Performance Analysis of a Limited-Contention Media-Access Control Protocol

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Abstract: This paper presents an analysis of the benefits that a limited-contention protocol, Distributed Load Sensing with a Priority Mechanism (DLSPM-2), has over a purely contention-based protocol such as CSMA/CD. A theoretical analysis of both protocols is outlined and the individual performances have been compared through simulation.

1. Introduction

The main media-access control protocol for wireless local area networks (WLAN) is of a contention nature. The major standard that has emerged is the IEEE 802.11, which uses a MAC protocol called the Distributed Corodination Function (DCF). DLSPM-2 has been proposed as a fairer and more efficient alternative to this protocol [1,2]. This paper demonstrates mathematically the benefits of DLSPM-2 protocol by comparing its delay and efficiency equations to those of contention-based protocols, such as CSMA/CD or DCF, whose performance has been thoroughly investigated in the literature. It is concluded that the efficiency and delay gains associated with the DLSPM-2 algorithm are strong incentives to propose it as an alternative protocol for WLAN.

2. Brief Description of the DLSPM-2 Protocol

The network configuration is group-oriented. Nodes are arranged within groups of communication. Nodes belonging to the same group can hear each other signals within a very short period of time, whereas nodes belonging to different groups will experience a delay before sensing each others' transmissions. DLSPM-2 acts as a load sensing protocol; it allows nodes to seize the medium of communication whenever they have packets to transmit. A node seizes the medium of communication by transmitting a request-to-send (RTS) signal to its destination station which will respond with a clear-to-send signal (CTS), thus informing all near-by nodes that a transmission is going to take place. A collision occurring within the same group is called an intra-group collision whereas a collision occurring between nodes of two different groups is called an inter-group collision. An inter-group collision might arise if the CTS/RTS messages were not heard by the contending stations due to propagation delay considerations. The protocol solves this collision by selecting one of the contending nodes through an exchange of messages between a central monitoring node and the contending nodes. Contending nodes do not transmit a unique ID, they transmit a group ID in order to reduce bandwidth utilization and transmission delays. The central node will allow a single node to transmit based on its priority level and number of successfully completed transmissions. The occurrence of an intra-group collision is greatly reduced by the use of a CTS/RTS transmission protocol prior to seizing the medium of communication. Furthermore, each networked node keeps in memory its transmissions and that of other nodes in the same group, thus, if a local collision arises a node knows if it has priority over other nodes or not. During a contention-solving situation, all networked nodes hear the exchange of information between the central monitoring nodes and the contending nodes and will refrain from transmitting during that period.

3. DLSPM-2 Efficiency Calculation

The DLSPM-2 protocol is basically a contention-based protocol; we will therefore base our analysis on a contention-based protocol namely, the CSMA/CD protocol. The probability of success for CSMA/CD is given by the following equation:

$$A = Np^{1}(1-p)^{N-1} \tag{1}$$

Where, p is the probability of transmission and N is the number of nodes.

The difference that has to be included in the DLSPM-2 equation is the limited-contention mechanism that characterizes it, hence a node could suffer a collision and be allowed to transmit, the probability that a colliding node is selected depends largely on the number of colliding nodes. This factor can be calculated by summing the individual probabilities that a node can emerge successfully from a colliding situation multiplied by the number of combination of having k-1 nodes in contention among a total of N-1 nodes. This factor is given by equation 2:

$$X = \sum_{k=2}^{N} \frac{C_{k-1}^{N-1} p^{k} (1-p)^{N-k}}{k} \tag{2}$$

Where, N is the total number of nodes in the network, and k is the total number of contending nodes at any given time.

Factor X calculates the probability of success in a contentious situation, it must be added to the probability of success of a contention-based protocol. Therefore, the DLSPM-2 general equation for the probability of success can be expressed by the following equation:

$$A = Np^{1}(1-p)^{N-1} + X \qquad (3)$$

The general efficiency equation of any contention-based protocol can be formulated as follows:

$$\eta = \frac{1}{1+2*a*CP} \qquad (4)$$

Where, CP is the average number of slot periods within a contention period, $2a$ is assumed to be the timeslot period and a is the propagation time divided by the transmission time. For a transmission time equal to one, a is therefore the propagation time.

The efficiency of DLSPM-2 can be deduced from the average contention period. Pure contention-based protocol efficiency equations can be found in multiple textbooks and publications [3,5,6]. We can state that the average number of slot periods is given by the probability of failure divided by the probability of success [3]. We can therefore deduce the following equation:

$$CP_{dlspm-2} = \frac{1-A_{dlspm-2}}{A_{dlspm-2}} \qquad (5)$$

Where, $A_{dlspm-2}$ is given by equation 3.

Finally, the efficiency for DLSPM-2 can be given by the subsequent equation:

$$\eta_{dlspm-2} = \frac{1}{1+2*a*CP_{dlspm-2}} \qquad (6)$$

4. DLSPM-2 Delay Calculation

In order to accurately determine the delay of a communication protocol, one must accurately know the average number of retransmissions needed to successfully transmit a packet. The total traffic on a contention-based protocol channel, commonly known as the channel load (G) can be expressed in terms of S (the number of frames generated per frame time) and the number of retransmitted frames per frame transmission time (*NRTX*).

$$G = S + \overline{NRTX} \qquad (7)$$

The expected number of retransmissions per frame [4] is given by:

$$\frac{G}{S} - 1 \qquad (8)$$

but the former equation can be restated as:

$$NRTX = \frac{1}{\eta} - 1 \qquad (9)$$

Since,

$$\frac{G}{S} = \frac{1}{\eta} \qquad (10)$$

Hence, the total delay is the number of retransmissions per frame multiplied by the different delays to carry out successfully a transmission. Delay calculation for DLSPM-2 is also based on the delays associated with contention-based protocols such as CSMA/CD. We first developed the delay equation associated with CSMA/CD, then, we modified that equation to take into account the additional delays that can be expected from a limited-contention protocol such as DLSPM-2, namely the time needed to solve a contentious situation that resulted in a collision. The delay equation for CSMA/CD can be found in different publications [5,6]. The main equation for DLSPM-2 delay is presented below. The main difference with CSMA/CD is the inclusion of an additional delay such as the propagation time of the response to a contention-reduction situation, and the contention reduction period (*CRP*) which is the time needed to solve a contention situation. The additional propagation delay that accounts for the time needed to receive the id of the selected node, is represented by a.

$$D_{DLSPM2} = (\frac{1}{\eta_{dlspm2}} - 1) * (1 + 3a + CP + ACK + CRP) + 1 + 2a + \frac{1+2a}{2} \quad (11)$$

The contention reduction period (*CRP*) for DLSPM2 is assumed to be equal to the time needed to receive a CTS(clear-to-send) from the base station when a collision has been detected. It can be formulated as follows:

$$\overline{CRP} = \frac{\frac{\log(\frac{N}{N_g})}{\log(2)}}{R_b} \quad (12)$$

Where N is the number of nodes, N_g the number of nodes per group and R_b the bit rate.

As the contention period (*CP*) is assumed to be proportional to the number of time slots needed to successfully transmit, one can assume that the maximum contention period is $(K+1)*2a$ for k contending nodes and $1*2a$ for a single contending node, thus, the average *CP* period can be given by:

$$CP = \frac{K+1}{2} * (2a) \quad (13)$$

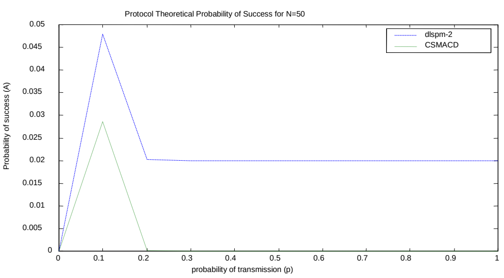
The time needed to receive an acknowledgement (ACK) is considered negligible and will therefore not be used in our calculations.

5. Comparison between DLSPM-2 and CSMA/CD

Using MATLAB, we first studied the probability of success of each protocol by plotting the probability success (*A*) against *p* (the probability of transmission). We also produced a MATLAB simulation that analysed the efficiency and delay performances of each protocol by plotting them against the offered load.

The first set of results (figure 1) show the probability of success for DLSPM-2 is the same as that of CSMA/CD for low loads ($p<0.5$) and bigger than that of CSMA/CD for high loads ($p>0.7$). Since a node has a higher probability of seizing the medium of communication even in a collision situation, it is therefore plausible to assume that even at high network loads, the probability of transmission for DLSPM-2 is higher than that of CSMA/CD due to the limited-contention protocol, hence, it is reasonable to conclude that the probability of success for DLSPM-2 will be bigger than that of CSMA/CD when the network is experiencing high transmission loads. It is also worth noticing that the probability of success for DLSPM-2 never falls to zero even at high traffic loads, whereas, in the case of pure contention-based protocols, the probability of success will eventually collapse to zero at high traffic loads. Thus, limited–contention protocols can be viewed as contention-based protocols for low or medium traffic loads and reservation or priority-based protocols for high traffic loads. This unique feature makes this type of media-access control protocol adaptable to different traffic load types and more resistant to traffic collisions and delays.

The second set of results (figure 2) presents a plot of the efficiency against the traffic load for each protocol. The results show that the efficiency of DLSPM-2 is comparable to that of CSMA/CD for low loads, however, one can clearly see that the gap between both efficiencies widens in favour of DLSPM-2 as the traffic load increases. For extremely high traffic loads, the CSMA/CD efficiency tends towards zero whereas that of DLSPM-2 moves towards an asymptotic value defined as the minimal efficiency rate since the DLSPM-2 protocol always transmits data even under very high traffic loads, due to its limited-contention functionality or characteristic as described in the previous section.



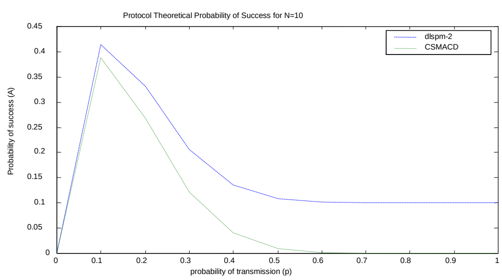


Figure 1 –Probability of success for CSMA/CD and DLSPM-2-

The third set of results (figure 3) presents a plot of the delays against the traffic load for each protocol. The results show that the delay performances of both protocols are similar for low traffic loads, as the traffic load increases, the delays associated with CSMA/CD increase faster than those of DLSPM-2 due to the contention-solving mechanism and priority mechanism of the latter.

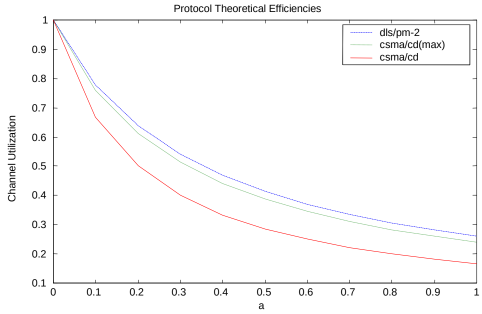


Fig 2 –Protocol Channel utilization –

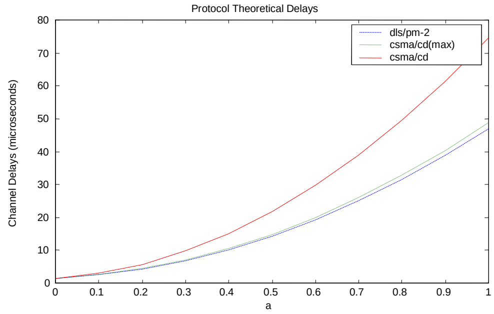


Fig 3 –Delays for CSMA/CD and DLSPM-2-

6. CONCLUSION

General efficiency and delay theoretical models for DLSPM-2 have been produced from the general theory of contention-based protocols. The DLSPM-2 delay and efficiency equations were compared to the general performance equations of a contention-based protocol such as CSMA/CD using MATLAB.

The simulation results have shown that the performance of DLSPM-2 is much better than that of CSMA/CD for high and medium traffic loads, and equivalent to the performance of CSMA/CD for low traffic loads. These results were predictable since limited-contention schemes will reduce the number of re-transmissions due to collisions. The implications of such an algorithm are two-fold. First there is an improvement in the overall efficiency of the protocol when compared with efficiencies of purely contention-based protocols, secondly, the reduction of media-access delay through the use of a contention-reduction algorithm based on group identifications rather than individual identification numbers, allows a noticeable improvement over contention-based schemes.

REFERENCES

[1] R.Skakni and C.G.Guy, “Novel Media-Access Control Protocol for Wireless Local Area Networks”, Fourth Euromedia Conference, April 1999, Munich, Germany.

[2] R.Skakni and C.G.Guy, “Media-Access Control Protocols for Wireless Local Area Networks carrying multimedia traffic”, First Gemisis Technical Symposium, May 1998, Salford, England

[3] W.Stallings, “Data and Computer Communication”, 6th Edition, 2000.

[4] W.Stallings, Local and Metropolitan Area Networks, Fourth Edition, 1993.

[5] L.Kleinrock and Fouad A.Tobagi, “Packet Switching in Radio Channels: Part 1- Carrier-Sense Multiple-Access Modes and Their Throughput-Delay Characteristics”, IEEE Transaction on Communications, Vol. Com-23, no.12, December 1975.

[6] L.Kleinrock and Fouad A.Tobagi, “Packet Switching in Radio Channels: Part 2- The Hidden Terminal Problem in Carrier-Sense Multiple-Access and The Busy Tone Solution”, IEEE Transaction on Communications, Vol. Com-23, no.12, December 1975.