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Robust Model to Improve the Energy Efficiency in IEEE 802.15.4 Sensor Network

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ABSTRACT

Wireless Sensor Networks (WSNs) are among the very promising solutions for several practical applications. Currently, WSNs have also found their application in the case of industrial scenarios, even for crucial applications. There are two significant requirements for an efficient deployment of WSNs such as energy efficiency and reliability. In this paper, robust model is proposed to enhance the energy efficiency in IEEE 802.15.4 sensor networks. The robust model is tending to restrict collisions and optimizing the access parameters without changing the existing architecture of MAC protocol.

Keywords: Wireless Sensor Network, 802.15.4/Zigbee, cross layer, collision avoidance, energy efficient

1. INTRODUCTION

The present improvements in Wireless Sensor Networks (WSNs) have helped in making advancements in the state of the art of a variety of applications corresponding to security, surveillance, military, health care, environmental monitoring, inventory tracking and industrial controls. Managing such an extensive range of application will be greatly impossible without any knowledge of a WSN. A wireless sensor network (WSNs) is an infrastructure that comprises of sensing, computing, and communication elements that renders the administrator the capability to operate, observe, and act to events and phenomena accordingly in a highly demanding environment [1]. This has been possible because of the introduction of: (i) the IEEE 802.15.4 standard [2], which defines the physical and Medium Access Control (MAC) layers of the protocol stack; and (ii) the ZigBee specifications [3], covering the network and application layers.

Zigbee was targeted at remote control and sensor applications. It is appropriate for operation in aggressive radio environments and in locations that are isolated. It is constructed over IEEE 802.15.4 standard that defines the physical and MAC layers [4]. Energy preservation [5] is an important concern in WSNs, even though reliability is equally significant [6]. In fact, it has been observed that WSNs based on IEEE 802.15.4/ ZigBee are affected by critical unreliability issues, specifically when energy management is enabled for the purpose of energy consumption [7], [8]. Therefore improved effective and efficient mechanisms are required in order to gain reliability along with low energy consumption. The Message transfer and network conditions in a WSN are modified, owing to both the noisy wireless channel and the probability of failure of sensor nodes. Hence, Information collection mechanisms that are based on energy-awareness and reliability should be capable of adapting to the real-life operating conditions [9].

Further, they must be flexible enough to provide a support to a huge variety of operating environments, in the absence of any previous or global knowledge on the network topology and the message transfer pattern. All of these requirements render the design of energy-efficient adaptive schemes for the purpose of

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effective data collection a critical challenge. To achieve this, a cross-layer approach is truly beneficial, as it is capable of exploiting the knowledge obtained from the different layers of the protocol stack for minimizing the energy expenditures [10].

In the protocol stack [11], a cross layer interaction refers to having communication between layers, which in turn, means with any other possible layers not in the neighborhood. Cross layering was considered to deal with QoS (Quality of Service), energy consumption, poor performance, wireless links, mobility, packet loss, delay problems that are often seen in wireless networks. It attempts sharing information between various layers, which can be utilized as input for algorithms for assisting decision processes for combinations and adaptation. In [12] study, the author has proposed an adaptive and cross-layer approach for obtaining dependable and energy-efficient data collection in WSNs using IEEE 802.15.4/ZigBee standards. This approach incorporates an energy-aware adaptation module capturing the application's reliability requirements and independently makes the configuration of the MAC layer, in accordance with the network topology and the present traffic conditions. Particularly, the ADaptive Access Parameters Tuning (ADAPT) algorithm is proposed, that is based on an analytical study of the IEEE 802.15.4 standard. In IEEE 802.15.4 MAC, collisions can occur because of the hidden node problem and the cluster mobility on data transmission receives no focus in this approach.

The work presented is organized as below Section 2 introduces the related work, and Section 3 presents the background studies of IEEE 802.15.4 CSMA/CA and cluster mobility and hidden node issues. Section 4 analyzes the energy-efficiency of the IEEE 802.15.4 cross layer MAC protocol and studies the proposed robust model energy-efficient data collection and finally, Section 5 presents the conclusion of the proposed method.

2. RELATED WORKS

This section shows the review of related literatures reference to IEEE 802.15.4 wireless sensor networks. Mounib Khanafer *et al.,* [13] investigated about a survey on these protocols and highlighted the technique of IEEE 802.15.4 which is the de facto standard for Wireless Sensor Networks (WSNs) and depicts the specifications of the PHY layer and MAC sub-layer in these kinds of networks. The MAC protocol is required to engineer sensor nodes access to the wireless communication medium. Even though differentiated by a collection of strengths contributing to its popularity in different WSNs, IEEE 802.15.4 MAC is affected by many limitations which deteriorate its performance. Further, from a practical point of view, 80.15.4-based networks are generally exploited close to other wireless networks operating in the same ISM band. This indicates that 802.15.4 MAC should be ready to deal with interference due to other networks. These factors have influenced efforts for devising enhanced IEEE 802.15.4 MAC protocols for WSNs. The performance of IEEE 802.15.4 slotted CSMA/CA algorithm, inclusive of packet delivery ratio, latency and energy consumption, is analyzed by NS-2 simulation in [14]. It also takes the difference between tracking and non-tracking synchronization mechanisms into consideration. Petrova et al. [15] analyzed the properties and performance of IEEE 802.15.4 by means of measurement of the RSSI, PER. They also examined the performance of IEEE 802.15.4 slotted CSMA/CA via NS-2 simulation in accordance with the model in [16]. However, only few settings and metrics are taken into account.

Chavan S.G, Shirsat S.A.[17] conducted ZigBee, a two-way wireless communication standard which yields economical cost and low power depletion, designed by Zigbee . Zigbee network, which is based on IEEE 802.15.4 standard, provides benefits for wireless applications. One of the request areas of Zigbee is its focus on short-range wireless data transfer at lower data rates. ZigBee networks are applied in areas like consumer electronics, home and building computerization, industrial controls, medical sensor requests, and entertainment electronics. MD-MAC is presented in [18], which extends DS-MAC and MS-MAC. The protocol compels on *Te* value and at any point of time in case the the value of energy consumption is doubled then the duty cycle is halved. In addition, the mobile node only comes under neighborhood discovery instead of other neighboring nodes, which, in turn forms an active zone as in the case of MSMAC. MD-MAC is complicated and needs high overheads. In [19] presented is MA-MAC, which is energy efficient while preserving high goodput, low latency and fair behavior among the nodes simultaneously in comparison to the already in place mobile sensor standards and protocols. The energy efficiency is accomplished by (i) preventing the hidden as well as contention collisions and by (ii) transmission of the sleep schedule each time such that the node does not make waste of inessential energy for performing backoff and sensing of the channel when the channel is being held by some other competing nodes.

A cross-layer optimization framework was introduced in [20] based on the experimental evaluation of interference in IEEE 802.15.4 networks. This idea of making use of an optimization agent for provisioning the exchange and control of information between the different protocol layers in order to improve the performance in wireless sensor networks. The approach is aimed at investigating the impacts of the wireless channel and the physical layer performance of wireless sensor network (WSN) for developing insights, which can be useful in the design and development of the optimization agent in the new cross-layer framework.

3. BACKGROUND

In this section, IEEE 802.15.4 backoff mechanism, uncontrolled mobility of clusters and the hidden node issues are studied.

(A) Carrier Sense Multiple Access/Collision Avoidance (CSMA–CA)

The CSMA–CA algorithm is employed for the channel access in order to transmit data or MAC command frames. The devices primarily need to ensure the channel is unoccupied before trying to transmit their data. This is accomplished by imposing a check on the idleness of the channel at frequent intervals of time. The units of time during which the devices shall wait for data transmission are known as the backoff periods. One backoff period is equivalent to a Unit Backoff Period (=20 Symbols, for IEEE 802.15.4). Based on weather beacons are used/unused, the CSMA–CA will select either a slotted/unslotted procedure. The unslotted version is also made use in cases when the detection of the beacons could not be done in the PAN. In the slotted mechanism, the alignment of the backoff period boundaries of every device in the PAN will be along with the beginning of the beacon transmission.

(B) Hidden node problem

Hidden nodes are a basic problem potentially affecting any wireless network where nodes cannot hear each other even when they are separated by short distance. In this condition, blind nodes cannot get any control packets, hence packets that are sent to the visible node with no regard to any other nodes sending packets, results in collisions and packet loss. There are three situations when a node can be a hidden node. In the first situation, having the worst throughput, every node is hidden. The second situation considered all

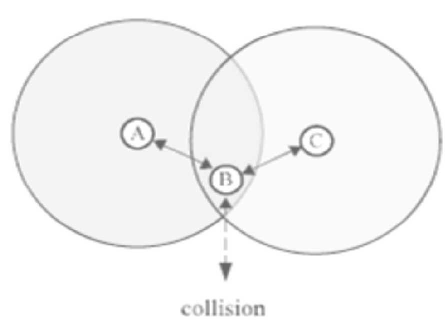

Figure 1: Collision appearance due to the hidden node

nodes are visible and competing with each other for resources such as Access Points (AP). The final situation, referred to as the hybrid schema, is one where hidden nodes and contending nodes are seen together.

The hidden node problem has not given importance in the ADAPT method. Addressing such hidden node problem will reduce the collisions and improvise the energy conservation. The energy efficiency can be achieved when a sleep schedule is invoked.

4. PROPOSED METHODOLOGY

In this section, the proposed Mobility Adaptive (MA) and Cross-Layer (CL) framework aiming for reliable and energy-effective data collection in WSN is described in detail. The MA with MAC layer is used for minimizing the power consumption in accordance with the cluster tree network topology and the traffic situations is discussed.

(a) Cross layer with IEEE 802.15.4/Zigbee

ZigBee wireless network grounds its basis on IEEE 802.15.4 standards, which is targeted at low rate Wireless Personal Area networks (WPAN). IEEE 802.15.4 standard concentrates on the lower two layers of the protocol stack to define the fundamental communication techniques for instrument networks that require much more extra work for producing marketable product. The ZigBee specification is developed for utilizing the features that are supported by IEEE 802.15.4, specifically the low data transmission rate and energy consumption features. Its goal is controlling and monitoring applications, in which case low-power consumption is a basic requirement. The candidate applications are wireless sensors, lighting controls, and surveillance. Zigbee is a popular specification for wireless personal area network useful for conveying information within short distances. Zigbee contains three categories of devices, PAN Co-ordinator, Router and End devices.

Cross layer design may be defined as, “the breaking of OSI hierarchical layers in communication networks” or Zigbee routing protocol by various challenges owing to a number of attributes from other adhoc wireless networks. The PAN co-ordinator keeps a record of the entire network information and it is responsible for acceptance and rejection of nodes as per the parameters. Routers are positioned as in-between node for transmitting the routing message from source node to sink. In addition, routers can allow a new router or end device to join with the newly presented network by address assignment and construct link to transport data packets to sink nodes. End device perform the functionality of leaf node with restrictions. It simply can be used in sensing data as well as for transmitting to the router and it possesses low energy

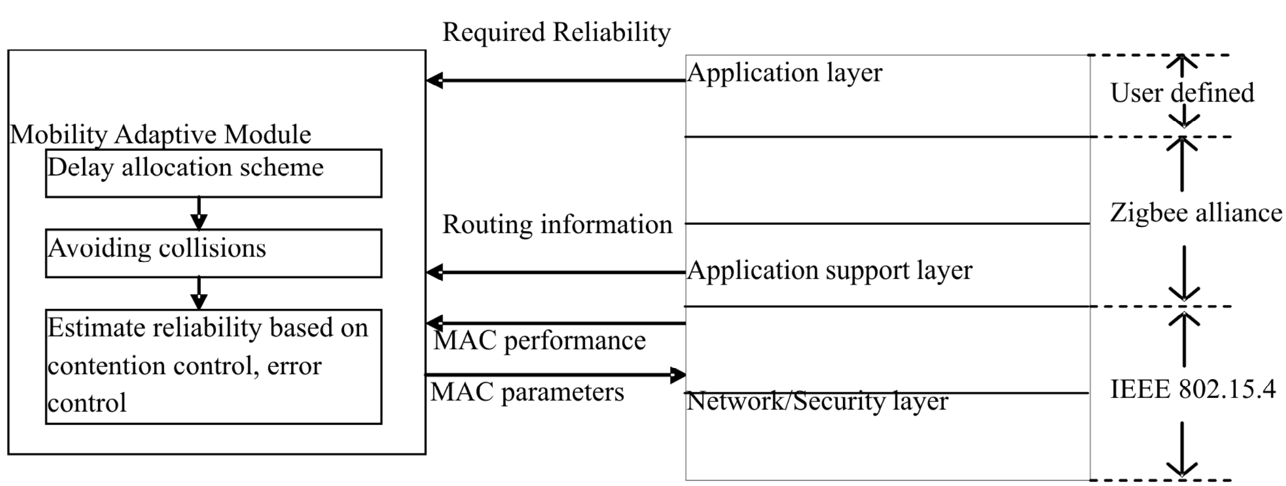

Figure 2: The cross-layer mobility adaptation module

(b) Adaptive Access Parameters Tuning (ADAPT)

The presented solution for adaptive data collection is cross-layer, and is involved with a mobility adaptation module that has its interactions with the different layers of the WSN protocol stack (Fig 2). The scheme proposed follows the approach in [22], in which a vertical component is appended to the layered architecture to enable the sharing of information between the various layers of the protocol stack. This prevents the duplication of efforts to gather internal state information, and results in a more effective system design, since the information gathered by the adaptation module can be utilized for the optimization of the protocols' functions [21]. Consequently, the information that comes from one layer can be brought into use for tuning the operations of protocols that reside in another (non adjacent) layer. Next, a mobility adaptive scheme is presented for a robust and energy-efficient data collection in WSNs. The goal of the proposed research is satisfying the reliability requirement as specified by the application with the support of a distributed and low-overhead algorithm which expends low energy, with particular reference to the IEEE 802.15.4 and ZigBee standards. For this purpose, a heuristic algorithm referred to as the ADaptive Access Parameters Tuning (ADAPT) is proposed, that estimates the present traffic conditions, and modifies MAC parameters in accordance with the necessary degree of reliability.

(c) Impact of MAC parameters

Subsequently, the effect of individual MAC parameters is characterized based on the delivery ratio and power consumption. The proposed research analyses the measures for MACMINBE (the minimum backoff exponent), MACMAXCSMABACKOFFS (the maximum number of backoffs, i.e., transmission attempts), and MACMAXFRAMERETRIES (the maximum number of retransmissions), as they have the most important impact on the metrics considered.

(d) Contention control

The contention control scheme begins from a measured (original) delivery ratio, d_i, in proportion to the i^{th} BI, obtained as the ratio among the amount of messages acknowledged through the destination and the number of messages transmitted by the source node. In order to make robust model extremely less sensitive to unexpected variations in the measured delivery ratio, a smoothing scheme is utilized to acquire the estimated delivery ratio, $\hat{d}_i$. More particularly, an exponential moving average is applied as given below:

$$\hat{d}_i = \delta.\,\hat{d}_{i-1} + (1-\delta).d_i \quad (1)$$ Where $\delta \in [0, 1]$ represents a memory factor.

(e) Error control

There are fundamentally two schemes for error control, namely *adding redundancy to sent messages* or *exploiting timeouts/ acknowledgements and retransmissions* [25]. In the specific circumstance of WSNs based on the IEEE 802.15.4 standard, the MAC layer offers error control in the structure of Automatic Repeat reQuest (ARQ). Scheme in accordance with redundancy are not applicable, because they would necessitate modifications to the physical or MAC layer of IEEE 802.15.4, consequently making the related solutions not compliant with the standard. As a result, in the following the ARQ scheme is utilized which is offered by the IEEE 802.15.4 MAC for error control functions. With the intention of decoupling the effects of the noisy channel from other aspects, it is essential to estimate the message loss as well as the delivery ratio. In particular, the message loss l_i is measured, in proportion to the *i*-th BI, since the ratio among the messages discarded because of exceeded number of retransmissions and the overall amount of messages sent in the last BI. As like the scheme utilized for the delivery ratio, an exponential moving average is also applied to extract the estimated message loss $\hat{l}_i$ as follows:

$\hat{l}_i = \psi.\hat{l}_{i-1} + (\psi).\, l_i$ (2) Where ø” [0, 1] represents a memory factor.

(f) Proposed Robust Model MAC design

In WSNs, contention based protocols were makes use of random backoff scheme for avoiding collision. The random backoff delay with the aim of resolving the collisions, however, since the amount of nodes increases the probability of nodes choosing the same backoff increases consequently resulting in access collision. Here, a novel MAC presented which determines not only the complication of access collision. However, collision caused through hidden nodes by employing robust model MAC scheme. It solves the complication of collision through allocating delay to each node joining the network more willingly than choosing the delay arbitrarily. Further, it can improvise the throughput and reduces the number of retransmission occurrences. In addition, robust model MAC reduces the association time for the nodes, which are moving from one cluster to another significantly without incurring energy losses and computational complexities. As a result, solve one of the key concerns of mobile sensor MAC protocols. The robust model MAC initiates priority, which enhances the effective utilization of the available channel bandwidth as compared against the other mobile standards and protocols. Robust model MAC makes use of cluster tree topology. The transmission of every successful frame in robust model MAC undergoes five major stages:

Stage1: The contending node gets hold of the backoff delay in accordance with the priority of the node from the coordinator, which is not an arbitrary value. The coordinator includes different values in a delay table, which it maintained and assigns the delay values to the requesting node from this delay table. The priority information is transmitted by the node to the coordinator for the first occasion when it is associating with the coordinator and subsequently transmits the update on priority following every successful data transmission in order to obtain next delay value from the coordinator. When the priority of data buffered in the node is different, then transmitting first data packet the node request a new delay value from the coordinator in accordance with the existing status of priority. If mobile node moving from one cluster to another, it always has the high priority. When there are above one node having the similar priority level, subsequently the coordinator provides the least possible delay to the node, which transmits the request first. On the other hand, in order to maintain fairness between the nodes same node will not be given lower delay for the second time if there is no other competitor node accessible in the cluster, which has the similar priority level. The only possibility of collision is during the stage when there are several nodes trying to carry out association phase with the coordinator for the first time. With the aim of mitigating this complication, wait timer is introduced in order that the joining node does not hinder with the ongoing data transmission within the cluster.

Stage 2: Node comprising data packet in the buffer undergoes the acquired backoff delay value prior to transmitting the packet.

Stage 3: Transmit the request signal and initialization of response timer.

Stage 4: Sending of data in addition to reception of acknowledgement of data packet is received.

Stage 5: Get hold on new delay values from the coordinator in accordance with the priority status, which provide a fair chance to other competing nodes. When the node has high priority data, subsequently the coordinator will give least possible delay value from delay allocation table. New delay value in proportion to the priority of the node. Mobile nodes are constantly given more priority once they are coming into the cluster, following that normal procedure is adopted. This guarantees that the entire nodes are given fair chance to access the channel and enhances the network response to real time data traffic on the fly. This protocol can be subdivided into two major phases, which are the Initialization and Running phases respectively.

(g) Initialization Phase

If nodes come into the network for the first time, they carry out the initialization process shown in fig 3. The new joining nodes transmit their request to connect the network together with their data priorities to the coordinator. When a node is mobile and receive signal from neighboring cluster coordinator, it will observe the signal strength. Since, the signal strength continues to be strong; the node requests the current cluster coordinator to assign the delay from the neighboring cluster. The coordinator chooses the appropriate delay values based on the priority information transmitted by the node to the coordinator. The delay value is obtained from the delay allocation table. In addition, if the request is initiated from neighboring cluster coordinator, the delay is assigned to a mobile node moving the similar direction. The nodes after obtaining the respective delay from the coordinator wait for the data packet to be arrived in the buffer. The process is appropriate for high mobile network, where nodes are moving from one cluster to another repeatedly.

Since, node starts upon receiving the data packet in the buffer it undergoes backoff delay, which it accepts from the coordinator at some point in the initialization phase. Since the node terminates backoff delay, it begins to sense the channel for any ongoing activity, when it finds the channel available it transmits the request to send signal (RTS) to the coordinator and at the same instance activates the response timer. The coordinator upon getting the request from one node triggers the timer. Since, the timer of the coordinator terminates, it transmits the clear to send (CTS) signal to the node, its RTS is being obtained by the coordinator at some point in the period in which the response timer was active. The coordinator with the CTS also transmits the sleep schedule to remaining nodes in the network. In this manner, the nodes can conserve the energy in addition to the problem of collision because of hidden node is resolved. Upon receiving the CTS signal from the coordinator the participating node, transmit the data in the direction of the coordinator. The coordinator transmits the acknowledgement signal to the node with the new delay value, in order that all the nodes will be able to communicate in the direction of the coordinator.

6. CONCLUSIONS

In this work, robust model is proposed to improve the energy efficiency of IEEE 802.15.4 WSNs. Majority of MAC protocols proposed for WSNs assume static nodes, which typically causes ruin in WSN performance in circumstances involving wireless sensors. In order to overcome before mentioned complication, here robust model is proposed to enhance the energy efficiency through Cross Layer approach. This proposed method is adaptive for different operating conditions, for both single-hop and multi-hop networking scenarios.

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