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Analysis and Evaluation of the Contention Access Period in Slotted CSMA/CA for IEEE 802.15.4 Networks

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Abstract

Because of its widespread relevance, IEEE standard 802.15.4 is the subject of much research. This comparative analysis relies on the analytic procedures and procedures detailed in the IEEE 802.15.4 standard within the framework of a contention access time frame. Standard specifications indicate that the CSMA/CA algorithm used in CAP has two minor variations, and that it operates on distinct frequency ranges. In these spectral regions accepted in many parts of the globe. Depending on the kind of media access method used, only one flavor will acknowledge a successful transmission with an ACK frame. While previous studies have extensively simulated the CSMA/CA ACK mode, there has been no research examining the behaviour of the non-ACK mode. For use cases that aren't very concerned about receiving an acknowledgment of each transfer, IEEE 802.15.4 recommends switching to the non-ACK mode. We adapt a Markova chain model to the non-ACK mode, do lengthy simulations and debates, and draw conclusions on the relative merits of the two forms. While ACK mode proves its utility in medical settings, non-ACK mode is often used for streaming data or playing games because to its reduced latency, better throughput, and lower control burden.

1. Introduction

Because of the rapid evolution of our planet, it is now essential that all facets of human existence be mechanized. As a result of this automation, we humans are constantly surrounded by processors that analyze a wide variety of characteristics. The field of communication is where these transformations, often known as information, are sent, stored, and ultimately used. Processing is combined with, Networks are born from the need to transport, store, and make use of this data, first through wires and later via wireless connections. As we go into the realm of wireless technology, many new networks are suggested for various uses. Wireless sensor networks (WSNs) are a relatively new area with vast potential for practical use. Tiny sensors with limited battery life and processing power make up these networks.

Wi-Fi LANs are defined by the IEEE 802.15 working group, which has subgroups for various WPAN enhancements. IEEE 802.15.4 [1] is an addition within these that prioritizes low data rates and extended battery life. Because of its ease of use, durability, and versatility, the IEEE802.15.4 standard has garnered attention from both academics and businesses. In contrast to other approaches (WiFi), this one places an emphasis on using as little resources as feasible while yet facilitating communication between devices. This specification was developed to provide for a data throughput of 250kbps and a communication range of 10 meters. ZigBee, ISA100, Wireless HART, and the Midi alliances are all built on top of this Standard, which defines the MAC and Physical Layers. A device may function in either a contention free period or a contention access period in the MAC sub layer. During the contention-free interval, a node may schedule guaranteed time slots, and during the contention access interval, carrier sense multiple access with collision avoidance is employed, however with some tweaks from the previous standards. There are three distinct frequency ranges in which IEEE802.15.4 may function at the physical layer. This study examines the viability of the IEEE802.15.4 contention access period over three distinct frequency allocations, as suggested by the title.

2. Related Work

If a node with a packet to transmit requests and receives channel access and decreases the back off counter by one, it is allowed to transmit; otherwise, it is denied. This is according to IEEE802.11 [2]. If we take IEEE802.15.4 into account, the back off counter will be reduced whenever the channel is either accessed or discovered to be in use. Since these differences piqued the curiosity of Researchers, they set out to develop mathematical models of Early studies [4-7] on IEEE802.15.4 used Markova chain models without considering the super frame structure. [8] Added to the study by taking into account super frame structure. In order to better represent the aforementioned standard, [9] suggested a model for slotted CSMA/CA. Probabilistic estimates of dependability, energy consumption, and latency were first estimated by the authors of [10], and were then refined by the authors of [11] and [12]. In [13], the author presents the results of an investigation of the performance of all frequency assignments listed in the referenced standard book [1].

Taking into account medium access strategies of contention access time, [14-16] provides a comparison of several systems that may be implemented in body area networks. Key parameters of route loss, latency, and good put were used to observe access schemes such time- and frequency-division multiple-access, pure and slotted Aloha, and CSMA/CA. Research into the efficiency of CSMA/CA in IEEE802.15.4 is extensive, however the standard language also specifies a non-ACK mode for use in situations when receiving an acknowledgement of a sent packet is not strictly necessary. If this control packet is missing, CSMA/CA still functions normally. In this research, we use a Markova transitional model (an improved version of [10] and [12]) to compare the ACK and non-ACK modes over all three frequency assignments specified in [1] for the aforementioned standard. We simulate the core aspects of any protocol using a Markov model and then compute transmission, delay, and channel access probabilities for comparative study in MATLAB. This section of the paper is structured as follows: Section 3 provides an introduction to IEEE 802.15.4 (MAC and Physical Layer aspect), Section 4 discusses probabilistic modelling of ACK and non-ACK mode of CSMA/CA, Section 5 presents simulation findings and Section 6 concludes.

3. An Overview: IEEE 802.15.4

MAC SUBLAYER

The MAC layer is responsible for transmitting data and offering management functions. Data services focus on ensuring the smooth operation of transmission/reception (MPDU's) operations in line with the physical layer, whereas management services tend to interface between higher levels with the MAC layer. The most important function of this, in terms of the IEEE 802.15.4 standard, the layers underneath never shift while there are changes to MAC from earlier standards [11]. The super frame structure of MAC may be divided into two categories, shown in fig. 1 as active and inactive. All processes involving data transmissions and receptions are carried out in the Active section of the super frame structure. When made with slots,

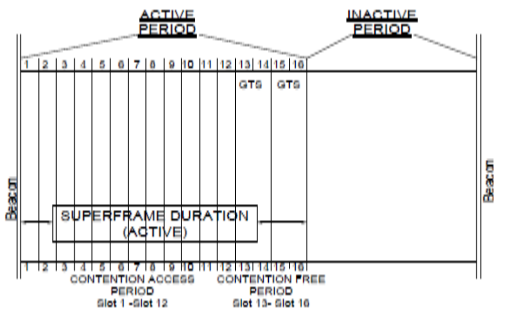


Fig. 1. Super frame Structure

This duration of activity is divided into regular increments. In the event of a packet collision, transmissions always begin at the beginning of one of these time periods. In addition to these features, active period has two more domains. The Conflict Access Period (CAP) and the Conflict-Free Interval (CFP). Differing Opinions free period, a point coordinator handles channel allocation, and nodes that choose CFP are each assigned a window of time during which they may send data without having to contend with other nodes for access to the channel. CAP, on the other hand, is founded on best-effort policies and practices. If many nodes want to share a single channel, they must all agree on the CAP active-period mode. The CSMA/CA method was mandated by IEEE 802.15.4 to provide rapid channel access. There are some minor adjustments made to the protocol in this standard that are in line with the use cases and constraints that have led to its widespread adoption and use (power and computational limitations). For example, in IEEE 802.15.4 [1], CSMA/CA conducts two clear channel evaluations convectively to get access to the channel, but in [2], only one clear channel assessment is performed. In this study, we zero in on the contested access time frame for a closer examination and assessment. This protocol, like any other, consists of a series of steps. A node in this network enters a sleep state at the outset of the network that this protocol is based on. Currently, it is in a state of "active waiting," during which it awaits the transmission of an upper-layer data packet. In addition, the retransmission counter, the contention window counter, and the back off counter are all created. To begin, the MAC layer must restore the following values to their defaults: Number of bakeoffs (NB = 0), Contention window (CW = 2), Back off exponent (BE = machine), and Retransmission times (RT = 0). The node transitions from the idle state to the channel sensing state when a packet from the network layer reaches the MAC layer.

Channel sensing is followed by an arbitrary hold time of mutes to two times the baseband error rate (BE-1). The sensing state of a channel is reached after two consecutive clear channel evaluations have been made without interference. (CCA). The contention window counter is reset to zero when the second CCA is completed successfully. Channel sensing has concluded, and the transmission state has begun, signifying that the channel has been accessible and a data packet is ready to be sent. Whenever a CCA attempt fails, the back off counter is increased by one, and the packet is put in a holding pattern until the counter reaches the maximum value specified by macMaxCSMABackoffs and macMaxBE. If the value surpasses the cut-off, the packet is deleted. Either the packet has been successfully transferred or there is an error.

Table 1. Slotted CSMA/CA MAC Parameters (IEEE 802.15.4).

Parameters	Value
macMinBE	3
macMaxBE	5
macMaxFrameRetries	3
ACK reception Time	*aTurnaroundTime + aUnitBackoffPeriod*
LIFS (for Larger packet)	40 Symbols
IFS (for smaller packet)	12 Symbols

They collided, which is what happens. If the transmission was successful, the node will enter an idle state and wait for the next packet to arrive from the network layer. However, if a collision occurs, the retransmission counter is increased, and the data packet is queued for a random back off time. Both the contention window counter and the back off counter are reset to zero when the back off period is complete. Defaulted to (CW = 2, BE = machine). Once again, the channel has to be detected, accessed, and sent per the outlined steps. A maximum number of retries will be made before giving up on a stalled transmission. Whenever the number of attempts approaches

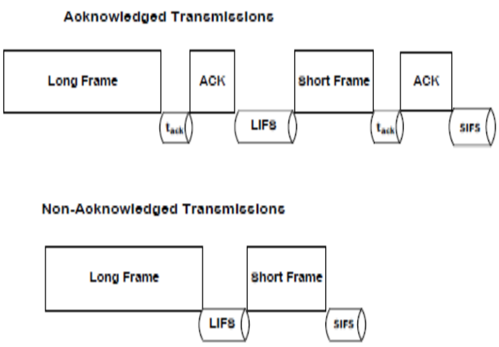


Fig. 2. Packet Transmission in IEEE 802.15.4

The packet is dropped and the node enters a sleep state if macMaxFrameRetries is exceeded. There are several protocols for different procedures. Modes of acknowledgment (ACK) and non-acknowledgement (NACK) are available. Once a packet has been received successfully in ACK mode, the receiver will emit a control packet to confirm the packet's arrival. ACK packet not received by sender for any reason In this case, the retransmission counter is increased and the packet must be sent again per the protocol. There is no specific mechanism for sending an acknowledgement of receipt (ACK) packet; they are simply broadcast once a data packet has been successfully received [1]. While this control packet is not necessary for the protocol to work in non-ACK mode, it does not hurt either. In this mode, data is sent and considered successfully sent if and only if there is no collision. There is much less of a danger of a collision now that we have two distinct channels assessed. This assertion is briefly examined in the remainder of this research. In order to facilitate the exchange of information, the MAC layer established a range of gap sizes between frame transmissions. These empty regions, known as inter frame space, are strategically positioned to prevent collisions caused by variables like delay in signal transmission. Short inter frame space (S IFS) and large inter frame space (L IFS) are the two most important forms of inter frame space that we care about (LIFS). Between relatively tiny data/control frames, (S IFS) is utilized, but for bigger chunks of data, (LIFS) is preferred.

PHYSICAL LAYER

IEEE 802.15.4 may operate in the 868MHz, 915MHz, or 2.4GHz bands, as specified by the standard. Speeds of 20 Kbps, 40 Kbps, and 250 Kbps are provided by all three. There are a total of 27 channels available in these frequency ranges. The 868MHz band is assigned to Channel 0, the 915MHz band is allocated to Channels 1-10, and Channels 10 and 11 are reserved for use in the 700MHz spectrum. 26 candidates have been put up for the 2.4GHz spectrum. Symbol rates of 20KSymbols/sec, 40KSymbols/sec, and 62.5KSymbols/sec are used with the BPS K modulation scheme in the 868MHz and 915MHz bands, and with the O QPS K modulation method in the 2.4GHz band. The central concept of this investigation is the Contention Access Period (CAP), which employs slotted CSMA/CA. The physical layer modes required for channel evaluation are detailed in the IEEE 802.15.4 standard. Any of these configurations may be used in a network to get the desired effects. According to Mode1, if the physical layer detects an energy level greater than a certain threshold, it must flag the channel as busy. If the physical layer discovers a signal with the same modulation and spreading scheme while using Mode2, it will indicate the channel as busy. In Mode3, the physical layer does more than just detect the energy level; it also synchronizes with the modulation technique. When such pattern is found to be a match, the status "channel busy" is reported. [1]. When it comes to data transmission and reception, the latter is prioritized. When a node that is currently receiving data has no more packets to receive, only then will it try to access the channel. For this project, we zeroed down on the IEEE 802.15.4 standard.

Table 2. Frequency Assignments for IEEE 802.15.4

Frequency Assignment	Number of Channels	Channel Bandwidth	Symbol Rate	Data Rate	Modulation Scheme
868-868.6 MHz	1	600KHz	20KSymbols/Sec	20Kbits/sec	BPSK
902-928 MHz	10	2MHz	40KSymbols/Sec	40Kbits/sec	BPSK
2.4-2.4835 GHz	16	5MHz	62.5KSymbols/Sec	250Kbits/sec	O-QPSK

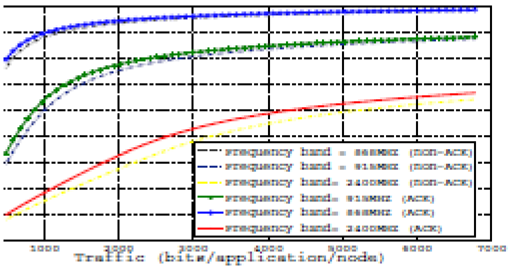
By making use of three common frequency ranges to compare different metrics. Not only do we support all of the required frequency ranges for

IEEE 802.15.4 CSMA/CA, but we also implement both the acknowledged and non-acknowledged varieties. We adapt the slotted 802.15.4 Markov model proposed by Park et al. [10] for non ACK mode. As a means to evaluate our talks via simulation (using MATLAB). All of the values have been established in line with canonical texts.

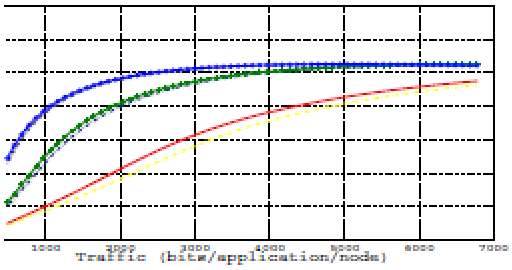
4. Analysis and Results

Channel Accessing

It is protocol standard for the MAC layer to continue transmitting after a random delay after receiving a packet to send. After this time has elapsed, it will begin detecting the transmission medium in preparation for packet transfer. As was previously mentioned and as is the norm, a node will send two consecutive clear channel evaluations to First CCA transmission are critical to channel access. The likelihood of developing CCA2 increases when CCA1 is picked up. CCA1 is more likely to occur while using CSMA/CA in its non-acknowledged mode. To determine which frequency range is optimal for IEEE 802.15.4, we run simulations of the protocol at 868 MHz, 915 MHz, and 2.4 GHz. The effect of the ACK packet is greatest at the 858MHz transmission range, as compared to the other two higher ranges. The rationale for this is straightforward: a longer communication range means less time spent waiting for messages to pass. The likelihood of CCA1 being busy is maximum at 858MHZ, and rises progressively as traffic load rises over 1000 bits per application/node. In the other two frequency bands, however, the likelihood of CCA1 being busy is significantly reduced. Comparing



(a)



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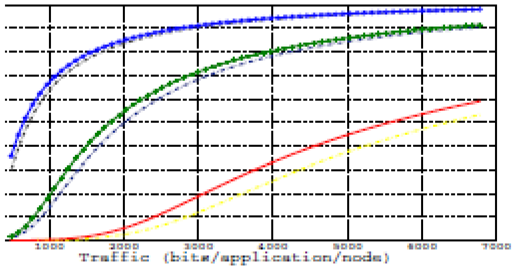
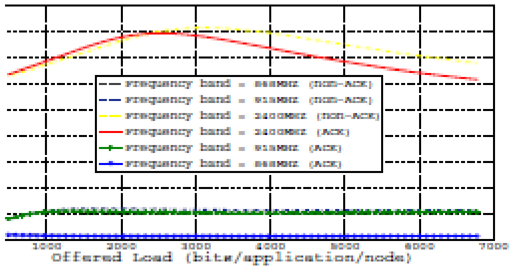


(c)



(d)

Fig. 4. (a)Busy Channel Probability during CCA1, (b) Busy Channel Probability during CCA2, (c) Discarded Packets Probability due to Channel Unable to Gain Access, and (d) Packets Being Thrown Away Figures 4a and 4b show the results of the retry limits for CCA1 and CCA2, respectively, and reveal an important fact: the likelihood of encountering a busy CCA1 is greater than that of a busy CCA2. This seems sense, given that CCA2 includes Probability of CCA2 being in use because of an ACK packet is vanishingly small. Since data packets are longer than ACK packets, there is a higher probability of success with CCA2 if CCA1 is completed successfully. The findings are consistent regardless of the frequency range considered, with greater ranges yielding superior performance. The protocol specifies a mechanism wherein each node will make a limited number of attempts to acquire a channel. When that counter reaches zero, the packet is thrown away. Simulation findings suggest that CCA1 and CCA2 are more likely to be obtained effectively at 2.4GHz. This is also demonstrated by our

simulations of the likelihood of packets being destroyed as a result of a failed attempt to access the channel. Figure 4c shows that the ratio of the chance of packet drops is highest at 858MHz, then drops to a minimum at 915MHz, and finally reaches a minimum at 2.4GHz.

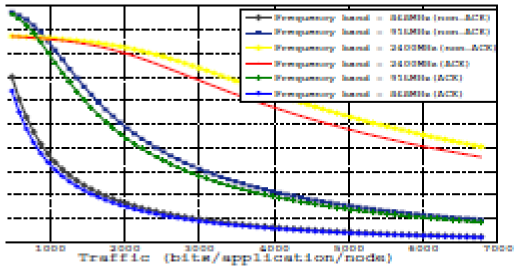
Packet Transmission

Once a node successfully obtains two CCAs, it immediately begins transmitting the packet it has been holding. Although the method greatly reduces the prospect of collisions, they are not eliminated entirely. If a collision occurs, each node is required to resend the packet a certain number of times according to the protocol standards. At the point that that counter reaches a maximum packet size above which no further action is taken. The ACK and non-ACK modes of the protocol display contrasting behaviours, as seen in Fig. 4d. In this case, ACK mode of CSMA/CA dominates non-ACK mode at higher frequencies while maintaining parity in the 858MHz range. Either the transfer was successful, or the packet should be discarded. Each node's protocol will automatically update and replicate itself.

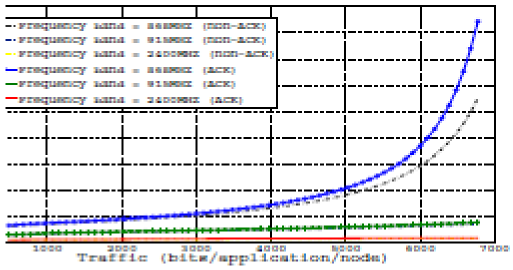
5. Performance Metrics

Reliability

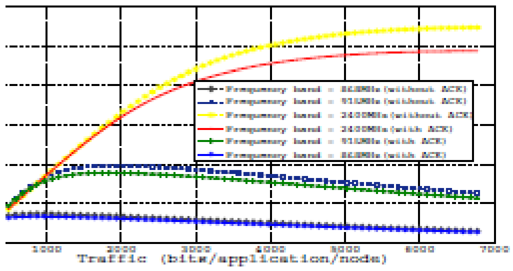
Packet loss as a result of failed channel access or excessive retries reduces the likelihood that a transmission will be successful. The number of successful transmissions is a measure of reliability. Above, we modelled the likelihood of a packet being lost in a network. We need to sum and visualize these packet-loss probabilities in order to get a reliability estimate. Inversely. Taking into account the simulated outcome, we learn that the 915MHz band has an extremely high dependability right off the bat, nearly reaching 1 for a short period of time, and then a significant fall. The 858MHz band has the same gradual loss of dependability as the other two bands, but at a far faster rate. There is a general decline in dependability as traffic grows throughout all frequency bands; however, IEEE 802.15.4 (slotted non-beacon enabled CSMA/CA) performs much better in the 2.4 GHz range because the degree of declination is less severe. When comparing the two modes, non-ACK mode is preferable due to its lower control overhead and greater channel access probability. The dependability probability curve outlined previously is shown in Fig. 5a.



(a)



(b)



(c)

Fig. 5. (a) Reliability Factor (Probability) Vs Traffic Load, (b) Delay (Probability) Vs Traffic Load, (c) Throughput (Probability) Vs Traffic Load

Delay

The amount of time it takes for a protocol to complete an operation is one of the most important metrics to consider. In this research, we examine this performance parameter across various implementations of the IEEE 802.15.4 standard, since there are cases in which delay cannot be allowed. Delay may be broken down into two distinct phases. One is lag caused by the protocol algorithm itself, which includes back offs and collisions, etc., whereas the latter relies on variables like as packet size, transmission duration, and gap sizes between frames. The simulation results demonstrate that the 2.4GHz band has the least amount of delay compared to the other two frequency bands because of the shorter length of the back off slot. Non-ACK mode is used because of its ease of use and low control overhead (fig.5b).

6. Conclusion

The contention access period of IEEE 802.15.4 was the primary research topic. Both the ACK and non-ACK modes recommended by the canonical text are studied analytically and simulated to test the effect of the ACK packet on the algorithm. Based on our research, in situations when real-time health monitoring is essential, Even if sensors aren't surgically implanted, ACK mode becomes useful because of its low packet loss ratio. Nevertheless, non-ACK mode outperforms ACK mode because to its improved throughput, excellent put, and reduced latency, control load, and battery life when used for streaming data or applications that do not need ACK of every sent packet. Higher frequency assignments may seem to increase energy consumption, but they actually reduce packet loss, delay, and difficulty in gaining access to channels.

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