ORIGINAL ARTICLE

Implementation of Multichannel Technology in ZigBee Wireless Sensor Networks in Nodes Wake-up Mode

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Abstract: In wireless sensor networks, multiple channels are used to send parallel data to decrease interference. Low power and high reliability are among the features of multichannel technology in terms of wireless sensor network. Zigbee is a technology based on IEEE 802.15.4 standard which is designed a class of high level communication protocols, and it is used by small, low consumption digital radios for making personal wireless networks for such usages as home automation, data gathering from medical devices, and other needs with narrow band width for small projects requiring wireless communication. Reducing energy consumption, improving operational power, increasing correct packet sending rate, and delay are some issues related to the usage of multichannel technology. Therefore, in the proposed method using multichannel technology in ZigBee wireless sensor networks with state of nodes wake-up, it is attempted to resolve the aforementioned issues. The simulation results show that the proposed method decreases the delay, improves the operational power, and reduces the energy consumption.

Keywords: Multichannel Technology; Nodes Wake-up; Wireless Sensor Networks; ZigBee.

Introduction

A wireless Sensor Network (WSN) includes a spatial distribution of hundreds or thousands nodes, participating in monitoring the environmental or physical situation and gathering data. In fact, these nodes are capable of gathering data from their environment which is impossible to collect through other ways, or it takes so much time and requires high costs. In the wireless sensor networks, the integrating data method is used to reduce the transmitted traffic. Many proposed routing protocols exploit the method to decrease the data transmission energy [1]. The nature of wireless sensor networks mostly used in harmful and remote environments affects the quality of data transmission. Therefore, their packet error rates are variant and high (up to 40%) [2]. In data integration, the sensing data gathered by the sensor nodes are combined based on the data integration algorithm, and the integrated data is transmitted to the central station. Reliability and energy saving must be compromised. There are various strategies for data integration which are generally categorized in four classes as centralized methods, inter-network integration, tree-based methods, and clustering-based methods [1].

ZigBee technology in IoT is useful for the applications which use batteries, and their main requirements are low transmission rate, low cost, and prolonged battery life. In most applications, the total time of the wireless device engagement in an operation is short, and it is mostly in the power saving mode also referred to as sleep mode. Hence, ZigBee devices are capable of working continuously with no need to change the battery [3]. In the conducted researches in terms of using multichannel technology in smart houses, some of the communication protocols including ZigBee have been studied. Considering the results obtained from the studies, it seems that the Z-Wave as a proper standard with high security and narrow band width is appropriate for smart houses. In the proposed scheme, the goal is providing a conceptual model for a smart house by using multichannel technology.

For the objects in a smart house, a specific IP address based on the Z-Wave communication protocol is considered by which individuals can be informed about the house circumstances at any time by their tablet and or cell phone. Analyzing the results from implementation, it is attempted to provide a conceptual model with more effective energy consumption compared to the other available models. The devices equipped with smart counters by establishing bilateral communication transmit the information of consumption loads to the power supplier unit; thereby, it allows managing the network and response to the consumption load [4]. On the other hand, the informed consumer is able to change the consumption tariff. Considering the importance of consumption energy management and control in smart houses, in this research, the objective is to study the situation of consumption energy in smart houses by using Z-Wave communication protocol. The proposed implementation method investigates the multichannel technology in the ZigBee wireless sensor networks in the nodes wake-up mode.

Theoretical Fundamentals

Applicable Specifications of Multichannel Technology

In the conventional wireless sensor networks, only a single channel is used for the network. In this type of networks, capacity can be increased by exploiting several channels, and the nodes can be equipped with multiple connectors. For the future calculations, data storing and communication will be highly comprehensive and distributed. Multichannel technology applications are related mostly to green information and communication technologies. As the multichannel technology, guidance applicable plans with effective energy, smart grids, connected electric cars, and effective energy buildings can be mentioned; consequently, they help to construct green smart cities. Moving away from the hierarchal region, shifting from closed to open systems, and acting based on the open APIs and standard protocols in various systems levels are among very important factors for multichannel technology success [3].

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Smart Energy and Smart Network

There are several reasons that energy supply in the future must not be relied upon fossil resources. In the future, energy is mostly supplied by various renewable resources. Energy consumers' behaviors should be focused increasingly. The nature of demands requires supplying a smart, flexible power grid with capability of responding to power swings and its losses through controlling electric energy resources. Such an application relied upon the smart networked devices (home appliances, micro generation equipment, infrastructures, and sellable products), and network infrastructures mostly are based on the multichannel technology principles [5].

The smart network is expected to implement a type of "Internet" in which energy packages are managed like data packets throughout routers and gates, to decide autonomously, and to choose the best route to their destination with the best integration level. In a smart network, the scenario of energy consumption with a volatile energy price acquired from momentary demands is fulfilled sophisticatedly by smart counters, and the available energy and renewable energy generation. In a virtual energy market, software agents may interact with the power companies about the energy price and order. These circumstances must be in a very proper time scale and with capability of spatial separation. In long term, electrical mobility will become another important element for smart power networks [5].

Information Management

The long-term opportunity for wireless communication chip manufacturers and emerging M2M calculations are raised from technology activation for multichannel technology. Some of the relevant principles which help to understand the challenges and opportunities of data management are: data gathering and analyzing, big data, meaning sensor networking, communication and virtual sensors, complicated processes events. The largest challenge is that all of the data with the size of petabyte cannot be stored, but it must be understood. Companies focused on big data such as Google and facebook have chosen the cloud distributed approach and open source systems [6].

Reliability of Multichannel Technology

Applications and services in the multichannel technology scale throughout executive areas are complicated and relevant, including multiple ownership organizations. They require a reliable framework for system users to exchange the reliable information and services: Lightweight Public Key Infrastructure (LPKI) as a base for trust management, lightweight key management systems [7].

Background

Helmi in the thesis (2016) studied the association rules extraction by using artificial security system. In the project, an algorithm based on the artificial security system was designed, implemented, and assessed in order to extract information from the data of the web access. The results from the proposed algorithm indicate the validity of predictions about AIS results proportionality as a pattern for solving the problem of finding the repeating items set in the data of web access [8]. Developing a novel security system based on RFID, the authors in [9] attempted to decrease the accessibility of data. Exploitation of the multichannel technology in factories and industrial centers is the authors' main objective of using it. Also, in this paper, the former methods proposed for improving data privacy in the multichannel technology are studied extensively. The proposed system is applicable in the wireless sensor networks, mobile and wireless networks. Asha et al., [10] investigated the problem of exploitation of multichannel technology in the electronic health systems. There are many challenges for providing a proper base. However, the paper is focused on the data privacy and steganography in the multichannel technology for electronic health. Various standards are studied in the paper, and finally, a novel framework is proposed for the problem being studied.

Proposed Method

Overall description

The effect of lost packets due to instability of the wireless sensor networks in the multichannel technology was extensively analyzed. Each lost packet must be resent; thereby, sending is delayed and more energy is consumed. Although the problem of lost packets exists in the ZigBee, its effect on the proposed method is different. In the multichannel protocol, the nodes set their sleep time based on the interval of the packet entrance. When a data packet has to wait a long time to be received, ZigBee speculates that the traffic is heavy and reduces the node's sleep time. Now, more time and energy are spent and assumed to receive the data packets. In this case, the competition on accessing the channel is more severe, increasing collisions and deteriorating the network situation. Poor situation of the wireless sensor network causes to loss the data packet and to decrease traffic load. Now, the nodes decrease their sleep time, increasing energy loss. However, in the proposed protocol, nodes set the wake-up time adaptively based on the number of the received data packets. The receiver increases the wake-up time because it has not received data packets for a long time, and this saves the waiting time. Due to packet loss, the receiver does not receive the packet for a long time, and this indicates that the network situation is not appropriate for communicating. Therefore, the receiver increases the sleep time to save energy and prevent the congestion in the channel. The ZigBee protocol copes with the packet loss by decreasing sleep time for sending the data packets by which the energy is more consumed, the situation of network deteriorates or even it will be disabled. In terms of network situation improvement under data loss in the heavy traffic load, the multichannel protocol outperforms the single channel protocol. Hence, the multichannel technology is used to solve the problem although the average energy of the network increases. Finally, the multichannel technology indicates that the network is formed as a continuum, and that the dead nodes are removed. Nevertheless, the energy consumption throughout the network increases.

System Model

To achieve the energy efficiency, most of the ZigBee protocols have used periodic sleep and wake-up mechanism for communicating senders and receivers. To reduce the delay, in the sleep mode, the nodes are tuned in a form that the predicted sleep time of the cycle could be added to the authentication packets. In this research, the wireless sensor networks model was used. The nodes in the identified region are distributed randomly and densely. It seems that the wireless sensor network is connected. The resource nodes are not limited by the data for transmission, but the wake-up time of the nodes is adjusted adaptively and according to the received data. To save the energy, when a node wakes up, it samples the channel, and decides whether it is idle.

Protocol Design

In many applications, ZigBee protocols outperform the single-channel ones in terms of throughout delay, energy efficiency, and traffic performance. In ZigBee, nodes according to the received data adjust the sleep time adaptively, and insert the wake-up time of the next task in the authentication packet, reducing the delay and saving the consumed energy by sending the indication packets. In the proposed protocol, the nodes are shifted periodically between active and sleep modes.

Wake-up time

The total waiting time for the resource node A before sending data packet is given by Eq. (1) [11].

$$T_{(A,B)}^{wait} \leq \sum_{i=0}^{n}(t_s^i + t_a^i) = (n+1)(t_s + t_a) \quad (1)$$

The sending time of a data packet is obtained from Eq. (2) [11].

$$T_{data} = t_d + t_a \quad (2)$$

According to Eq. (1) and Eq. (2), the total time for sending a data packet is shown with T_{data} which is determined by the following relation [11]. In the relation, T_{one} shows the single-channel delay.

$$T_{one} = T_{A,B}^{wait} + T_{data} \quad (3)$$

$$T_{listen} = t_D + t_s^l + t_e \quad (4)$$

T_{listen} presents the receive and decoding time of an indication packet.

Sleep time

In the multichannel protocols, the nodes usually choose their sleep time according to a random choice mechanism in the interval $\left[T_{sleep}^{\min}, T_{sleep}^{\max}\right]$. Here, $T_{sleep}^{\min}$ and $T_{sleep}^{\max}$ indicate minimum and maximum of sleep time, respectively.

ZigBee energy consumption

The energy consumption relation in each mode is expressed as $e_s < e_w < e_l < e_t$ [11], where T_{sleep} and T_w indicate minimum node sleep time and switching time from sleep to wake-up mode, respectively. A constant value is determined for T_w.

$$T_{sleep}e_s + T_w e_w \leq T_{sleep}e_1 \quad (5)$$

$$T_{sleep} \geq \frac{T_w e_w}{e_1 - e_s} \quad (6)$$

Dynamic sleep time determination

Before turning to sleep mode, the node calculates the spent time for the data packet receiving [12].

$$T_{sum} = T_{one} \times n \quad (7)$$

Total time and the resting time of a work cycle are shown by T and T_{rest}, respectively.

$$T_{rest} = T - T_{sum} - T_c \quad (8)$$

When a node samples the channel, and understands there is no data to send, then it returns to sleep mode [11].

$$T_{sleep}^{max} = T - (t_D + t_s^l + t_e) = T - T_{listen} \quad (9)$$

Where $T_{sleep} < T_{reset} < T_{sleep}^{\max}$, T shows that the residual time is less than or equal to the minimum sleep time.

Node wake-up

In the ZigBee protocols, nodes choose their sleep and wake-up work cycle independently. However, in a dense wireless sensor network, it is possible when an event occurs, many nodes wake up to sample the data and to send the data packets. To solve the issue, ZigBee inserts the sending time between two communication nodes into the indication packets, and the sleep prediction time into the ACK packet. The prediction time is defined as follows.

$$T_{predict} = \alpha T_s{}' + \beta T_s{}'' \quad (10)$$

where, T_s' and T_s'' are the spent sleep time and the sleep time before the spent time, respectively.

Gathering and application mode

We consider the monitoring applications for data gathering. All of the data packets related to a similar process are considered as a packet of the same content which can be processed by one of the nodes. A generic data gathering model is defined for each node i with process function s:

$$R_i^{out} = \omega_s \times R_i^{in} \quad (11)$$

$$0 < \omega_s \leq 1 \quad (12)$$

where R_i^{in} and R_i^{out} indicate the input and output traffic, respectively. ω_s shows data gathering or amount of compression. Eq. (10) divides data gathering operation and that of proposed algorithm into several rounds. There are two main steps in each round: 1- the first step is network installation. 2- the second step is data transmission.

The proposed algorithm uses multichannel technology with ZigBee protocol, and it finds a rout and the optimal clustering for the network. This causes the proposed algorithm be centralized. In the first phase, all of the existence nodes in the sensor network and gates send the information related to the location ID in the network and the residual energy to the sink. This information is sent by CSMA/CA protocol in the MAC layer. After completing the phase, all of the information related to the existence nodes in the network are in the sink, and it can perform the routing and optimal clustering algorithm.

Results Analysis

Network Model

In this study, 201 sensors in a space of 100*100 m^2 are placed randomly. The center of network is considered as the information receiving server from multichannel technology sensors at the point of (50*50). First, to obtain the optimal consumption energy it is assumed that each sensor acts ideally with no loss of information with an infinite energy resource (battery). Figure 1 shows formation of nodes for a sensor based on the multichannel technology information.

The most generic mode of network

In the next step, the most generic mode of the network is formed in which each node is connected to n-1 nodes, as shown in Figure 2. The centric network is depicted very dense by MATLAB software. It is clear that such a network structure contains a heavy traffic in each node. On the other hand, its energy consumption is very high. Also, the energy consumption for transmission process and receiving each energy byte are summarized as a reference in Table 1.

Because the nodes locations are chosen randomly, each node's average energy consumption was calculated in 200 iterations in Figure 3. Clearly, the energy consumption in the network is so high.

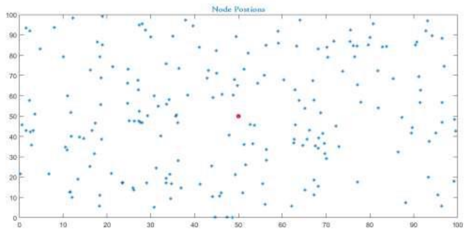

Figure 1. Sensors locations

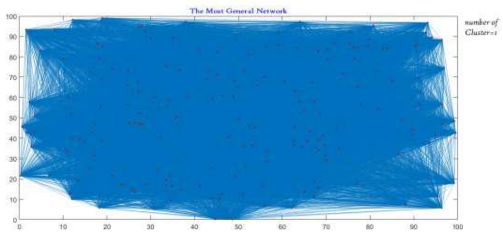

Figure 2. The most generic network for 200 nodes.

Table 1. Energy consumption for each byte

Type of energy	Value in μj
Send	9.72
Receive	8.22
Process	0.76

The simulation area is 2D with size of 500m*500m where the sink is placed in the center. The number of sensors and gates varies, and different values are inserted in various simulations. The simulation parameters values are summarized in Table 2.

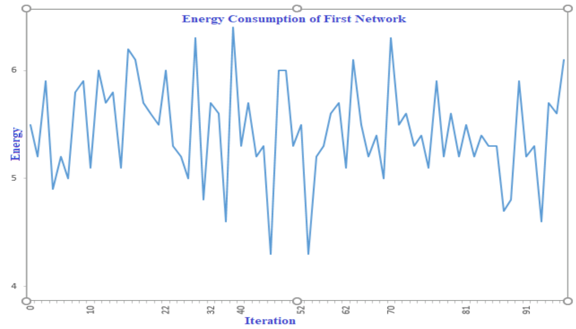

Figure 3. Average energy consumption in each iteration

In this simulation, the sink is located in the center, i.e. in the coordination (250, 250), and it is static, meaning still.

Table 2. Simulation parameters

Definition	Value	Parameter
Number of sensor nodes	200-700	N
Number of gate nodes	60-90	M
Initial energy of each sensor node	2J	E_0
Initial energy of each gate node	10J	E_0'
Radio range of each sensor node	150m	R_0
Wasting energy to run radio tools	50 nJ/bit	E_{elec}
Amplifier empty space model	10 pJ/bit/m2	ε_{fs}
Amplifier multi-path model	0.0013 pJ/bit/m4	ε_{mp}
Data package length	4000 bits	L
Control package length	200 bits	L_c
Distance threshold limit	$\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$	D_0

Messages Used in Simulation

The list of messages used in the simulation is summarized in Table 3.

Simulation Results Assessment

To calculate the number of received packets, simulation is run in accordance with the number of different gates; then, the received packets number by the sink is calculated. Figure 4 shows the received packets number by the sink.

It can be said that for the problem of ZigBee routing algorithm, the gate nodes choose better Next Hop in which the number of received packets are more than the single channel algorithm. The next important parameter, measured for assessing the algorithm performance, is the energy consumption in the wake-up mode. The energy consumption is summation of total energy consumption for all of the sensor and gate nodes expressed as follows:

$$Energy\,Consumption = \sum_{i=1}^{N} energy\,consumption(s_i) + \sum_{i=1}^{M} energy\,consumption(g_i)$$

Table 3. List of the messages used in the simulation

Definition	Massage
By this message each node in wake-up mood communicates its own information to its neighbors	Send info
By this message each node in wake-up mood sends information about itself and its neighbors to the sink	Info_for_sink
Sink transmits the results of executing routing and clustering algorithms using the Zigbee protocol with this message to the nodes	BroadcastResult
The headers send information to their member sensor nodes, which sends a message between the cluster member nodes to send information to the header	TDMA
Local data collected by sensor nodes is sent to the header in the form of this message	Datapkt

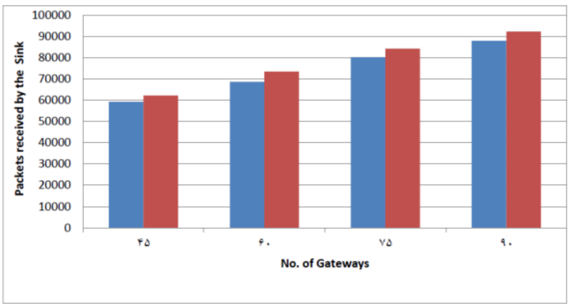

Figure 4. The received packets number by the sink

The number of gates and sensor nodes are set 60 and 500, respectively, and the simulation is performed. Consumption energies of three algorithms in Joel are shown in Figure 5.

Energy consumption in ZigBee is less than single channel because of choosing more optimal cluster heads and NextHops for gate nodes. When the cluster heads are chosen more optimal, it means that the sensor nodes do not need to send their data much far away to reach the cluster head; thereby, less energy is consumed. When a more optimal NextHop is chosen for a gate, the number of steps required to send information from cluster heads (gates) to the sink is decreased, declining the energy consumption.

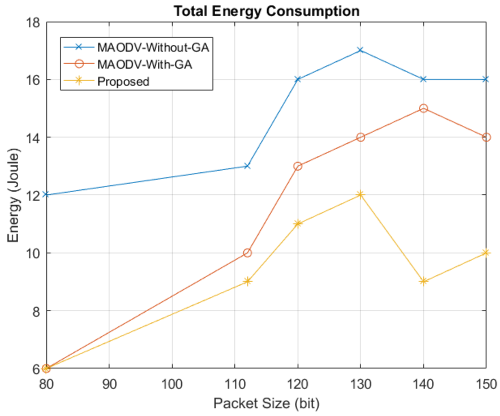

Figure 5. Energy consumption throughout network

The next parameter to assess the algorithm is the network lifetime. The lifetime is calculated based on the rounds number, and the variable is the sensor nodes. Figure 6 shows the algorithm lifetime for 90 gate nodes versus the round.

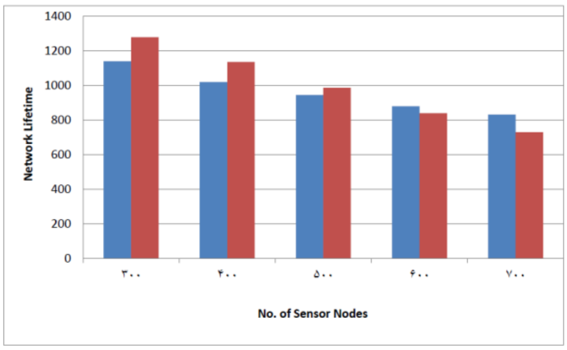

Figure 6. The network lifetime

When the senor numbers are 300, 400, and 500, the ZigBee algorithm has a better performance. For 600 and 700 sensor nodes, the single channel algorithm has a more prolonged lifetime. The result is that using the proposed algorithm in this research for sensor networks with size of 500 sensor nodes or less prolongs the network lifetime compared to the single channel algorithm.

The next test is related to the number of the dead nodes versus rounds. In a simulation, the numbers of sensor and gate nodes are set 400 and 90, respectively. The way of dying sensors and gates nodes is shown in Figure 7.

In the energy consumption diagram, it is clear that the single channel algorithm consumes more energy. Therefore, more nodes finish their energy, and there are more dead nodes in the ZigBee algorithm. Table 4 summarizes the precise number of dead nodes in the two algorithms.

 https://doi.org/10.5875/ausmt.v12i1.2310

Comparison of Power and Delay

In Figure 8 and Figure 9 , operational power and the number of lost packets for the three protocols MAODV - without – GA, MAODV - with – GA, and proposed method are compared by increasing the number of nodes from 10 to 50.

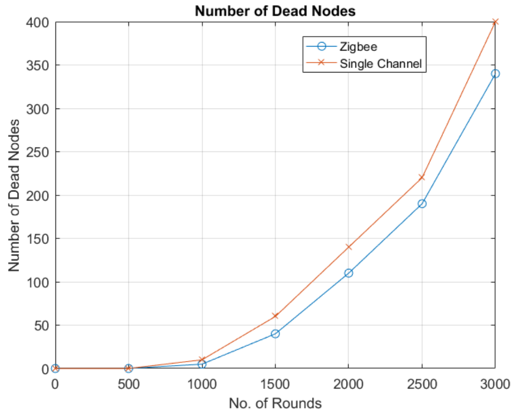

Figure 7. The number of dead nodes

Table 4. The number of dead nodes in each round.

No. of Rounds	Single Channel	Zigbee
0	0	0
500	0	0
1000	5	3
1500	56	41
2000	135	112
2500	220	193
3000	398	350

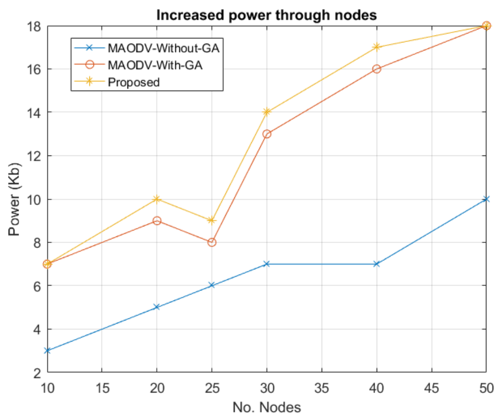

Figure 8. Power by increasing the number of nodes

Figure 10 compares the transmission delay of protocols of Lin et al., (2017), Basaran et al., (2016), and the proposed method by increasing the number of nodes. According to the figure, as the nodes increase, the proposed method has higher permeability than the two aforementioned methods.

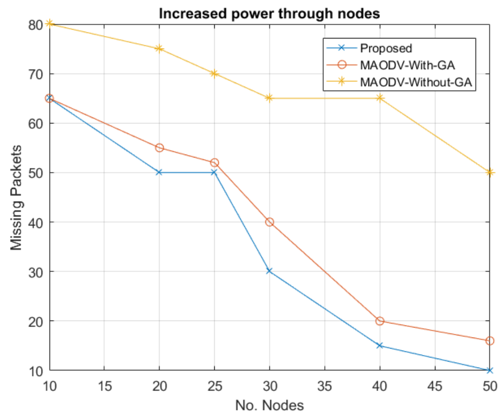

Figure 9. The number of lost packets by increasing the number of nodes

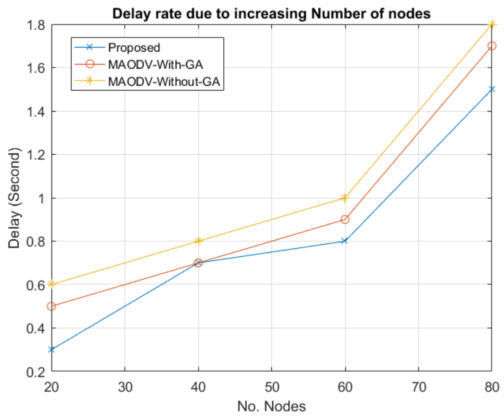

Figure 10. Delay by increasing the number of nodes

Conclusion

In this research, a novel framework was proposed for the optimal routing in wireless sensor networks by using the multichannel technology. The objective of the proposed method is to find an optimal route with appropriate performance. The proposed algorithm was implemented with different parameters and the related diagrams were presented. The proposed approach was compared to the two protocols of MAODV - without – GA and MAODV - with – GA in terms of operational power and the number of packets, and it showed more proper.

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