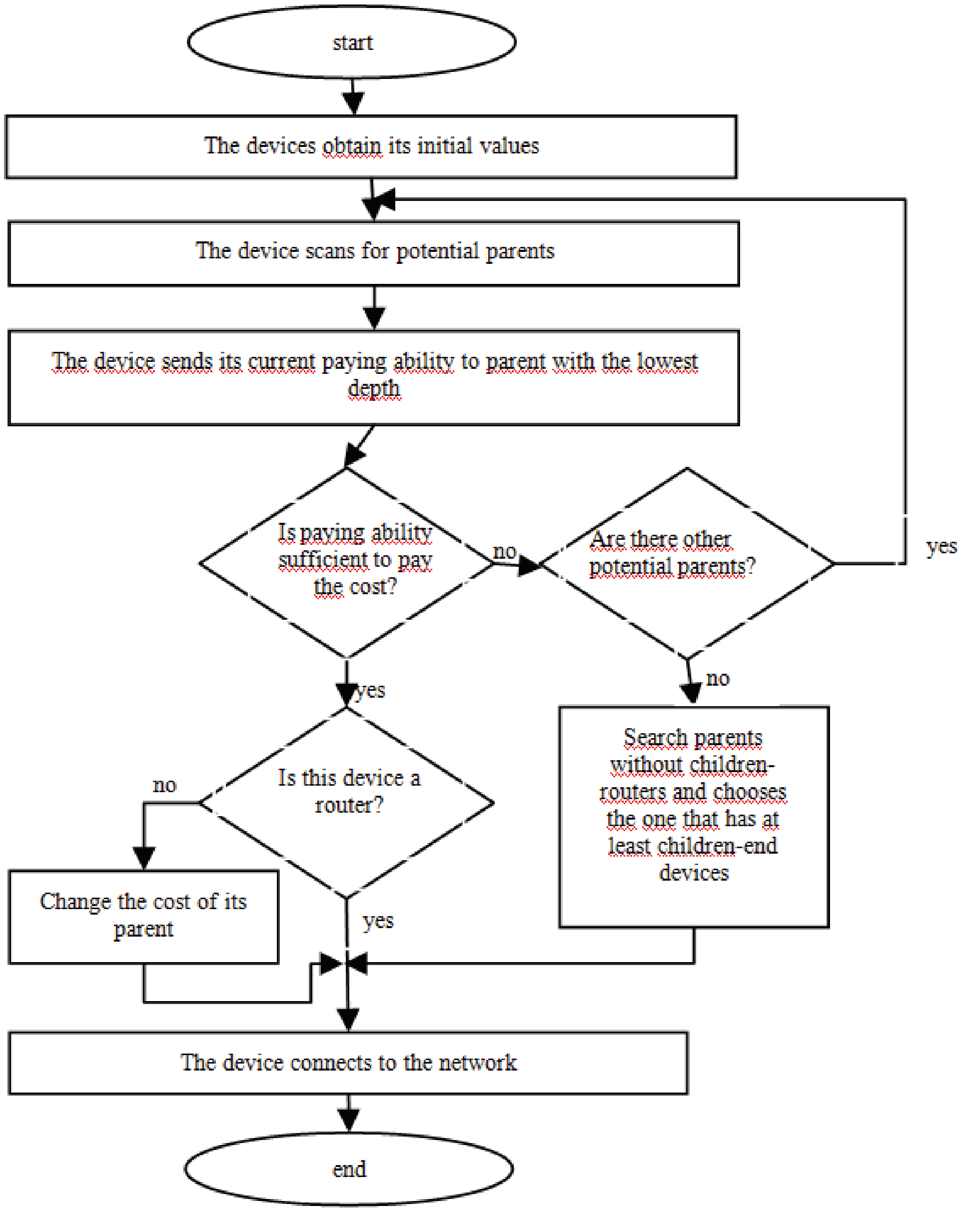


Figure 5. Algorithm for sorting devices in ZigBee network

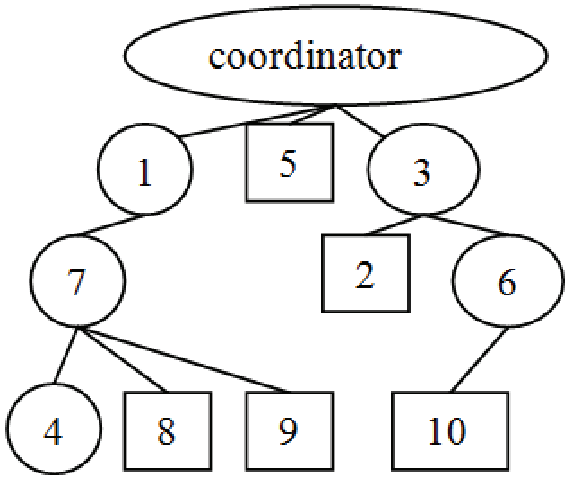


Figure 6. Connecting the ZigBee devices on the network using the algorithm based on cost

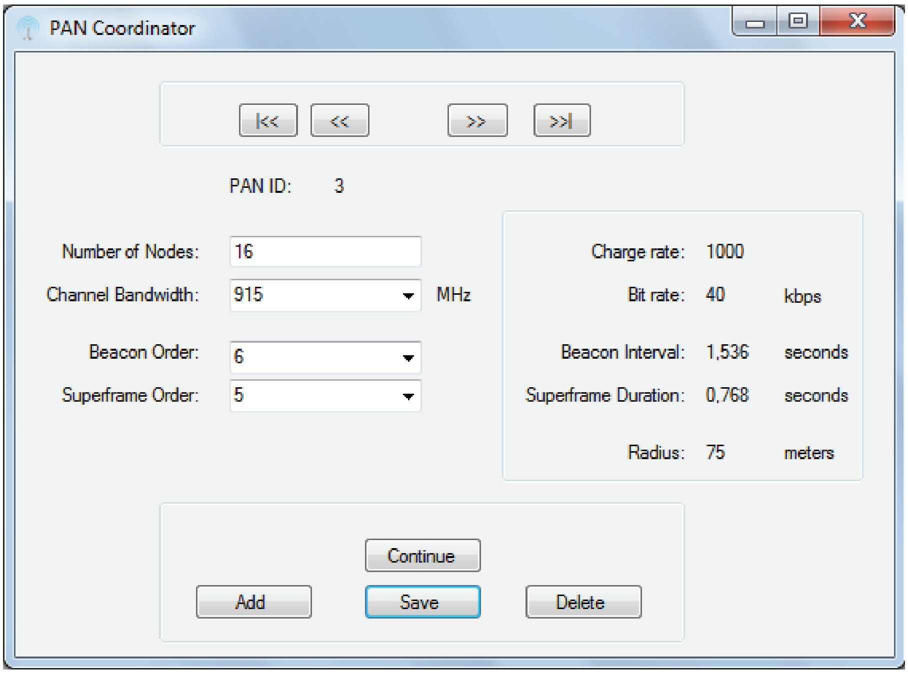
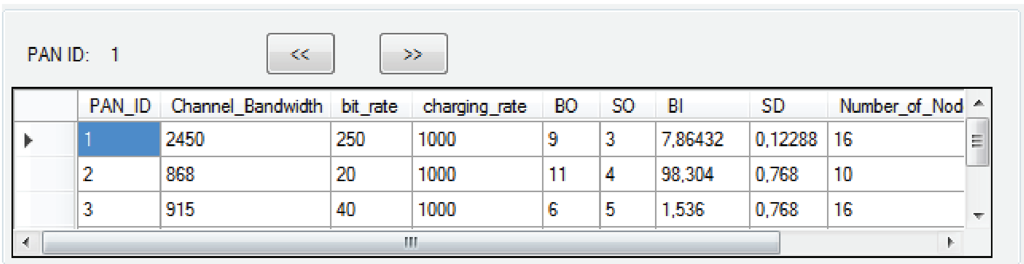


Figure 7. Form about input of the parameters of coordinator



PAN_ID	Channel_Bandwidth	bit_rate	charging_rate	BO	SO	BI	SD	Number_of_Nod
1	2450	250	1000	9	3	7,86432	0,12288	16
2	868	20	1000	11	4	98,304	0,768	10
3	915	40	1000	6	5	1,536	0,768	16

Figure 8. Database with information of coordinators

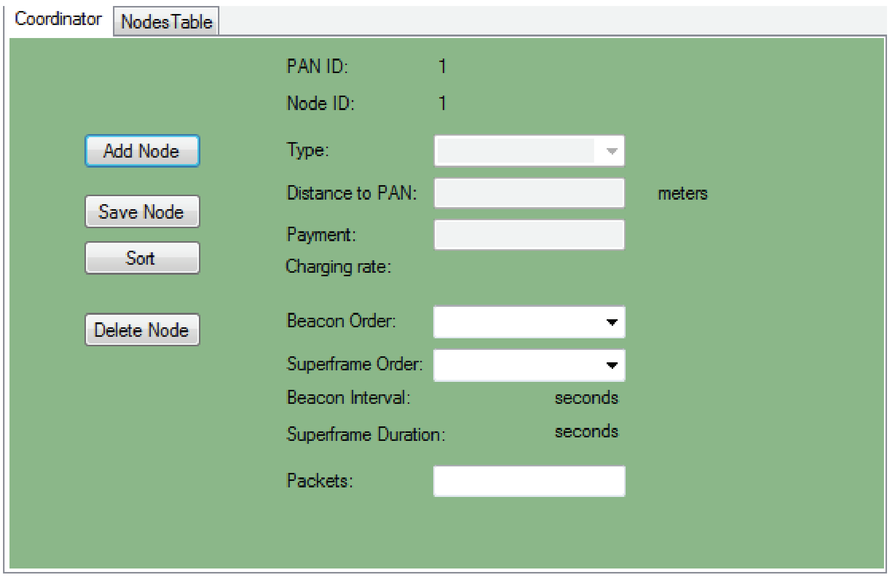
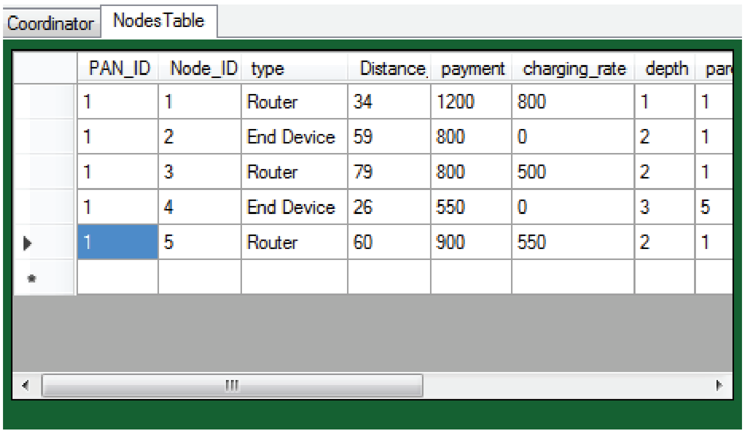


Figure 9. Data of a device, connected to the network coordinator



	PAN_ID	Node_ID	type	Distance	payment	charging_rate	depth	par
	1	1	Router	34	1200	800	1	1
	1	2	End Device	59	800	0	2	1
	1	3	Router	79	800	500	2	1
	1	4	End Device	26	550	0	3	5
	1	5	Router	60	900	550	2	1

Figure 10. Tree topology for root coordinator 1

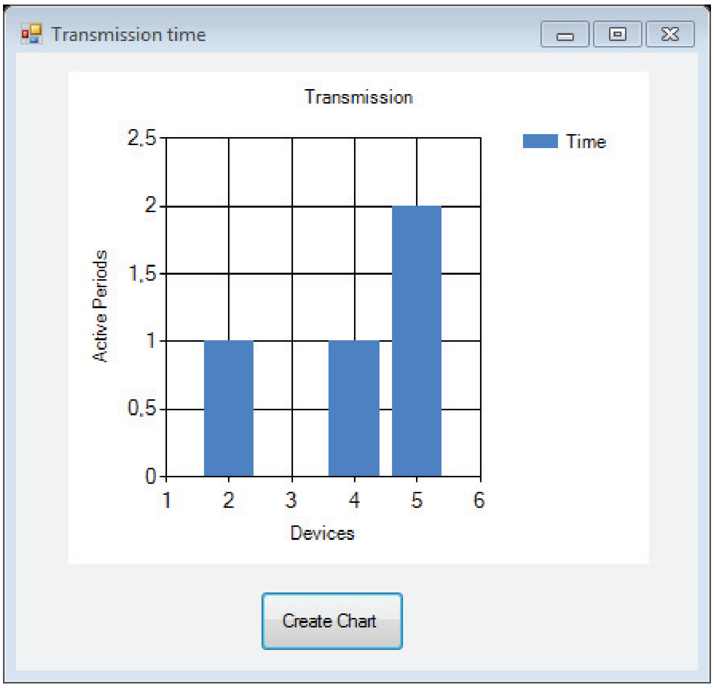


Figure 11. Timing diagram of a packet during active periods of individual devices

with the same volumes of transmitted data. The results are presented in *figure 12*.

There has been improvement in the average rate of transmission in network topology achieved with the algorithm of pricing.

In [7] it is not possible to set a hierarchical topology constructed to have a levels, where are connected end devices. The testing is done only with routers. This simulator offers the possibility to build any real topology, which consists not only with routers and it consists from routers and end devices. To test this topology have been input network data presented in *figure 4* and they are compared with data obtained by a simulation environment that implements the network of *figure 6*. In selected priorities of the devices with respect to the topology of the ZigBee network, it appears that only the positions of device 2 and device 5 are changed, therefore it has compared only their transmission speeds and the results are presented in *figure 13*.

The results indicate that the device with a higher priority (it is connected at a point where collisions are avoided) transmitted with better speed at topology achieved with the algorithm of Pricing, which demonstrates the advantage of the proposed and simulated algorithm.

Conclusion

This paper proposed a modified algorithm for the construction of a priority-based and energy-balanced ZigBee network. The presented algorithm determines the priorities of the devices by the method of pricing, where the priority of the end devices and the energy level of the routers appear as price they are willing to pay. It has created simulation environment for its implementation, which allows visualization of the Beacon-Only-Period method of transmission among devices in ZigBee tree network topology. A

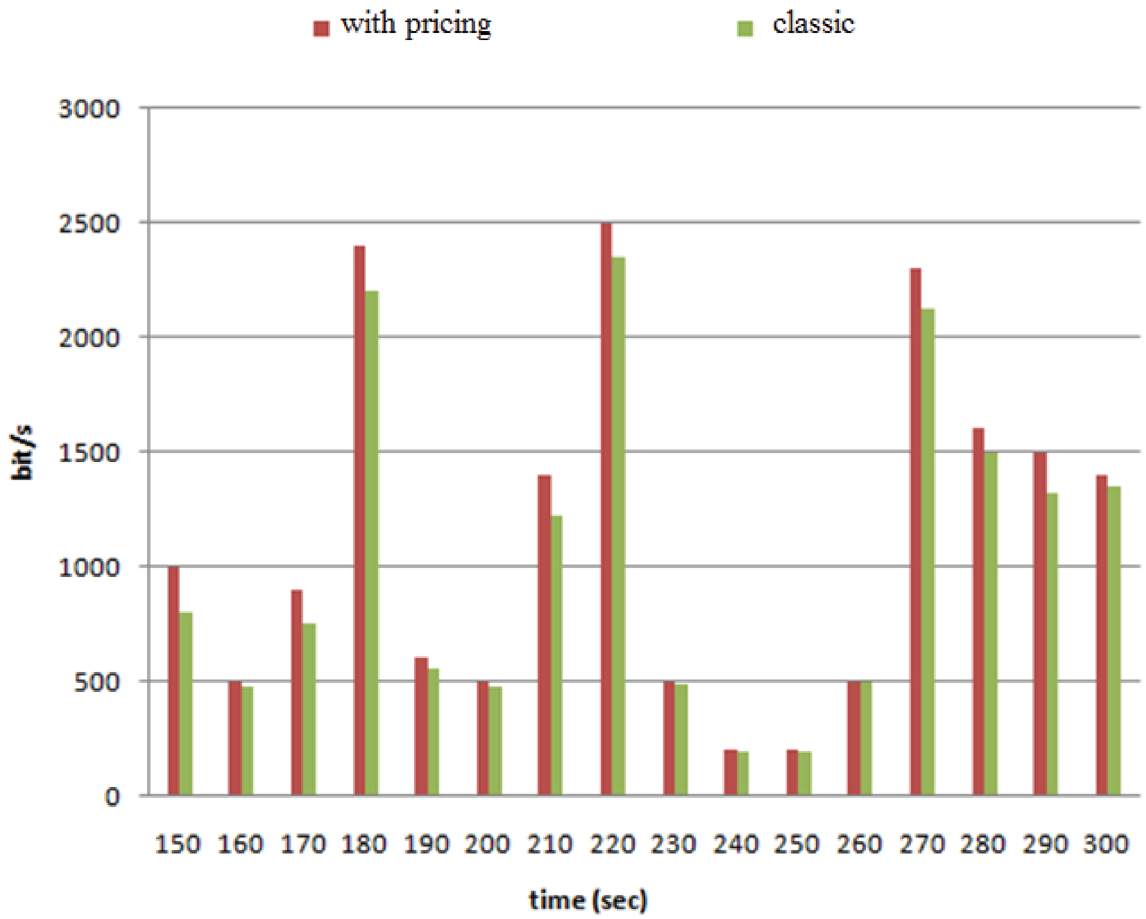


Figure 12. Average transmission speed in the classic method and the method with pricing

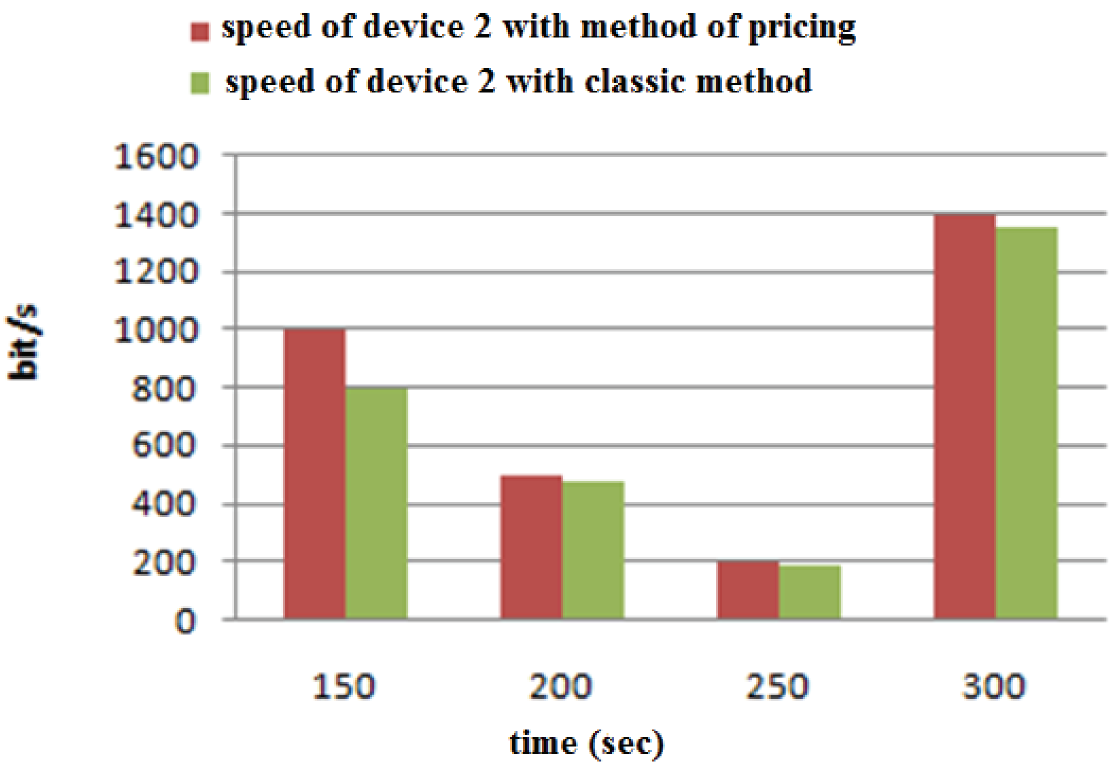


Figure 13. Average transmission speeds of a device in ZigBee network using the conventional method and the method of pricing

comparative analysis of the average transmission rate of packets for varying lengths of transmission via ZigBee network has created by the classical method and the method of pricing. An improvement in average transmission speed in ZigBee topology is observed, when the ZigBee network is created with method of pricing.

The proposed simulation framework for ZigBee can be applied in the MSc discipline of wireless technologies for observing QoS in ZigBee networks.

For further development of the simulation environment will provide implementation of an alternative methods for avoiding collisions at beacon enable mode coordinator and combinations and comparisons amongst them.

References

1. Koubвa, Anis, Al-Imam Muhammad, Andre Cunha, Mario Alves. A Time Division Beacon Scheduling Mechanism for IEEE 802.15.4/ZigBee Cluster-Tree Wireless Sensor Networks. 2007, ECRTS'07, 125-135.
2. IEEE 802.15 WPAN™ Task Group 4b (TG4b), http://grouper.ieee.org/groups/802/15/pub/TG4b.html, June 2016.
3. Koubвa, Anis, Mario Alves, Melek Attia, Anneleen Van Nieuwenhuyse. Collision-Free Beacon Scheduling Mechanisms for IEEE 802.15.4/ZigBee Cluster-Tree Wireless Sensor Networks. http://www.open-zb.net/publications/ASWN2007.pdf, last available 2016.
4. Wang, Jun, Min Chen, Victor C. M. Leung. Forming Priority Based and Energy Balanced ZigBee Networks—a Pricing Approach. Springer Science+Business Media, LLC 2011, Published online: 14 September 2011.
5. IEEE 802.15.4/ZigBee OPNET Simulation Model. http://www.open-zb.net/wpan_simulator.php, November 2009.
6. Riverbed modeler. http://www.riverbed.com/gb/products/steelcentral/steelcentral-riverbed-modeler.html, June 2016.
7. Benakila, Mohammed. I., George Laurent, Smain Femmam. A Beacon Cluster-Tree Construction Approach For ZigBee/IEEE802.15.4 Networks. UBICOMM 2010: The Fourth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies.

Manuscript received on 11.11.2016

Veneta Aleksieva *received her PhD in Computer Science from Technical University of Varna, Bulgaria in 2012. She is currently Associate Professor at the Department of Computer Science, Technical University of Varna, Bulgaria. Since 2002 she is Instructor in Cisco Networking Academy Program. Her current research interests include computer networks, MPLS networks, 4G, network security.*

Contacts:
Technical University of Varna
Department of Computer Science
e-mail: valeksieva@tu-varna.bg