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Performance Evaluation of 802.11 MAC Protocol with QoS Differentiation for Real-Time Control

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ABSTRACT: As one of the most widely used wireless network technologies, IEEE 802.11 wireless local area networks (WLANs) have found a dramatically increasing number of applications in soft real-time networked control systems (NCSs). To fulfill the real-time requirements in such NCSs, most of the bandwidth of the wireless networks need to be allocated to high-priority data for periodic measurements and control with deadline requirements. However, existing QoS-enabled 802.11 medium access control (MAC) protocols do not consider the dead-line requirements explicitly, leading to unpredictable deadline performance of NCS networks. Consequentially, the soft real-time requirements of the periodic traffic may not be satisfied, particularly under congested network conditions. This paper makes two main contributions to address this problem in wireless NCSs. Firstly, a deadline-constrained MAC protocol with QoS differentiation is presented for IEEE 802.11 soft real-time NCSs. It handles periodic traffic by developing two specific mechanisms: a contention-sensitive back-off mechanism, and an intra-traffic class QoS differentiation mechanism.

KEYWORDS: Networked control systems, IEEE 802.11, soft-real- time control, deadline, MAC protocol, performance evaluation.

I.INTRODUCTION

As one of the most widely deployed network technologies, IEEE 802.11 wireless local area networks (WLANs) are increasingly used in industrial environments particularly in real-time control systems[1]. To maintain normal and safe operations of an industrial plant, periodic sensor measurements of the production process must be received timely by the controllers through computer networks so that prompt control actions can be taken [5]. Real-time control systems are either hard or soft real-time systems. In a hard real-time system, missing a deadline will cause a system failure at the best or a disaster at the worst. In comparison, soft real-time systems can tolerate deadline misses to a certain level specified by the underlying applications. The characteristics of the network traffic in a real-time networked control system (NCS) are quite different from those in normal network services[1]. Firstly, the NCS network traffic for measurements and control is periodic. Secondly, the data packets for measurements and control must be delivered before their respective deadlines[2]. While deadline misses degrade system's quality of service (QoS) in soft real-time control, they can be tolerated as long as system's QoS does not fall beyond a threshold specified by the underlying application. Furthermore, the traffic load of an NCS network is typically known in advance, and the sizes of the data packets are typically small. All these features make NCS networks unique, particularly in wireless environments.

II. PROTOCOLS USED AND THEIR WORKING

Deadline-Constrained MAC Scheme

Our new deadline-constrained MAC scheme with QoS differentiation aims to improve the real-time performance of the periodic traffic under congested conditions. To achieve this aim, it includes two main parts. One is the introduction of a contention-sensitive binary exponential back-off (BEB) algorithm as a modification to the existing IEEE 802.11 BEB algorithm to improve the back-off delay performance. The other is the design of an intra-AC QoS differentiation

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mechanism to address the real-time deadline requirements directly. In addition to the four Access Categories provided by EDCA, different priority levels are assigned to the periodic traffic flows according to their real-time QoS deadline requirements

A. CONTENTION-SENSITIVE BACK-OFF ALGORITHM

Sensitive to collisions, the IEEE 802.11 BEB is effective under light to moderate traffic load . A transmitting station uses back-off mechanisms to determine how long to wait following a collision before attempting to retransmit. For each transmitting station, the BEB algorithm selects a uniformly random back-off value less than the contention window sizeW. Stations wait before trying retransmission until the back-off value counts down to zero. This process is repeated after each collision with a new contention window size W. W = Wmin is set for the first transmission, after a successful transmission, or when the retransmission counter reaches the retry limit. It is doubled after each collision until it reaches Wmax. Once W reaches Wmax, it remains unchanged until it is reset to Wmin. When the medium is sensed busy, the back-off countdown is paused. The back-off timer resumes decreasing once the medium is sensed idle. This process is shown in Figure Under congested conditions, this BEB may lead to a large back-off delay and deadline misses.

Figure. The IEEE 802.11 BEB and our new BEB. In IEEE 802.11 BEB, each transmitting station generates a uniformly random back-off value from [0,W -1] and counts down its backo_ value. The station reaching to zero first transmits. Meanwhile, since the channel is busy, others freeze their countdown till the channel is free. The one that counts down to zero next transmits next and so on. In the case of a collision, the contention window size W doubles, each transmitting station generates a new uniformly random back-off value from [0, W -1], and countdown restarts with the new back-off values. In our new BEB, not only in the case of a collision but also when the channel is busy, the contention window size W doubles

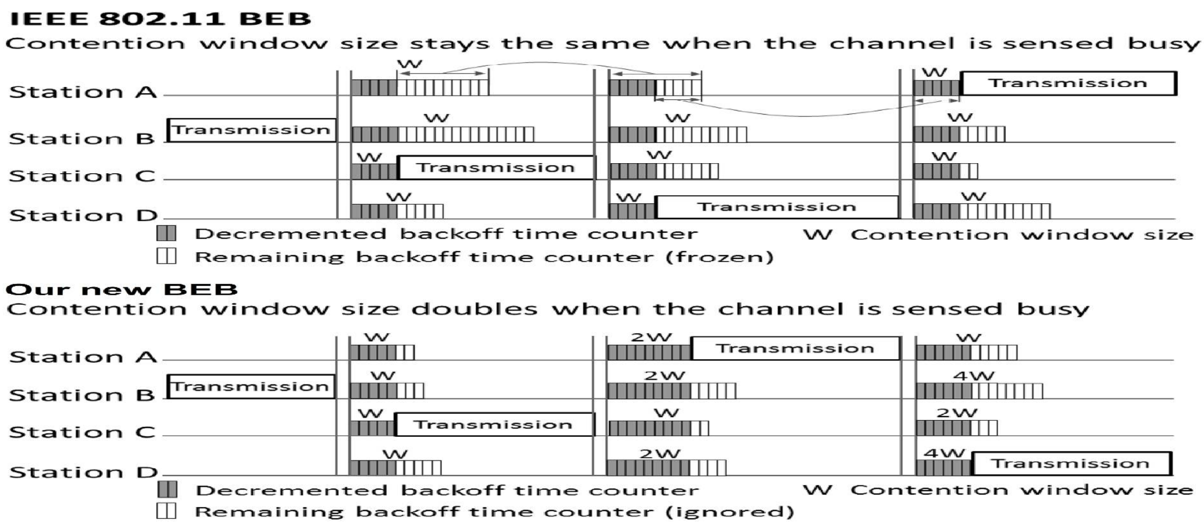

Fig: 1. IEEE 802.11

The 802.11 BEB doubles the contention window size W following a collision only, and keeps the window size W the same but pauses back-off value countdown (back-off timer) when the channel is sensed busy. Delay analysis shows that a larger initial back-off window size is desirable as the network traffic load increases . Therefore, for improved back-off delay performance, a contention-sensitive BEB algorithm is developed, as summarized in Algorithm 1 and graphically shown in Figure 1. It doubles W not only in the case of collisions but also when the channel is sensed busy. Specifically, for each transmitting station, the new BEB chooses a uniformly random back-off value from [0, W - 1]. Stations wait before trying retransmission until the back-off value counts down to zero. In the case of collisions or when the channel is sensed busy: 1) the contention window size W is doubled until it reaches Wmax; 2) the retransmission counter is incremented; 3) the BEB chooses a new uniformly random back-off value from [0, W _ 1]; 4) the new back-off value counts down as soon as the medium becomes idle; and 5) a retransmission is tried when the new back-off value counts down to zero. The retransmission attempts continue until the retry limit is reached. Once W reaches Wmax, it remains unchanged until it is reset to Wmin. Similar to 802.11 BEB, the new BEB sets W =Wmin for the first transmission, after a successful transmission, or when the retransmission counter reaches the retry limit.

Compared with the existing 802.11 BEB algorithm, the new contention-sensitive BEB algorithm is more sensitive to the channel conditions because when the channel is sensed busy, instead of freezing the countdown, it doubles the contention window size W and requires each station to generate a new Back-off value within a larger contention window size. This reduces the possibility of collision under heavy traffic load.

B. INTRA-AC QOS DIFFERENTIATION

A new intra-AC QoS differentiation mechanism is also designed for periodic NCS traffic flows that belong to the same high priority TC but have different deadline requirements: 1) There are four ACs in EDCA . For real-time control, all periodic real-time traffic flows belong to a single AC _VO with the highest priority. In this paper, periodic real time traffic flows are classified into additional traffic classes within AC _VO to differentiate communications types found

in real-time control applications. 2) To differentiatea the periodic traffic with different deadline requirements, a deadline-dependent retry limit is assigned to each of the new traffic classes in AC _VO. Let L(m) denote the retry limit for class-m periodic traffic flow. As a basic MAC parameter, it is calculated in terms of the deadline of class-m periodic traffic, Tm;deadline, in our design. 3) Retry limits for other three ACs are set according to the 802.11e EDCA specifications. Apart from the retry limits, other EDCA parameters are kept unchanged. To specify how to calculate L(m) in our intra-AC QoS differentiation mechanism, we need to derive the maximum delay of class-m traffic, Tm;max_ delay.

$$Tm,\max_{delay} = \sum_{j=0}^{L(m)} W[i]j\,Tslot + Tm.\max_{suspend} + Tm,c, \quad (1)$$

Where i ∈(0,1,2,3) denotes one of the four ACs; for the ith AC, W[i] j is the maximum back-off window size at the jth transmission attempt $\sum_{j=0}^{L(m)} W[i]j$ is the maximum number of back-off slots that a frame encounters without considering the case when the counter suspends for class-m periodic traffic; Tm;max suspend is the maximum number of back-off slots when the counter suspends for class-m periodic traffic; and Tm;c is the maximum time that the channel is sensed busy because of a successful transmission for class-m periodic traffic. We have

$$Tm,c = TAIFS[i] + TH + Tm,LF * + TSIFS + Tack \quad (2)$$

where $TAIFS[i]$ and $TSIFS$ are AIFS and SIFS times, respectively; TH is the duration to transmit the frame header; LF* is the maximum length of the frame for class-m periodic traffic; Tm,LF* is the duration to transmit a class-m frame with length LF*; and Tack is the time duration to transmit an ACK.

Let us calculate Tm;max suspend, the maximum freezing back-off slots due to a successful transmission from other stations or a collision. A station has to wait for an AIFS period, TAIFS , in a transmission attempt. There is at least an AIFS time between two successive transmissions from all stations. With a collision, a station waits for a duration for a successful transmission and an ACK timeout Tack_ timeout. We have

$$Tm,\max\_suspend = L(m)(Tm,c + TSIFSbb + Tack_{\_timeout}) \quad (3)$$

For class-m traffic with deadline Tm;deadline, the maximum number of transmission attempts for a successful transmission

III. MAC PERFORMANCE METRICS

There are hundreds of MAC protocols proposed for wireless networks. We need performance metrics so that we can compare one protocol from the other.The key metrics are:

1. Delay : Defined as the average time spent by a packet in the MAC queue, i.e. from the instant it is enquired till its transmission is complete. Sensitive to traffic characteristics, so two MAC protocols should be compared under identical traffic conditions
2. Throughput **:**Fraction of channel capacity used for data transmissions**.** MAC need to maximize throughput while keeping the access delay to minimum.
3. Fairness :When all nodes are treated equally, and no node is given Preference. Leads to fair sharing of bandwidth Traffic with different priorities can bias this definition.For multimedia traffic, usually the MAC is considered fair when (voice, data, video) get their allocated bandwidth
4. Stability : System need to be stable if instantaneously high load is seen by the MAC

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5. Robustness against channel fading: Wireless channel is time varying and error prone.Fading may make channel unusable for short durations.MAC needs to work reliably while channel in fade.
6. Power consumption : Wireless nodes have limited battery power .MAC should conserve energy.
7. Support for Multimedia :MAC should support multimedia applications (voice, video, data) Multimedia data implies data with real-time constraints.By using priorities and scheduling – delay can be controlled and/or guaranteed.

IV. SIMULATION RESULTS

To verify the new MAC scheme, we consider a 11 Mbps 802.11b WLAN with the access point at the center of a circle of 50m radius. All other nodes are randomly placed on the circle. Simulations are conducted under ideal channel conditions with no transmission errors or hidden terminals. The performance of the presented MAC scheme is evaluated from two aspects: average delay and packet loss ratio. The average delay characterizes how timely the periodic frames can be delivered, while the packet loss ratio indicates how reliable the frame delivery is. As both of them are significant for real-time control applications, performance improvement in these two aspects directly benefits the distributed real-time NCSs. Simulations in this paper are carried out by using Network Simulator Version 2 (NS2). The parameters of the 802.11b standard are used with a data rate of 11 Mbps: TS IFS =10_s, Tslot=20_s, and TACK timeout=300_s. Two ACs consisting of 20 AC VO nodes and 10 AC BE nodes with the same packet size of 200 bytes are considered. Each station has only one traffic flow. The AC BE nodes generate 547.13 kbps background traffic in total following a Poisson distribution. The retry limits are calculated from Algorithm 2. The first scenario compares EDCA and our new MAC scheme in terms of average delay and packet loss ratio under different periodic traffic transmission periods. The deadlines for the traffic are the same as the transmission periods. Some performance comparisons are shown below. It is seen that both EDCA and our MAC work well under light traffic (period ¡ 10 ms). The results match well with those from references which concludes that EDCA is just able to guarantee industrial communication if there are less than 10 stations and message streams have periods above 10ms. However, under congested conditions (period ¤ 9:5 ms) in real-time NCSs, EDCA behaves poorly in average delay and packet loss ratio. This is due to the increased number of collisions, which cause stations to lose frames and experience additional delay in frame transmission. The delay and packet losses increase as the network gets more congested. In contrast, our MAC scheme enlarges contention window size W when the medium is sensed busy. This results in better average delay and packet loss performance due to the reduced probability of further collisions under congested conditions (periodic traffic period≤ 9:5 ms) in real-time NCSs.
The following Simulation parameters used for performance evaluation of the above protocols as shown in table 1

Table 1: Simulation parameters

Parameter	Value
No. of Nodes	10, 20, 30,40
Area	1250 X 1250 sq.m
MAC	IEEE 802.11, EDCA
Simulation Time	15 sec
Initial energy	4.5
Data rate	I Mbps
Traffic Source	CBR
Packet Size	200 MB
Mobility Model	Random Way Point

The performance evaluation of MAC protocol and EDCA has been evaluated using NS 2 Network simulator in terms of number of nodes transmission rate versus delay, delivery ratio and loss rate is compared and presented below.

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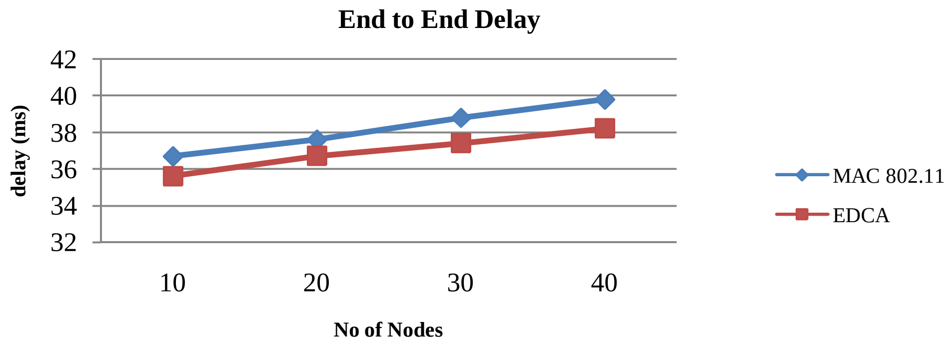

Fig:2 End to End Delay Vs No Nodes

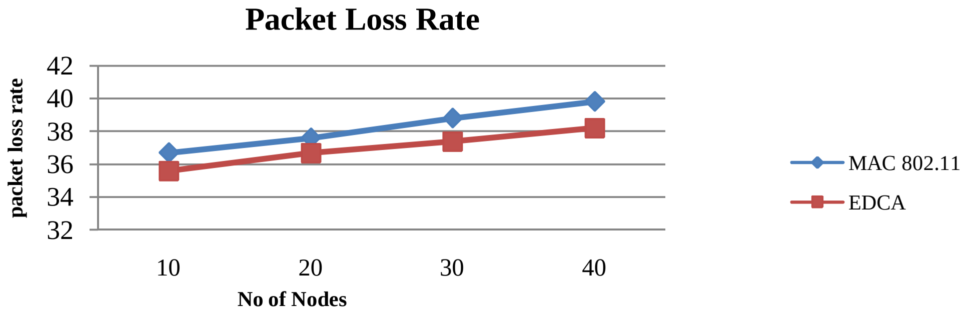

Fig : 3 Packet Loss Rate Vs No Nodes

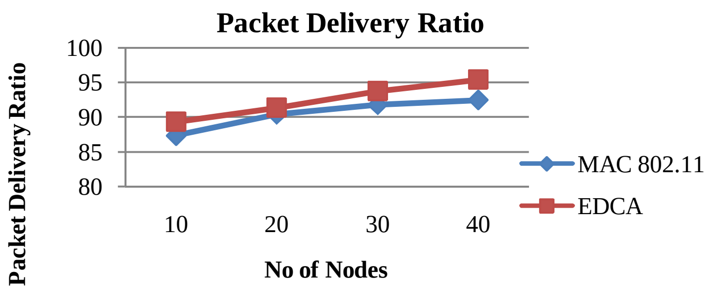

Fig : 4 Packet Delivery Ratio Vs No Nodes

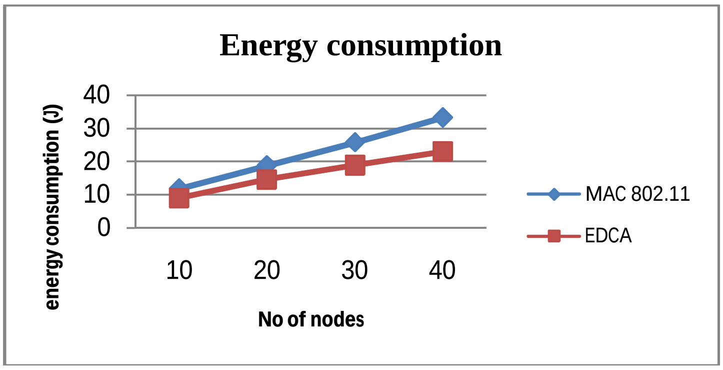

Fig : 5 Energy consumption

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V. CONCLUSION

In this project MAC protocol for load balancing in mobile ad hoc networks is developed. The congestion is detected using congestion detection technique and routing overhead is reduced using the load balancing technique. The performance of the proposed EDCA MAC Protocol and MAC 802.11 Protocol is evaluated and compared using different metrics such like packet delivery ratio, end – end delay and loss Rate by varying the number of flows nodes using NS2 simulator. From simulation results it is observed that there is improvement in PDR and delay in EDCA Protocol

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