Investigating Impact of $ACK$ in Non-Beacon Enabled Slotted IEEE 802.15.4


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Abstract—IEEE 802.15.4 standard is gaining attention of researchers day by day due to its wide application arena. Till now numerous studies have conducted and yet lot more is in progress for understanding and rounding off sharp edges of this standard. This study briefly describes the standard i.e. IEEE 802.15.4 and explicitly non-beacon enabled slotted CSMA/CA. In slotted or non-beacon enabled CSMA/CA there are further two flavors. One deals with transmission of an extra control packet ($ACK$ frame) on successfully reception of data packet however, other flavor do not transmit any control packet representing successful transmission. In later part of this paper, extensive simulations are conducted in comparison with these two flavors. Our studies imply to use non-$ACK$ mode in low scalable environment ensuring high probability of getting channel access, low delay and better good put.

Index Terms—802.15.4, slotted, CSMA/CA, MAC, Modeling, Markov, State, diagram.

I. INTRODUCTION

Low energy, low data rate and low latent distributed networks are today’s need. In almost every field of life such networks are gaining their rightful place. Wireless personal area networks or wireless sensor networks or body area networks have different applications that need to get excellence. For that purpose, IEEE802.15.4 standard is receiving substantial attention in academia/ research and industry arena as well. Numerous experimental studies are conducted on various functionalities of this standard, refining and explaining its philosophy even better.

A. IEEE 802.15.4 MAC SUBLAYER

In said standard, MAC sub layer is responsible of providing MAC data services and MAC management Services. MAC management services interfaces with network access point while MAC data services enables smooth transmission and reception of MPDUs to and from physical layer.

MAC Super frame clearly defines the processes and protocols being utilized in data transmission. As shown in fig.1 super frame is divided into two portions, i.e. active period and inactive period. Moreover, it is divided into equal sized slots. In active period, two functions are deployed i.e. distributed coordination function (DCF) and point coordination function (PCF). DCF defines Contention Access Period (CAP) while PCF relates Contention Free Period (CFP). In CFP, a point coordinator takes control of rest of the normal node’s transmission and reception with the help of a periodic beacon message. However, in CAP, nodes get access to channel in best effort fashion using CSMA/CA (a widely accepted MAC protocol). For contention access period, in enabled IEEE802.15.4 adopted slotted version of CSMA/CA however, it is different from previous IEEE802.11 standard[1][2].

The standard suggests two mechanisms for accessing channel. One in un-slotted fashion which is beacon enabled and 2nd one is slotted or non-beacon enabled.

If a network is initialized in slotted CSMA/CA mode of IEEE802.15.4 and a node wants to access channel for transmission, MAC sub layer is bound to reset the following four parameters

1) Number of backoffs (NB=0)
2) Contention window (CW=2)
3) Backoff exponent (BE=macMinBE)
4) Retransmission times (RT=0)

Once these variables initialize, node has to wait for a back off period within range of $[o − to − 2^{BE} − 1]$ interval. After completion of this back off tenure, the node has to sense channel. This sensing in CSMA/CA is termed as clear channel assessment (CCA). If node finds idle channel after

![Superframe Structure](image-url)
The reception of the corresponding ACK is interpreted as successful packet transmission. If the node fails to receive ACK due to collision or ACK timeout, the variable RT is increased by one up to macMaxFrameRetries. If RT is less than macMaxFrameRetries, the MAC sub layer initializes two variables (CW = 0, BE = macMinBE) and follows the CSMA/CA mechanism to re-access the channel. Otherwise the packet is discarded after it exceeds retry limit. This ACK frame do not follow main CSMA/CA procedures[1]. However, in non-ACK mode, data is transmitted and is considered to be reached at its destination within a calculated time frame if no collision occurs. Sensing channel two times before sending a packet eliminates huge probability of collision by itself.

During communication MAC defines a fixed tenure between two consecutive transmissions. This fixed tenure is termed as Inter Frame Space (IFS) and is placed so that forwarded data can be processed by physical layer or vice versa. However, for longer chunks of data, Standard defined a Long Inter Frame Space. Fig.3 represents this concept more clearly.

B. Default MAC parameters for Slotted CSMA/CA (IEEE 802.15.4)
- macMinBE = 3
- macMaxBE = 5
- macMaxFrameRetries = 3
- ACK reception Time = aTurnaroundTime + aUnitBackoffPeriod
- LIFS (for Larger packet) = 40 Symbols
- IFS (for smaller packet) = 12 Symbols

II. RELATED WORK AND MOTIVATION

Considering IEEE802.11, back off counter decrement by one if they found any vacant channel ready to accept any data for transmission, else it is blocked. Contrary to this, in IEEE 802.15.4, said counter decrements in either case (channel is free or busy). Considering such contradictions, there was a need of establishing mathematical facts regarding IEEE 802.15.4. For that purpose different researchers, [4-7] presented their state transitional model using Markov chains for slotted CSMA/CA. The above mentioned researches were conducted without considering super frame structure however, [8] gives such an analytical model. Getting the work further ahead [9] proposed Markov transitional model for slotted CSMA/CA taking super frame structure into account.[10] considerably calculated reliability, normalized delay and energy using probabilistic state transitions further modified by [11]. However,till now, work is done on ACK based slotted CSMA/CA for IEEE802.15.4. In this study, we take mathematical models presented by [9] and [11] to modify analytical study for ACK less slotted CSMA/CA considering said standard.

Fig. 2. Flowchart: Slotted CSMA/CA

Fig. 3. Packet Transmission in IEEE802.15.4

Two convectively performed CCAs, it will transmit its data. If channel is found busy in performing CCA, number of back off and back off exponent variables will be incremented reaching up to maximum value of macMaxCSMABackoffs and macMaxBE. If number of back offs reach its maximum value, node has to abandon its transmission of said data packet.

If channel access is successful, node will transmit its data. Now there are two procedures involved. Acknowledge based or non-acknowledge based. In acknowledge based procedure, node will wait for the ACK of transmitted packet.
Amongst many, the main features of any protocol is its reliability, latency, throughput and energy consumption. Considering these parameters a lot of experimental and analytical work has been done. It is an established fact that, there always is a tradeoff between different attributes or functionalities of a network. Studying the points where these tradeoffs work in desirable fashion is the key point. In our work, we focus on this vary statement and studied the impact of control load (ACK frame) on reliability, delay and throughput with respect to number of nodes of network.

III. Modeling Slotted CSMA/CA

A. State model for 802.15.4

Let us suppose that as in [9] and [11] there are three stochastic processes i.e. backoff stage = \( b(t) = i \), backoff Counter state = \( c(t) = k \) and retransmission counter stage = \( r(t) = j \). We denote the MAC parameters by

\[
W_0 = \gamma_{macMinBE}
\]

\[
m_0 = macMinBE
\]

\[
m_b = macMaxBE
\]

\[
m = macMaxCSMABackoffs
\]

\[
n = macMaxFrameRetries
\]

Backoff States = \((i, W_m - 1, j)\) to \((i, W_0 - 1, j)\)

Idle states = \((Q_{i-1}Q_{j-1})\)

Let \( q_0 \) the probability of going back to the idle state \( Q_0 \)

\( p_b \) be the probability that a transmitted packet encounters a collision

\[-1; k; j] = \text{Successful Transmission}
\]

\[-2; k; j] = \text{Packet Collision}
\]

\[(i; 0; j) = \text{Clear Channel Assessment 1}
\]

\[(i; 1; j) = \text{Clear Channel Assessment 2}
\]

\( \alpha \) = CCA1 is busy

\( \beta \) = CCA2 is busy

We know that sum of all the state probabilities yield 1 hence

\[
\sum_{i=0}^{m} \sum_{k=0}^{n} \sum_{j=1}^{m} b_{i,j,k} + \sum_{i=0}^{m} \sum_{j=0}^{n} b_{i,-1,j} + \sum_{j=0}^{n} \sum_{k=0}^{m} b_{-1,k,j} + \sum_{k=0}^{m} b_{-2,k,j} + \sum_{i=0}^{n} = 1
\]

\[ (1) \]

Fig 4 represents state diagram for slotted CSMA/CA Markov chain model with respect to the stages referred above.

B. Slotted CSMA/CA: ACK Vs Non-ACK

Studying two modes of CSMA/CA using Markov Chain models reveal interesting facts. Considering ACK mode, as discussed in [13] probability of getting first clear channel assessment busy has two sub divisions. Channel can be found busy due to data traffic or due to ACK packet. It proves that, this ACK packet is one cause of finding channel busy out of two, going forth of rest of transition states, we come to know that getting clear channel for data transmission has key role in network performance. If a node gets higher probability of accessing free channel, not only probability of collision, probability of retransmission, probability of throughput/good put gets better but also lower the probability of coming to back off state that certainly results in minimizing packet drop ratio. On the other hand, this ACK packet is used only to ensure transmitter about successful delivery of data.

In this study, we have compared these two procedures i.e. Slotted CSMA/CA for 802.15.4 with and without ACK using three dimensional Markov model. Model is tested and simulated using MATLAB with scalability scenarios of 5 nodes per network and 50 nodes per network keeping rest of the parameters according to IEEE 802.15.4 specifications.

C. Clear Channel Assessment

In Slotted CSMA/CA every node before transmitting its packet needs to get two consecutive CCA’s. This step is very critical in overall performance of routing protocol. [11] enhanced the probability (earlier calculated by [9]) of a node for transmitting a packet or attempting for CCA1 tau (\( \tau \)) as

\[
\tau = \frac{1}{1 - P_0} \left( \frac{(1 - x)^{m+1}}{1 - x} \right) \left( \frac{(1 - y)^{n+1}}{1 - y} \right)
\]

\[ (2) \]

\[
\tau(1 - p_0) = \left( \frac{(1 - x^{m+1})}{1 - x} \right) \left( \frac{(1 - y^{n+1})}{1 - y} \right) b_{0,0,0}
\]

\[ (3) \]

\( \alpha \) and \( \beta \) with ACK: Alpha is failurein CCA1 while beta is failure in CCA2. Alpha and beta are the bases of CSMA/CA performance. Change in probability of alpha or beta effect the whole of the network model. According to [13] \( \alpha \) or not getting CCA1 has two parts. One is due to data packet collision (\( \alpha_1 \)) and other is due to ACK packet (\( \alpha_2 \)). Hence

\[
\alpha = \alpha_1 + \alpha_2
\]

\[ (4) \]
Comparing ACK and non-ACK CSMA/CA schemes it is obvious that the probability of collision at 1st CCA is minimum with minimum number of active nodes in network underlying non-ACK scheme. Seeing the plots (fig 6 and fig 7) expressing a network of only 5 nodes, there is a massive reduction of collisions at CCA1 but as the network grows larger, the difference between these two schemes gets lower. In ACK scheme, the chances for collision are higher as, a collision can occur not only due to data packet but also due to ACK packet. This ACK packet is absent in non-ACK scheme.

### D. Delay

According to IEEE 802.15.4 standard for Acknowledged based CSMA/CA

\[ L_s = L + t_{ack} + L_{ack} + IFS \]  

and for non-ACK based CSMA/CA it will be

\[ L_s = L + LIFS \]

If data packet is greater than 40 symbols else it will be (according to IEEE standard).

\[ L_s = L + SIFS \]

It is logically obvious that there will be more delay in ACK based scheme. The same results are proved experimentally as well. Moreover, scalability does not change results with some impact as in CCA1. To validate this analysis, we simulated networks comprising of 5, and 50 nodes under same scenarios as shown in fig 8 and fig 9 respectively.
E. Reliability

Reliability mainly depends upon the clear channel assessment probability along with successful packet transmission. The value of $\alpha$ and $\beta$ for both schemes i.e. acknowledged and non-acknowledged Slotted CSMA/CA are presented above. The same probabilities will be used for both of these schemes respectively to calculate probabilistic values of packet failure due to retransmission attempts and due to collisions. However, the initial difference in alpha and beta probabilities in both modes yields different results. Fig 10 and fig 11 represents probabilistic values of reliability for a network of 5 and 50 nodes respectively. $P_{cf}$ and $P_{cr}$ are the probabilistic values that have high impact on reliability factor. $P_{cf}$ stands for probability of packet drop due to busy channels while $P_{cr}$ relates with probability of packet drop due to retry limits.

Considering a network having 5 nodes, non-ACK based schemes seems to be more consistent in reliability and channel accessing. However, there are more retransmissions with respect to ACK based scheme. This is due to lack of ACK mechanism. However, at low scalable environment, non-ACK based scheme works fine. But as number of nodes of network increases, the performance considering reliability is almost same for both schemes.
has a huge impact on overall network performance. Probability propagates on receiving a packet successfully, therefore, there is always a chance of collision due to this ACK packet.

**References**

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**IV. Conclusion**

Increase in probability of getting access of a free channel has a huge impact on overall network performance. Probability of collision, probability of retransmissions, probability of success full transmission, probability of going to back off stage and probability of discarding packets, all are directly or indirectly linked with probability of getting a free channel. As discussed earlier, ACK packet do not follow CSMA/CA regulations according to IEEE 802.15.4 standard. It is just propagated on receiving a packet successfully therefore, there is always a chance of collision due to this ACK packet.

1) **Throughput**: As show in in fig 13 and fig 14, non-ACK based scheme is better due to its low control load, and better throughput and good put due to lack of ACK mechanism that puts extra load and takes extra energy of network. Considering control load of network, ACK packet is used only to inform transmitter about successful data delivery. Using non-ACK mode lowers control overhead by eliminating this packet proving a tradeoff between traffic accessing, reliability and good put, for a network that has low scalability should be used without ACK scheme.