International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)
Volume-2 Number-4 Issue-6 December-2012

Removal of IEEE 802.15.4 MAC Unrelaibility Problem in Hardware

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Abstract

IEEE 802.15.4 systems suffer from serious MAC unreliability problem due to contention based MAC protocol used for channel access and its default parameter values. Reliability issues arise on case of energy efficiency when power management is enabled; packet loss when number of contending nodes is increased. A method to use IEEE 802.15.4 MAC protocol with reduced unreliability as the number of nodes increases reliability decreases. The proposed WSN has central server and nodes, sink consists setting switches to fix the setting value of load through ZigBee communication using the microcontroller AT89C51. Controlling the node and monitoring them reduces the unreliability of receiving more number of packets from nodes to central server. Simulation analysis was carried out for monitoring and controlling the switching the nodes between normal and abnormal condition.

Keywords

MAC unreliability, Energy efficiency, power loss, WSN.

1. Introduction

Wireless sensor networks are thousands of sensors in a small space that have low power, limited range and self-organizing. Total low cost equipment based on battery of limited lifetime. The Energy efficiency, power management and packet delivery ratio are the considerations to be taken for the setup of the network [2]. For the above conditions to get satisfied and to get a wireless sensor network like this is a hard job. IEEE 802.15.4 WSN the standard MAC protocol IEEE 802.15.4 is proven to accommodate low data-rate and low power-consumption networks [2]. IEEE 802.15.4 protocol suffers from serious MAC unreliability problem, caused by contention based MAC protocol (CSMS/CA) [2]. Problems include energy efficiency, packet loss, low packet delivery ratio.

This paper was organised as follows. In section 2 background of the MAC unreliability is reviewed. In section 3 MAC reliability issues and the methods used to solve the issue was discussed. In section 4 the proposed method to solve the unreliability issue in this paper was discussed. Simulation results were discussed in section 5 followed with conclusion.

2. Background

The system architecture of IEEE 802.15.4(LR–WPAN) WSN are low cost, low power, low rate systems used for Personal Area Networks (PAN) [1], [2]. The networks have limited range [1]. Network consists of physical layer and medium access control layer specifications. These networks are used as co-coordinators, PAN-coordinators and network devices [2]. Zigbee works on this protocol which is a low cost wireless link for industrial and commercial sensor and actuator devices. IEEE 802.15.4 networks have operating frequency of 868/915 MHZ channels (0-10), 2.4 GHZ channels (11-26).

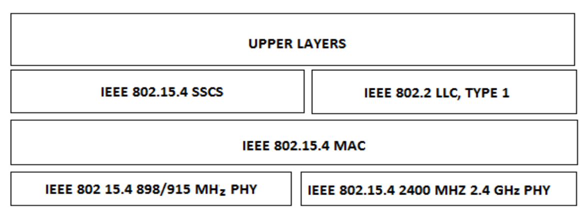

Fig.1: IEEE 802.15.4 System Architecture

The system architecture of IEEE 802.15.4 is as shown in the fig. 1. These networks use Star and Peer-peer network Topologies. Different types of devices that exist in a system are [1].

- ***FFD:*** Full Function Device - a node that has full levels of functionality. It can be used for sending and receiving data, but it can also route data from other nodes.
- ***RFD:*** Reduced Function Device - a device that has a reduced level of functionality. Typically, it is an end node, which may be typically a sensor or switch. RFDs can only talk to FFDs, as they contain no routing

functionality. These devices can be very low power devices because they do not need to route other traffic and they can be put into a sleep mode when they are not in use.

- ***Coordinator:*** This is the node that controls the IEEE 802.15.4 network. This is a special form of FFD. In addition to the normal FFD functions, it also sets the IEEE 802.15.4 network up and acts as the coordinator or manager of the network.

802.15.4 Star topology

IEEE 802.15.4 Star network topology is as shown in the fig. 2. Has one central node called the PAN coordinator with which all other nodes communicate [1]. Nodes are required to talk only to the central PAN coordinator. Even if the nodes are FFDs and are within range of each other, in a star network topology, they are only allowed to communicate with the coordinator node. [3] Explains the star topology.

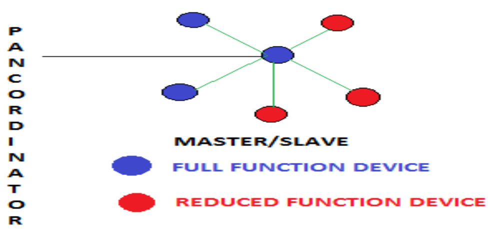

Fig.2: Star Topology

IEEE 802.15.4 MAC overview

MAC layer (medium Access Control) is the sub layer of data link layer of OSI model. The MAC layer main functions are frame delimiting and recognition, addressing, transfer of data from upper layers, error protection), and arbitration of access to one channel shared by all nodes. MAC layer protocols for WSN must be energy efficient to maximize lifetime. Additionally, protocols must be scalable according to the network size and should adapt to changes in the network such as addition of new nodes, death of existing nodes, and transient noise on the wireless channel [1].

MAC layer is responsible for the following tasks:

1) Generating network beacons if the device is a coordinator. 2) Synchronizing to the beacons. 3) Supporting PAN association and disassociation. 4) Supporting device security. 5) Employing the CSMA-CA mechanism for the channel access. 6) Handling and maintaining the GTS mechanism. 7) Providing a reliable link between two peer MAC entities.

Superframe structure

Fig. 3. Shows the superframe structure of IEEE 802.15.4 supports low rate wireless personal area networks working in the beacon mode by use of superframe. The structure of superframe, bounded by beacon frames is

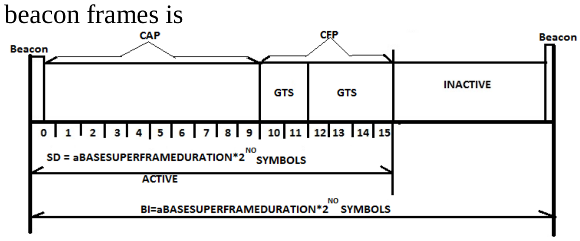

Fig.3: Superframe structure

The coordinator of the PAN defines the format of the superframe. The superframe beacons are transmitted periodically by the coordinator and are used to identify the PAN, synchronise the attached devices and describe the structure of the superframe [2]. By MAC Beacon order the transmission frequency of beacons are ranged from 0-14. Within the superframe structure, the coordinator may choose to enter sleep mode during the inactive portion. The length of the inactive portion depends on the MAC Superframe order (SO) and MAC Beacon order (BO). The active portion of the superframe is divided into 16 time slots. It may consist of two periods, namely contention access period (CAP) and contention free period (CFP). The CAP immediately follows the superframe beacon and completes before the CFP begins. All frames except acknowledgement (ACK) frames are transmitted in this period using a slotted CSMA-CA mechanism. A transmission in the CAP shall be complete one inter frame space (IFS) period before the end of the CAP. If this is not possible, it defers its transmission until the CAP of the following superframe. In slotted CSMA-CA, the back of period boundaries are aligned with the superframe slot boundaries of the PAN coordinator.

In order to support applications with particular bandwidth and latency requirements, 802.15.4 defines the second portion of the active period as CFP. Unlike CAP, channel access in CFP is based on reservations and is free of contention. Therefore, no transmissions within the CFP shall use a CSMA-CA mechanism. One part of the CFP is allocated for a particular device, which is denoted as a guaranteed time slot (GTS). The GTS direction, which is relative to the data flow from the device that owns the GTS, is specified as either transmit or receive. In other words, traffic flows from a device to the coordinator in a transmit GTS, while a device receives data from the coordinator in a receive GTS. A GTS may extend over one or more time slots. During the GTS, the wireless channel is dedicated exclusively for the communications between the particular device and the PAN coordinator. A maximum of seven GTSs are allowed to be allocated in a PAN. A device transmitting in the CFP shall ensure that its transmissions are complete one IFS period before the end of its GTS. Inter frame space (IFS) time is the amount of time necessary to process the received packet by the physical layer (PHY). Transmitted frames shall be followed by an IFS period. The length of IFS depends on the size of the frame that has just been transmitted. Frames up to a Max SIFS Frame Size in length shall be followed by a short IFS (SIFS) whereas frames of greater length shall be followed by a long IFS (LIFS).

The PANs that do not wish to use the superframe (referred to as a non beacon-enabled PAN) shall set both MAC Beacon Order and MAC Superframe Order to 15. In this kind of network, a coordinator shall not transmit any beacons, all transmissions except the acknowledgement frame shall use unslotted CSMA-CA to access channel, and GTSs shall not be permitted.

CSMA-CA algorithm

If superframe structure is used in the PAN, the slotted CSMA-CA is used. The algorithm is implemented using units of time called back of periods, which is equal to Unit ACK of Period symbols [2]. Each time a device wishes to transmit data or command frames during the CAP, it locates the boundary of the next back of period. Each device maintains three variables for CSMA-CA algorithm: NB, CW, and BE. NB is the number of times the CSMA-CA algorithm was required to back off while attempting the current transmission. It is initialized to 0 before each new transmission. CW is the contention window length, which defines the number of back of periods that need to be clear of activity before the transmission can start. It is initialized to 2 before each transmission attempt and reset to 2 each time the channel is assessed to be busy. BE is the back of exponent, which is related to how many back of periods a device shall wait before attempting to assess the channel. In the slotted CSMA-CA, NB, CW, and BE are initialized and the boundary of the next back of period is located. The MAC layer delays for a random number of back of periods in the range of 0 to 2^{BE} - 1, then requests the PHY to perform a clear channel assessment (CCA) [4]. If the channel is assessed to be busy, the MAC layer increments both NB and BE by one, ensuring that BE shall be no more than *a Max BE*. If the value of NB is less than or equal to *MAC Max CSMA back o*f, the CSMA-CA will start another around of delay for a random number of back of periods. Otherwise, it declares channel access failure. If the channel is assessed to be idle, the MAC sub layer ensures the contention window is expired before starting transmission. For this, CW is decremented by one first. If CW is not equal to 0, CCA is performed on back of boundary. Otherwise, it starts transmission on the boundary of the next back of period. Figure 2 illustrates the steps of the CSMA-CA algorithm.

Physical layer

The physical layer provides an interface between the MAC layer and the physical radio channel. It handles the data transmission request from the MAC layer and passes the incoming frame to the MAC layer. In order to provide these services efficiently, it supports Activation and deactivation of the radio transceiver, energy detection (ED), link quality indication (LQI), and CCA. The feature of activation/deactivation of the radio transceiver is very important for energy conservation in battery-powered devices. It allows devices to turn off their radio to avoid overhearing and idle listening. Receiver energy detection is intended for use by a network layer as part of channel selection algorithm. It is an estimate of the received signal power within the bandwidth of an 802.15.4 channel [2].

Link quality indication measurement is a characterization of the strength and quality of a received packet. The measurement may be implemented using receiver energy detection, a signal-to-noise estimation or a combination of these methods. How to use the LQI is up to the network or application layers. Before the physical layer transmits a frame in the contention access period, it checks whether the channel is available. Thus, CCA is performed by the physical layer using energy detection, carrier sense or a combination of both of them. In some sense, it is the front end of CSMA-CA in MAC layer.

3. MAC Reliability Issues and Methods Used to Solve the Issue

Fig. 4. Shows the standard MAC protocol of 802.15.4. MAC is based on the CSMA-CA procedure

tells the basic procedure of the 802.15.4 MAC. As seen in [4] the back off algorithm is processed inside the CSMA-CA algorithm. The initial value of battery life extension (BE) is given as Min BE and the system selects a back off time from random number between 2^{BE} -1. Setting of back off time makes the system start back off and the slots in the CAP [4].

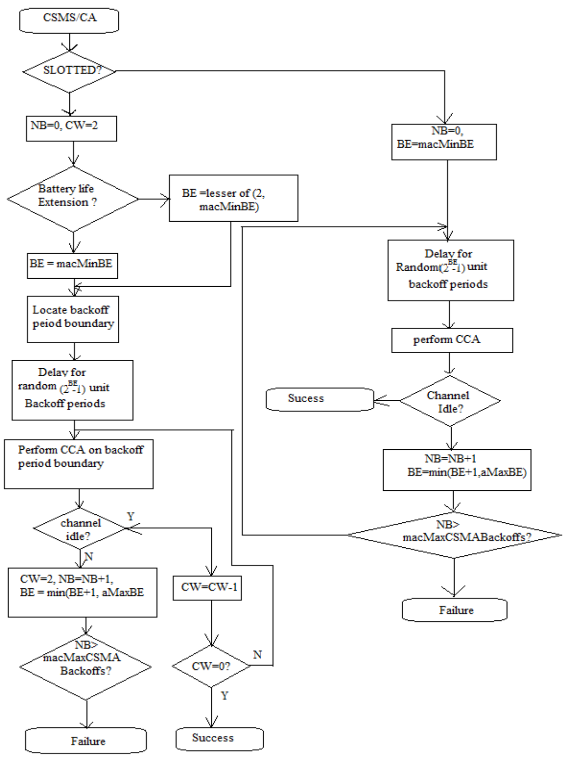

Fig. 4: Standard MAC Protocol

The 802.15.4standard states that the BE value is set to a random number between the range of two variables, *minBE* and *aMaxBE*. The *aMaxBE* indicates the maximum number of the backoff exponent. This value is limited to 5 in the standard. The *minBE*, which indicates the minimum value of the BE, can be set to a number between 0 and 3. The superframe structure in 802.15.4 is made of time slots between two beacons [4]. Explanation of superframe working is made in [1], [4]. Modifications on back off stages are made in [4]. In 802.15.4 standard, BE (back off exponent) is a random value choosen between aMaxBE and aMinBE. The aMaxBE is limited to 5 and aMinBE is limited to 3. If the value is made less than 3, the lower boundary of the possible backoff value decreases. The modification is shown in state transmission scheme of [4].

MAC protocols have low Duty-cycles [5]. Topology control is finding of optimal subset of nodes that guarantee connectivity. Controlling sleep and wakeup modes of sensor is power management but the energy efficiency is affected [4]. MAC protocols are divided into four categories [6]. Contention-based MAC, TDMA-based MAC, Hybrid contention based and TDMA-based MAC, Cross-layered MAC based on energy efficiency.

In IEEE 802.15.4 contention, based MAC is used. Contention based MAC are based on Carrier sense multiple access/Collision avoidance (SMA/CA). When node needs the data, it will compete for wireless channel [6], [7]. Typical contention based protocols are S-MAC, T-MAC AND UMAC. S-MAC is proposed for energy efficiency based on the IEEE 802.11 aiming at saving energy. S-MAC adopts effective ways for solving a problem. Its disadvantage is that its period length is limited by delay and cache size; active time depends on message transmission rate. T-MAC is an improvement to S-MAC to reduce energy consumption on idle listening. In contention based MAC protocols, nodes are allowed for independent access to medium and not required to form a cluster. Contention based MAC protocols have good scalability and support node changes and new node inclusions as well. The energy efficient MAC protocols are however remains low due to collisions, idle listening and excessive control overhead inevitable [6]. The design of the CSMA/CA MAC in IEEE 802.15.4 is such that the aggregate situation throughput decreases with the number of nodes. Results from [5] shows that a finite load analysis captures very well the qualitative behaviour of delay, throughput and packet discard probabilities.

In the case of more number of contending nodes in a star network, the packets are lost due to collisions in the IEEE 802.15.4 MAC protocol using systems. Without the acknowledgement, the nodes cannot know if the packets are being delivered.
The problems found in the IEEE 802.15.4 MAC are energy efficiency, Packet loss, idle loss that is explained above including the present methodology.

4. Proposed Methodology to Solve Unreliability Issues

Solutions found previous work are based on the consideration of specific scenarios. Solutions found are not be implemented in realistic and industrial scenarios. Unreliability in general occurs because of noise. The data transmission in the normal protocol has the slow data rate transmission. The condition of the data transfers from the multiple nodes to the single creates the slow rate data transfer. The unreliable problem may cause due to the losses in the amplitude, frequency and the slow data rate. In normal, the problem arises due to the analog transmission several data bits can missed while receiving.

For energy efficiency
Network to sense the temperature in the industrial environment is considered. In this node cannot be in sleep mode, it is to monitor the condition in real time. Temperature sensing is considered in an industrial environment. In this case, DC power supply can be considered for node or a mobile node. To overcome the MAC unreliability problem, in particular, packet loss in MAC layer of IEEE protocol for ZIGBEE is used, which cannot produce noise or loss of the data transmissions. The protocol's data transmission is high rate may not produce any losses. The ZIGBEE protocol is at the 2.4GHz transmission rate, which can send the data in the form of digital signals. By those data transmissions, the data losses do not occur due to the fast transmission and response.

Thermistor is used as temperature sensor, to sense temperature, the sensor in the node is connected to the microcontroller after signal conditioning. When the resistivity of temperature sensor increases and the voltage produced from the sensor is low. The signal conditioning circuit is normally gives a low signal to the microcontroller. If the temperature abnormal condition is sensed, produces high signal [3]. The microcontroller switches off the load by using of the relay driver and the relay. This work consists of the ZigBee medium, which is interfaced with the microcontroller by using of the MAX232 serial communication IC.

For packet loss
The central server unit consists of ZigBee, which is interfaced with the microcontroller by using MAX232 serial communication IC. The central server unit provide time slot for setting switches connected with the microcontroller [3]. A predefined value is set on these setting switches. When the nodes are transmitting the data to the central server, it receives the data from the nodes until it reaches the setting value. Once the data from the nodes exceeds the setting value, the central server takes change of the node.

5. Simulation Analyses

A simulation analysis is carried out on Proteus 7.6. Fig. 5. Shows the central server and node schematics, the temperature detection node shows the change in temperature, and the central server showing the condition of the loads. The server sends command to the node to transmit temperature and server receives and display indicates it is NORMAL.

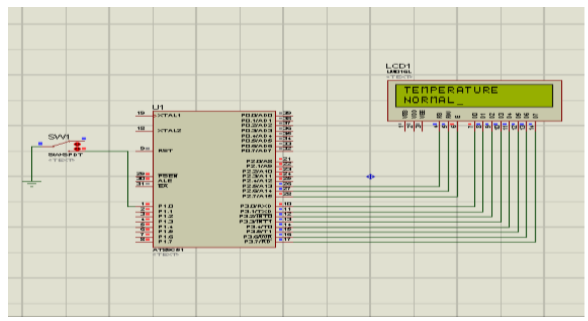

Fig.5: server with switch, showing the monitored temperature by the node and its status

A prototype of server using PROTEUS 7.6 SPO showing that switching is possible. Indicating TEMPERATURE NORMAL implies that the temperature of the load did not exceed the cut-off value, i.e. load temperature is below the set cut-off value. Therefore, the central server just monitors the nodes.
TEMPERATURE ABNORMAL indicates that the values of temperature in the load of the machinery read by the node have exceeded the set cut off value. Usually the cut off value depends upon the type of machinery used.

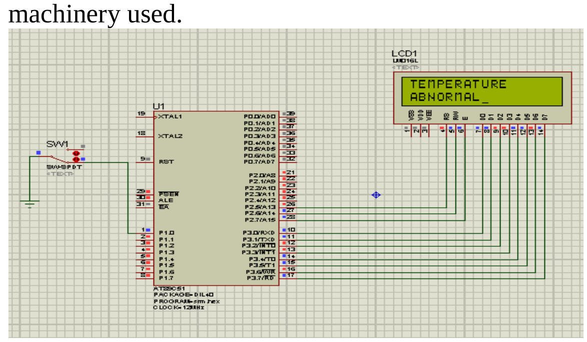

Fig. 6: Temperature Condition the node is ABNORMAL resulting due to excess load displayed in server.

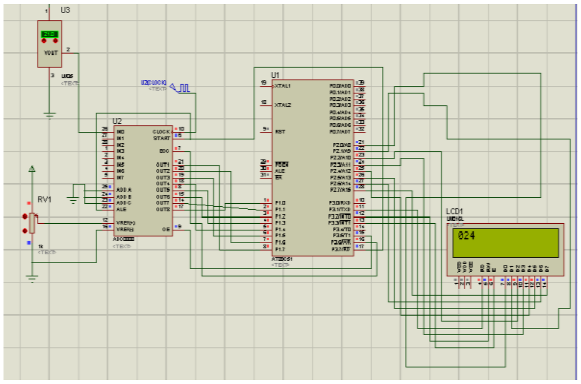

Fig. 7: Node with one temperature reading

Fig. 7. Shows the schematics of server node tested in Proteus 7.6. The server displays the temperature of test node.

6. Conclusion

The actual problem of MAC unreliability is explained. This problem can by appropriate MAC parameter setting, by changing the CSMA/CA protocol and by without changing the MAC protocol. Simulation analysis was carried out to explain MAC unreliability problem in IEEE 802.15.4. In WSN, this problem can be removed by giving the control to the central server. The sink node then is able to control the nodes deployed remotely, avoiding disasters near the load. It will be helpful to the industries to tryout this method in order to achieve safety and finally this can be a way of removing the coming MAC unreliability problem. It will be helpful to the industries to safety. This work further to be tested with real environment condition.

Acknowledgment

Author would like to thank the Department of Electronics and Communication Engineering of SRM University to carrying this work successfully.

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