ORIGINAL ARTICLE

Implementing Multi-Channel Technology in Node Sleeping Mode of ZigBee Wireless Sensor Networks

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Abstract: Using IoT technology, we can intelligently control and manage different parts of a city, industry, and home. One of the important goals of smart homes is to have more control and security in a home. One of the protocols used in IoT applications in smart homes is the Zigbee communication protocol. The Zigbee, as a high security standard, requires low bandwidth for smart homes. In wireless sensor networks, the main reason for nodes failure is their battery drain. Energy efficiency is a critical issue in wireless sensor networks. Therefore, the use of efficient programs and algorithms for optimal energy consumption is the most important issue. In this study, a fuzzy multi-channel media access control protocol is introduced which the sleep times of the nodes as well as the nodes' meeting together are optimized for data aggregation, adaptably and asynchronously. By using multiple channels, it reduces collision and concurrent transmission in the domain of node collision and thus increases the efficiency of packet forwarding rates on the network. A method similar to the AS-MAC method was chosen to better evaluate the proposed method, network structure, and energy consumption model. Simulation results show the effectiveness of the proposed method.

Keywords: Multi Channel Technology; Wireless Sensor; Zigbee.

Introduction

Using IoT technology and web-based or mobile-based applications based on this technology, devices can be integrated in the form of more controlled and under supervised objects into a smart home [1]. The main purpose of this technology is to provide convenience, security, environmentally friendly living and control and management of energy consumption. Smart homes use wired and wireless communication protocols such as WiMAX, WiFi and Zigbee [2]. Data integration issues include Redundancy, Delay, Accuracy and Traffic Load. These can greatly influence the performance of data integration techniques. Inter-network data aggregation is a relatively complex operation that requires inter-node collaboration to achieve better performance [3]. Energy efficiency is a critical issue in wireless sensor networks. Therefore, the use of efficient programs and algorithms for optimal energy consumption is the most important issue in these networks. Data aggregation by eliminating plug-in data can be of great help in reducing this energy consumption and the use of clustering methods to perform data aggregation helps to further reduce energy consumption [4]. Sensor nodes are prone to attacks such as node capture attacks. So, data integration and security are both critical issues for wireless sensor networks. It should be noted that even in the Zigbee protocol, reliability is not 100% achieved due to the buffer size limit and the number of re-transmissions [5]. In an environment with such a high error rate, the best way to solve this problem is to send multiple packets of data, but these transmissions will result in energy loss in the sensors with limited energy. The purpose of this proposal, therefore, is to provide a method to calculate the minimum number of transmissions required per node to achieve optimal network reliability with respect to the network structure [6]. Due to the specific features of wireless sensor networks and their applications, power consumption, lifetime and reliability of these sensor nodes are one of the main challenges of these networks. This problem becomes more acute when it is impossible to replace the battery of these nodes or the nodes themselves, depending on how they are placed in the environment. Most of the proposed Zigbee protocols aim to extend the lifetime of sensor nodes [7]. Energy consumption in the residential sectors accounts for a significant share of the country's energy. However, due to the small percentage of energy consumed in each home, less attention has been paid to consumption management in this sector. IoT technology is important for power management devices, sensors, microprocessors, and other devices used to manage and control energy consumption in smart homes. Smart meters equipped with a two-way communication transmit the load information to the electricity supplier unit, thereby enabling the network to be managed and responsive to the load. On the other hand, the consumer will also consciously be able to change the consumption tariff. The proposed approach will consider nodes implementing multi-channel technology to manage ZigBee power consumption in sleep mode.

Theoretical Foundations

A. Criteria for

Selecting a media access control protocol, the media access control protocol should incorporate other factors to improve network performance and provide services tailored to different applications: 1. Energy Efficiency: The amount of energy consumed per successful transmission. 2- Scailability: Ability to adapt to network size changes. 3. Adaptability: The ability to adapt to changes in node density and network topology. 4. Chanel Efficiency: Optimal use of bandwidth for efficient communication. 5. Propagation Latency: The delay from the time the packet was sent by the sender to the time it was received by the receiver is delayed. 6. Delivery: refers to the amount of data that is transmitted successfully from the sender to the receiver within a specified time. The transition rate is defined as bits or bytes per second.7. Firenees Sharing: refers to the ability of sender different nodes to share evenly the same transmission channel [3].

B. Zigbee Protocol Features

The most important feature of a Zigbee protocol is the efficient power consumption that will ultimately increase the network lifetime. In addition, there are other features such as scalability and versatility(adaptation). There are also other features such as latency, throughput and bandwidth. Some ways of wasting energy are: 1. Collision: When two or more nodes send information to one node at a time, the receiver cannot receive them all. 2. Overhearing: When a receiving node listens to a message unintentionally it wastes a lot of energy. 3. Protocol Overhead: In addition to the data sent between nodes, protocol control packets are also sent between the nodes. If these packets are relatively large, they consume a great deal of power. 4. Idle listening: refers to when no sender is sending data but the receiver is listening in vain and actually wasting energy. 5. Overemitting: Occurs when the sender sends a message but the receiver is not ready [8].

C. Multi-channel Zigbee Protocol

The main objectives of using multi-channelling for the Zigbee protocol of wireless sensor networks are as follows: (a) minimizing interference in the network: reducing interference between sensor nodes; (b) Avoiding external interference: Channel variation is a way to mitigate the impact of external interference between neighboring networks. (c) Improving Network Transmission: Using parallel transmission over multichannel protocols increases packet delivery rate and reduces network traffic latency. Some multichannel Zigbee protocols require synchronization between sensor nodes. Synchronous protocols usually require scheduling. Such protocols cannot optimally adapt to a node's traffic. In asynchronous multi-channel Zigbee protocols, sensor nodes independently schedule their wake-up times. Such non-synchronous protocols avoid sync overhead. But long initiating data results in longer delays and higher power consumption. None of the protocols mentioned above, namely synchronous and non-synchronous protocols, have considered the conditions in which a node may crash suddenly [9].

D. Background Research

In 2018 a demand-side optimization mechanism for smart homes in the smart grid have proposed [1]. The proposed mechanism is a model as a binary linear programming problem. The mechanism aims to minimize the cost of electricity consumed by smart homes. Iqbal in [4], have presented a conceptual model for the intelligent beta network of Internet of Things. Applications and devices are intended as objects. Each object has a specific IP address based on the 6LowPAN communication protocol. The advantage of this is the use of faster communication protocols than protocols such as Zigbee, Bluetooth, WiFi, WiMAX, LTE and PLC. The work in this paper is an evolving conceptual model, and the authors of this article have implemented it in a residential area. In [10], the three-layer cloud-assisted cyber system is introduced, comprising an integrated data collection layer, a data management layer for distributed storage and parallel computing, and a data-oriented service layer. The results of this study show that cloud and big data technologies can be used to improve the performance of the health care system.

The proposed method

The proposed method inherits asynchronous scheduling operations from multi-channel technology and It has packet bursting forwarding as well as multi-channel support for high-traffic wireless sensor networks, while it has the same energy efficiency of multi-channel technology per channel.

A. Overall system

A ZigBee's multi-channel technology in sleep node mode includes two initialization steps and a periodic listening and sleep phase. During the initialization phase, a new node that connects to the network listens to ensure that received hello packets from neighbors at a predefined time that is slightly longer than the hello interrupt. That node, after receiving all of the neighbors 'information, specifies its wake-up schedule in a manner that does not overlap with its neighbors' schedule. When a new node adjusts its wake-up interrupt, it performs a scheduling announcement to neighbors by sending hello packets and then begins the periodic node listening and sleep phase. During the periodic listening and sleeping phase, a receiver's waking time is as high as the hello time. For example, each node sends a hello message at each interval. After sending a hello message, the receiver sets an interrupt after the maximum size of the competition window for sending data. The receiver goes to sleep after an interrupt. If a frame start sign be detected, the receiver stops the timer and goes to sleep after receiving it. If the messages are received correctly, the acknowledge message will be sent. In this study, in order to support the high traffic load of the network, the mode of sending the packets in fuzzy mode using the extra time is activated after receiving the data and sending them. After sending a data packet, the sender remains awake for a TAS period and the packets are sent sequentially for the top layers to request additional packets. After receiving the data packets, the receiver stays awake for a TAR short time until it can receive the packets after receiving the previous packets. Also, the main feature of the proposed method is the use of asynchronous multi-channel structure which can be very useful in conditions of high network load.

B. Support of high traffic in the proposed method

The proposed method packet busting transmit mode and using additional time after receiving and sending data is enable, in order to support high traffic load of network. In the proposed method to reliably send packets and prevent sequential packets from being lost and collision detection and retransmission an extended and developed method of the one explain in [11] has been implemented.

C. Support of Multi-Channel

The proposed method extends the basic operations of multi-channel technology with multi-channel support. Due to power consumption and cost limitations, many sensors are equipped with a sender-receiver(transmitter). Therefore, the proposed method is designed for semi-duplex transceiver beta nodes. Because the main channel of each node is selected during the initialization phase and each time it manages its neighbors scheduling with the main channels, the proposed method does not require channel control for synchronization between nodes across different channels and it has available bandwidth to transmit data. In the proposed method, the channel only determines once in the initialization phase, so the channel overhead can be neglected.

D. Initialization step

Since it is impossible for a node to send and receive operations at the same time using a single transceiver, a unique scheduler for the main channel is provided using the multi-channel technology algorithm. In the proposed algorithm, each node sends only the packet to its neighbor for packet propagation operation. The proposed algorithm performs neighbor identification to maintain the network dynamics. Because wireless sensor networks generally operate in the ISM band (industrial, scientific and medical), the channels and sleep period may be occupied by other networks later in the initialization phase. In the proposed method it does not use the same main channel with the wake interval over the life span to avoid this problem, but the channel that has been least used finds the least wake interval and then generates new scheduling and scheduling information will be sent to all neighbors.

E. Fuzzy method

In the proposed method, fuzzy Sugeno method is used to determine the appropriate interface device for transmitting data by cluster headers to the center. The steps of the proposed method are repeated looping on all network devices until the error ends. In the proposed method, the selection of the interface device from all the healthy devices in the network that have ideal conditions is done by fuzzy logic considering three criteria of reliability and distance and quality differences. In the proposed method, the implementation of ZigBee multi-channel technology in nodes sleep mode is selected for mass fuzzy monitoring, and the results are compared with other methods for implementing multi-channel technology in ZigBee wireless sensor networks in node sleep mode.

Implementation and evaluation of the proposed method

The proposed method was implemented in MATLAB 2115 environment. Evaluation was done by criteria of energy consumption, operating power, correct packet delivery rate and delay rate. For a more detailed and realistic examination of the proposed method, multi-steps transmit were tested in two steps. In one step, a chain structure of nodes consisting of 10 nodes was used and in the second one a dense network of 100 nodes was selected which were in the form of a 10 × 10 wireless network.

A. Evaluation of the Proposed Method

The proposed method is evaluated in two stages. In the first step, the goal is to move the nodes in a single step, and most of the protocol capabilities are examined on two nodes that are directly related to each other and next step is multi-step forwarding and the network structure and number of nodes increase. In the simulation, all nodes are equal to the wake-up time, and each node can only communicate with its neighboring nodes. The default routing method is also used for the first and second routing step. The data generation time interval is constant and equal 100 seconds. But the wake-up time and hi are optimally calculated based on the energy consumption. The evaluation of the proposed method is based on the criteria of energy consumption, throughput, delay and the ratio of received packet to destination. For this purpose, the parameters of the wake-up time interval, data generation time interval, weekly cycle and traffic load are used.

B. Energy Consumption

To calculate energy consumption there must be a timer that calculates the time associated with various activities such as sending, receiving, listening and sleeping. **Figure. 1** shows the amount of energy consumed by different protocols at different wake-up intervals. The interesting thing is that the power consumption in the TMAC and CSMA protocols has nothing to do with the wake-up time. The energy consumption of the proposed method is higher than that of the AS-MAC method. The main reason is that the AS-MAC method is a single channel method and the proposed method is a multi-channel one and consumes more energy. **Figure 2** shows the result of comparing the energy consumption at different time intervals of data generation, of one node in the proposed method with the other methods. The lower the speed of data generation, the lower the energy consumption. In this case, both the TMAC and CSMA protocols have a constant amount of power consumption. But the proposed method, since it reduces collision, also performs well at high data generation rates and consumes less power.

Figure 3 shows the most important comparison in terms of energy consumption, in which energy consumption is calculated based on the number of packets received. In this experiment, the results are related to the Sink node. As can be seen, the energy consumption of the proposed method is lower than the number of different packets received.

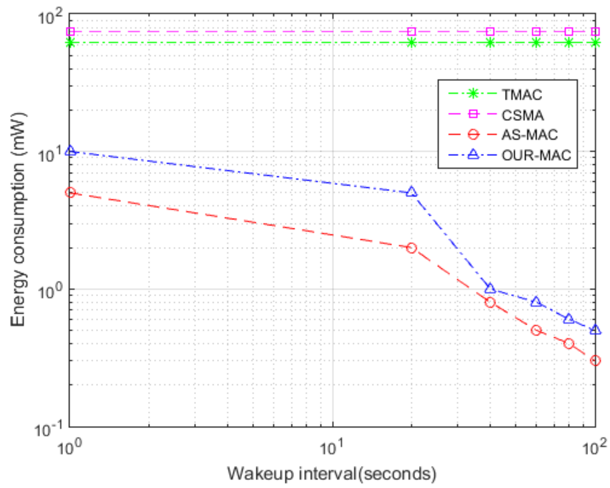

Figure. 1 Comparison of energy consumption at different wake up intervals

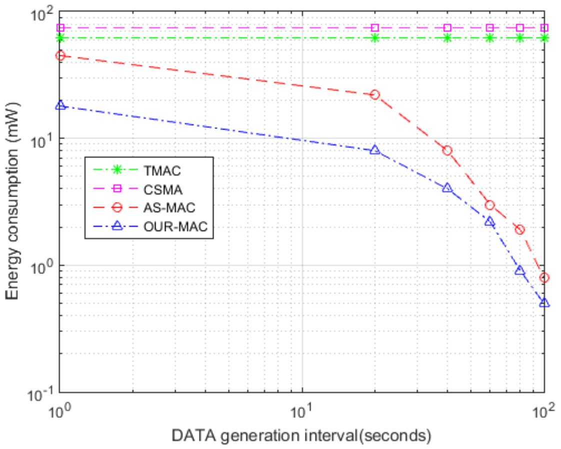

Figure 2. Comparison of energy consumption at different data generation intervals

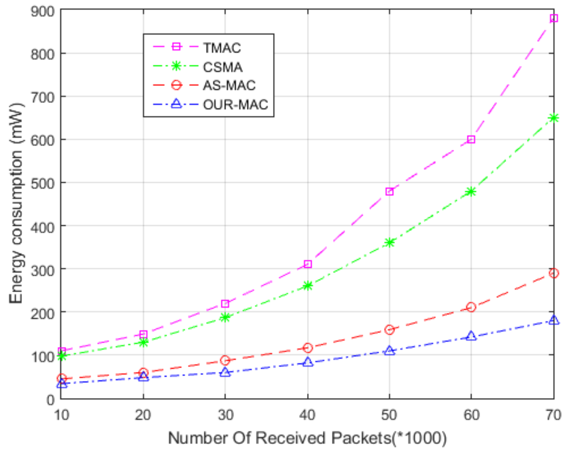

Figure 3. Comparison of power consumption with the number of packets received.

C. Operating Power

The operating power is calculated from relation 1, where T_e is the duration of the simulation period, N_{rp} specifying the number of sent packets and S_p the size of each packet.

$$T = \frac{N_{rp} S_p}{T_e} \tag{1}$$

The operating power is directly related to the speed of data generation. The faster the data generation speeds up, the greater the operating power, but the process of increasing the operating power continues to a threshold. When the speed exceeds a limit, the protocol is no longer able to send all the data and there is a problem of packet collision and loss. As shown in **Figure 4**, in the proposed method, as long as the node output speed reaches 200 pps, the maximum operating power is possible. But in other methods this is only possible up to speeds of 100 and 125 pps.

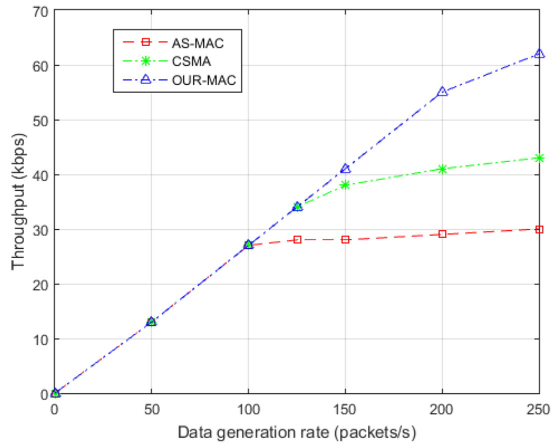

Figure 4. Compression of the operating power

D. Packet transmission rate

Figure 5 shows the packet delivery rates for the proposed ZigBee multi-channel technology in sleep nodes, CSMA and AS_MAC at different time intervals. In the proposed method transmission rate for intervals greater than 20 seconds reaches 100% and even within 5 seconds intervals the transmission rate is 95%. Compared to other methods, the transmission rates are much lower.

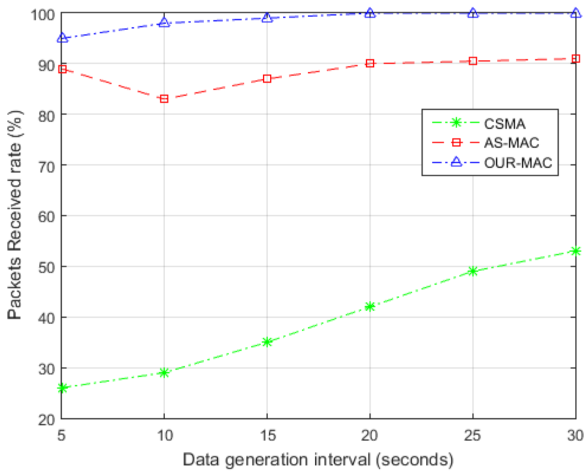

Figure 5. Comparison of packet delivery rates in different protocols

E. Multi-step Data Sending

The results for packet delivery percentages in the proposed method and other methods are shown in **Figure 6**. The lower the speed of data generation, the higher the packet delivery rate. In the proposed method when the data generation time interval is 3 and 4 the correct packet delivery rate is %98 and 99% and from 5 onwards the packet delivery rate is 100% while in the AS-MAC method only when the data generation interval is 10, the packet delivery rate is 100%.

Figure 7 shows the delay rate of the nodes for different number of steps. These results are assumed to be 11 seconds for the data generation time interval. This data rate is very low for the proposed method because the ZigBee multi-channel technology in node sleep mode performs better for high speeds. In the proposed method, after sending and receiving each packet, it waits for other packets to receive other data packets with, which this feature allows multiple data packets to be received at a delay rate, which reduces the overall delay. Also, simultaneous use of multiple channels reduces the amount of delay.

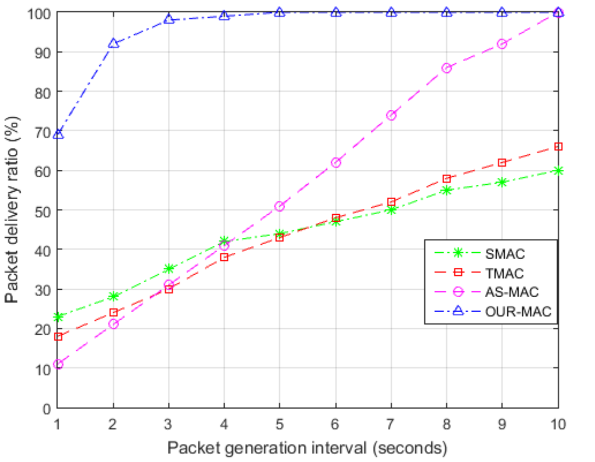

Figure 6. Correct transmission rate of the packages in multi-steps transmission

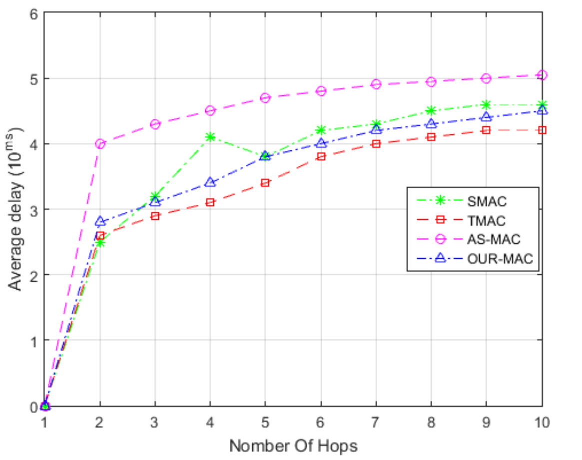

Figure 7. Comparison of the amount of delay in multi-steps transmission

In order to more accurate and realistic evaluate the proposed method, another experiment was performed for multi-steps transmission. In this stage a big and dense network of the sensors which consist of 100 nodes in 10*10 form was considered the wake-up time of the nodes is 1 second and the test time is 3600 second. **Figure 8** shows the percentage of success of data transmission by nodes at different time intervals. The packet transmission rate in other protocols and even the ZigBee multi-channel protocol in sleep mode nodes are very low at high data generation speed and heavy network traffic. But in the proposed method, this problem is minimized by using multiple channels and avoiding collisions. In the proposed method, the correct packet delivery rate in data generation interval is 5 times and the value is 95%, that's a significant amount. It reaches 100% at 9 and 11 seconds intervals, while the best packet delivery rate in other protocols is the ZigBee protocol in sleep nodes, which is 77% at 10 seconds interval.

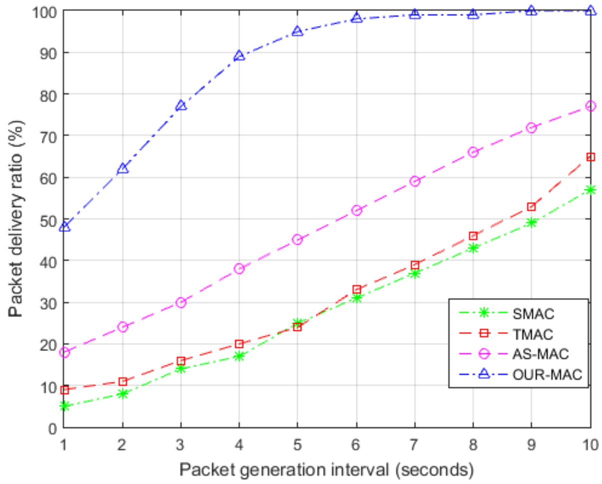

Figure 8. percentage of success of data transmission by nodes (dense network)

Conclusion

One of the protocols used in IoT applications in smart homes is the Zigbee. The Zigbee communication protocol, as a high standard security standard, requires low bandwidth for smart homes. In wireless sensor networks, the main reason for nodes failure is their battery drain. In this paper a method has been proposed which could reduce the power consumption of the nodes in the networks. The proposed method implements multi-channel technology in the node sleeping mode of the Zigbee networks. The result of the simulation shows the lower energy consumption, better transmission rate of the packages lower operating power and better delivery rate.

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