Performance Evolution of GTS based Wireless Sensor Networks under CSMA/CA with Variable Clear Channel Assessment Exponent

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Abstract— Wireless Sensor Networks forms an integral part of modern society. These are the networks that form the backbone of various types of modern aminities whether it is automatic fire fighting system, theft alarm, wildlife habitat monitoring or the real time adjustable temperature and humidity controller of an air flow system in a mall. The physical and MAC layer specifications for WSN are specified in IEEE 802.15.4 specifications. For real time wireless sensor networks, the underlying MAC layer data transmissions comes with GTS or Guaranteed Time Slots so that the time critical packets can be delivered to the destination with bounded delays. However, the mechanism followed for contention access period is CSMA with CD and CA in diversified implementations. The CCA is the most critical aspect of CSMA/CA. This paper attempts to model the throughput and performance of MAC under GTS and various values of backoff exponent for Clear Channel Assessment.

Key words: Wireless Sensor Network, Guaranteed Time Slots, CSMA, CCA etc

I. Medium Access Control Layer in Wireless Sensor Networks

The Medium Access Control mechanism in WSN can be implemented in slotted or unslotted time. As the name indicates, the slotted time refers to the implementation in which the time is slotted and any activity can begin only at the beginning of a time slot. In contrast, in unslotted time, the time is continuous and any activity can begin at any time instant. In this paper, the performance of WSN is evaluated at MAC layer. The simplest mechanism for shared channel access by competing senders is ALOHA (Abramson Logic Of Hiring Access). This has the simple definition that if there is data to send, then send it, if there is a collision, then try resending the data later. As intuitively suggested, the throughput performance of pure ALOHA is 18 percent whereas of that of slotted ALOHA is 36 percent.

II. CSMA mechanism in WSN

Carrier Sense Multiple Access is a means to access the channel in which the sender first listen to the medium to know if the medium is used by some other sender to transmit the data. This 'listening' of the channel is the reading of voltage spike on an electrical bus or a particular band in electromagnetic spectrum.

One can classify CSMA into two categories namely:

1) Persistent CSMA
2) Non Persistent CSMA

In persistent CSMA, the sender continuously sense the medium waiting for the instant when the medium gets free and then start sending the data frame the moment the channel gets free.

In non-persistent CSMA, if the sender senses the channel and finds it busy, then it waits for random amount of time and then senses the channel again. The process is repeated until the sender gets a free channel.

Actual deployments and simulations reveals that the performance of non-persistent CSMA is better than that of persistent CSMA is almost all deployments.

The persistent approach is also known as 1 persistent mechanism.

In between the persistent (1 persistent) and non-persistent schemes, there lies an approach called p-persistent approach. In this mechanism, if the sender finds the channel idle, then it may transmit the frame or it may not transmit the frame. Specifically, it transmits the frame with probability p, thus justifying the name p persistent.

This is why the persistent CSMA is called 1 persistent CSMA as it transmits with probability 1 if it finds the channel idle.

III. CSMA/CD and CSMA/CA mechanisms in WSN

A. *CSMA/CD*

CSMA/CD protocol can be considered as a refinement over the CSMA scheme. It has evolved to overcome one glaring inefficiency of CSMA. In CSMA scheme, when two packets collide the channel remains unutilized for the entire duration of transmission time of both the packets. If the propagation time is small (which is usually the case) compared to the packet transmission time, wasted channel capacity can be considerable. This wastage of channel capacity can be reduced if the nodes continue to monitor the channel while transmitting a packet and immediately cease transmission when collision is detected. This refined scheme is known as Carrier Sensed Multiple Access with Collision Detection (CSMA/CD) or Listen-While-Talk. On top of the CSMA, the following rules are added to convert it into CSMA/CD: (i) If a collision is detected during transmission of a packet, the node immediately ceases transmission and it transmits jamming signal for a brief duration to ensure that all stations know that collision has occurred. (ii) After transmitting the jamming signal, the node waits for a random amount of time and then transmission is resumed. The random delay ensures that the nodes, which were involved in the collision are not likely to have a collision at the time of retransmissions. To achieve stability in the back off scheme, a technique known as binary exponential back off is used. A node will attempt to transmit repeatedly in the face of repeated collisions, but after each collision, the mean value of the random delay is doubled. After 15 retries (excluding the original try), the unlucky packet is discarded and the node reports an error. CSMA/CD mechanism is typically used in all the Ethernet Networks.

As it is intuitively clear that the performance of CSMA/CD is better as compared to that of CSMA in non persistent modes.

B. *CSMA/CA*

Carrier Sense Multiple Access with collision avoidance is a collision-free protocols where collision is completely avoided. The primary motivation for this protocol was this that CSMA/CD was developed for Ethernet but it was completely useless for Wireless transmissions in which it is difficult to detect packet collisions and if a receiver is within the range of two active transmissions, then the received data will be garbled

Thus, CSMA/CA was developed for wireless transmissions in contrast to CSMA/CD which was developed for Ethernet. It was developed to handle problem known as Hidden Terminal Problem and Exposed Terminal Problem.

Here the sender sends a short frame called Request to send RTS which is about 20 bytes to the destination. The request to send also contains the length of the data frame. This means request to send packet will contain information about the length of the data frame. This destination station will respond to it with a short frame which is of 14 bytes known as clear to send frame and after receiving the clear to send the sender starts sending the data frame. Here all the stations which will receive this clear to send will defer transmission. So, if collision occurs of course there is a possibility that there will be multiple clear to send frames present in a particular situation and in such cases there is a possibility that clear to send frame will suffer collision. So, in such a case that back up technique has to be used so that the clear to send message or packet is received by the sender

IV. PERFORMANCE ANALYSIS USING ANALYTICAL AND STOCHASTIC MODELING

Let there be a total of N number of users of the system. Also, all the packets have the (time) length T. In other words, all the packets are of equal length and the transmission time of each packet is T. Each user transmits with a probability p during the time period T. Average number of a packets transmitted over the transmission medium over a time period T is λ=N.p.

The throughput is defined as the ratio of number of packets that are delivered successfully to the number of packets that can be transmitted assuming perfect global coordination.

The average number of packets that are transmitted in a time period 2T is λ'=2N.p. The arrival of independent events with a rate of λ within unit time is modeled by the Poisson distribution:

$$P(k) = \frac{\lambda^k . e^{-\lambda}}{k!}$$

In which λ is the rate, the average number of packet transmissions within unit time T, and P(k) is the probability that k packet transmissions occur within unit time T. The term vulnerable period is used to denote the period of time that a packet can possibly collide with a given packet x. In Aloha system, the vulnerable period has length 2T, any packet that starts within time T from the starting point of x (either before or after) will collide with x. In slotted Aloha, two packets either collide completely or do not overlap at all. The vulnerable period is reduced to T, the slot before the transmission of packet x.

Considering a specific packet x and calculating the probability that x is successfully delivered, one can have the following equations:

Prob{x is successfully delivered}

= Prob{No other packets within the vulnerable period 2T}

= P(0)

=

$$P(0) = \frac{(1). e^{-2N.p}}{0!}$$

The average number of packets that can be successfully go through is

= 2N*{probability of successful transmission}

$$T = 2N. e^{-2N.p}$$

The system achieve its maxima at p=1/2e and the peak value is .18 that corresponds to the maximum efficiency of 18 percent is pure aloha. In slotted time variant, the maximum efficiency achievable is 36 percent which is due to the half of the time that corresponds to the vulnerable period in slotted aloha as in compassion with pure aloha.

In CSMA/CD, the packet transmission stops as soon as the sender finds that there is a collision. Consider the slotted version in which the time is slotted, let the time period be 2T. Let there be k senders, each transmitting with probability p during the transmission time. This can be assumed that transmission behavior among hosts is independent and transmission behavior across slots is independent. The throughput of CSMA/CD can be modeled as:

$$T = \frac{E[good]}{E[good] + E[bad]}$$

Where E is the average length of the good or the bad period.

Probability that a host acquires a time slot is

$$\eta = kp(1-p)^{k-1}$$

Also,

$$\lim_{k\to\infty} \eta = \lim_{k\to\infty} (1 - \frac{1}{k})^{k-1} = 1/e$$

Let E[good] = ϒ. Converting it to seconds, one can rewrite E[good] = ϒF/B.where F is the frame size and B is the bandwidth in bits per second. Putting everything together, the throughput comes out to be

$$T = \frac{1}{1 + \left(\frac{2e}{c\Upsilon}\right) BL/F}$$

A. *Throughput Analysis of CSMA/CA*

The CSMA/CA policy can be modeled using the probability distribution of Discrete or Continuous time Markov Chains. Let there be N stations sending Data over the transmission medium. The CSMA/CA mechanism makes use of Request to send and clear to send (RTS and CTS mechanisms). Each of these packets gives an overhead on the transmission bandwidth as these packets are signals that are sent only to manage the flow of traffic effectively from the sender to the receiver.

The upper limit over the throughput of CSMA/CA as imposed through RTS/CTS is given by:

$$T = \frac{1}{1 + \frac{\left(\frac{2e}{c\Upsilon}\right)BL}{F} + \sum_{k=0}^{n} T_{RTS} + \sum_{k=0}^{n} T_{CTS}}$$

B. GTS utilization for Real Time WSN

The performance of time critical applications can be enhanced by using Guaranteed Time Slots in WSN. These Guaranteed time slots provides the guarantee of successful delivery to the senders as these are allocated dedicatedly to a specific sender in a cluster managed by the PAN coordinator.

$$T = \frac{1-\alpha+(1-\alpha)^{k-1}}{1+\frac{\left(\frac{2e}{cY}\right)BL}{F}+\sum_{k=0}^{n} T_{RTS}+\sum_{k=0}^{n} T_{CTS}+\sum_{k=0}^{n} T_{GTS\_REQUEST}}$$

Where k is the average number of attempts needed by the sender to transmit the frame to the receiver.

V. RESULTS AND ANALYSIS

The results of throughput on p persistant CSMA Scheme for various values of p is depicted in the following figures.

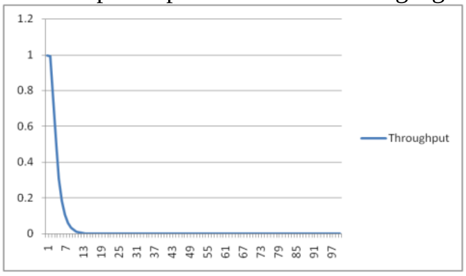

Fig. 1: Throughput as function of number of nodes for p=0.9

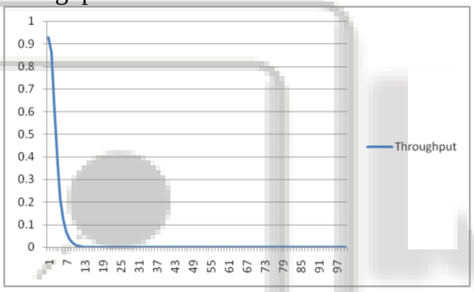

Fig. 2: Throughput as function of number of nodes for p=0.8

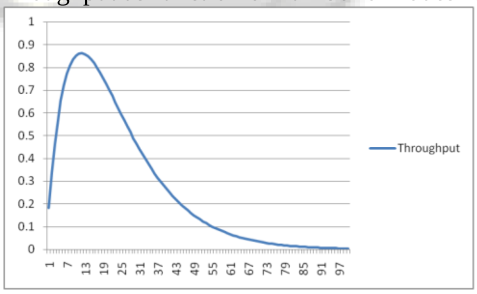

Fig 3: Throughput as function of number of nodes for p=0.4

It is clearly evident that the throughput varies at a very large extent with the probability of transmission or more appropriately, the traffic. The max value can be obtained by derivation w.r.t p and find the maxima of the curve.

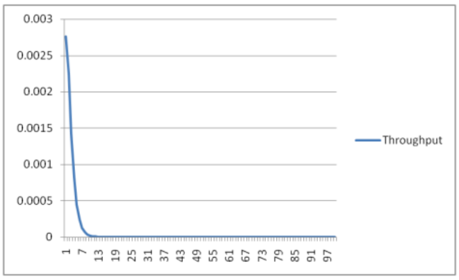

Fig. 4: Throughput of CSMA/CA as function of number of nodes for p=0.9

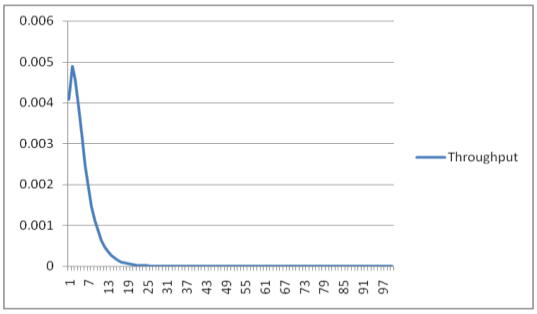

Fig. 5: Throughput of CSMA/CA as function of number of nodes for p=0.4

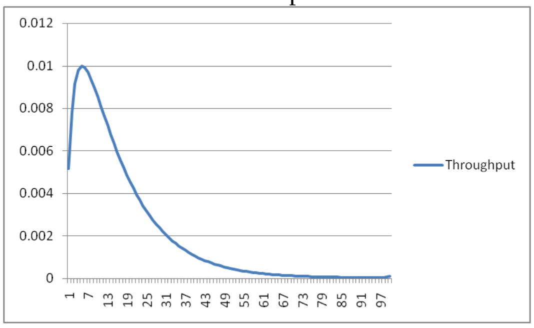

Fig. 6: Throughput of CSMA/CA as function of number of nodes for p=0.1

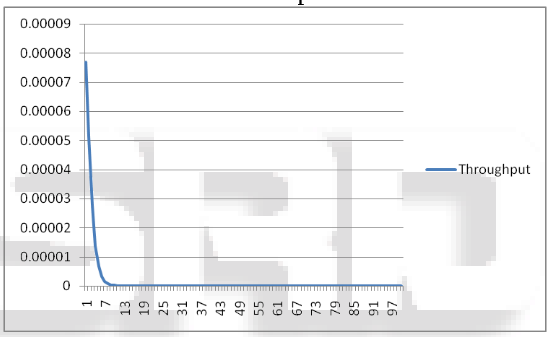

Fig. 7: Throughput of CSMA/CA with GTS as function of number of nodes for p=0.9

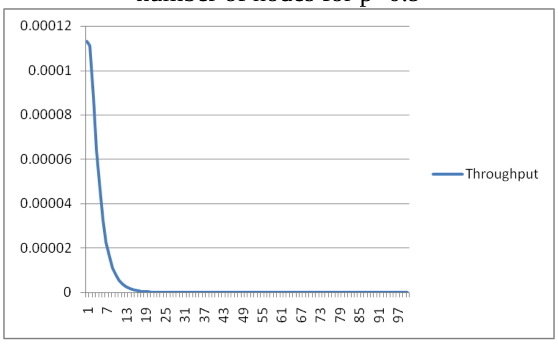

Fig. 7: Throughput of CSMA/CA with GTS as function of number of nodes for p=0.4

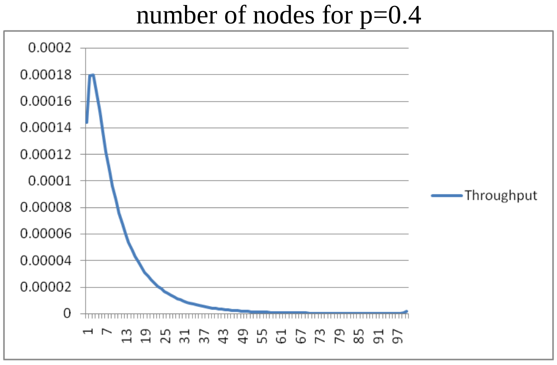

Fig 8: Throughput of CSMA/CA with GTS as function of number of nodes for p=0.1

VI. Conclusion

It is clearly evident that fixed p, as a function of k, CSMA/CD, CSMA/CA and CSMA/CA with GTS, the throughput is unimodal, i.e., dome-shaped and under excessive load, throughput goes down. The performances of the protocols are analyzed under varying traffic conditions and under the varying number of sender contending to send the data traffic over the same shared transmission medium. The normalized throughput and the mean access delay are derived using a modified Markov chain model that captures both types of sensing errors: false alarm and miss detection.

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