Fairness Enhancement in Wireless Mesh Networks

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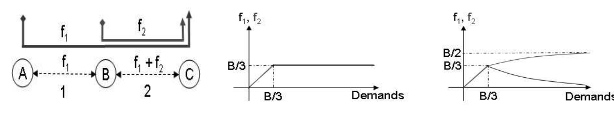
1. INTRODUCTION

Maintaining fairness in WMNs is quite important but has been given less attention relative to other aspects such as capacity maximization and maintaining connectivity [1]. IEEE 802.11 MAC protocol has been used as the defacto standard for WMNs although it has been initially designed to operate in wireless local area networks. It is known to be unfair in multihop networks. This unfairness is quite evident in bursty conditions which frequently occur in WMNs where subscribers to the same service level must be fairly regarded.

In this paper we tackle the fairness problem in WMNs and propose algorithms to ensure fairness while maximizing capacity. Our proposal is based on varying contention window (CW) values at each node inversely proportional to the fair rate allocations that are calculated based on the weighted cliques in a certain neighborhood. Preliminary numerical results show remarkable improvement in fairness. We also propose a distributed version of the algorithm that dynamically achieves that.

2. FAIRNESS PROBLEM STATEMENT

IEEE 802.11 MAC protocol operates well in WLANs while the ad hoc mode does not feature fairness. For instance users that are closer to the gateways (GWs) usually have better throughput under burstiness conditions and even they may cause starvation of other users. Figure 1(a) shows a network graph where 2 sources are originating flows towards the same destination (assumed to be the GW) with same bitrate G. f_2 is single hop flow while f_1 is a 2-hop flow. Figure 1(b) displays the fair network allocation for both flows while figure 1(c) shows the real throughputs and illustrates well the fairness problem that is realized when sources become more greedy and their traffic requirements exceed the network capacity. At this point, f_2 starts to dominate f_1 until it causes its complete starvation. This can be justified by 2 reasons: first, whenever both nodes have packets to send, they have the same long-term probability for accessing the medium and thus limiting the aggregate capacity to $B/2$. Second, the throughput of B dominates since the rate of its packets is normally higher than the arrival rate of packets from A and thus its buffer will have more packets for its own.



(a) (b) (c)

Figure 1: Fairness problem in WMNs.

3. DYNAMIC CONTENTION WINDOW

Our algorithm aims at varying the successful attempt rate of each node in function of the traffic state by tuning the CW values. Neighboring nodes that have the same values of CW_{min} and CW_{max}, have the same collison probability γ_i. Moreover they have the same attempt rate $G(\gamma_i)$ which is expressed in terms of γ_i [2]:

$$G(\gamma_i) = \frac{\sum_{k=0}^{K} \gamma_i^k}{\sum_{k=0}^{K} \gamma_i^k \times b_k},\ \gamma_i = 1 - \prod_{\substack{1 \leq j \leq n \\ j \neq i}} (1 - G(\gamma_j)) \quad (1)$$

where b_k denotes the mean backoff duration at the k^{th} retransmission of a packet, and K is the retry limit. This means that they also have the same probability of successful attempts regardless of the traffic load.

To improve fairness, we propose a 2-fold solution. First, we use a queue for every flow that passes through a certain node. Second we ensure higher attempt rate for nodes that has to forward more traffic. In figure 1(a), since link 2 must forward A's and B's traffic, we must maintain s_2/s_1 =2, where s_i is the aimed rate

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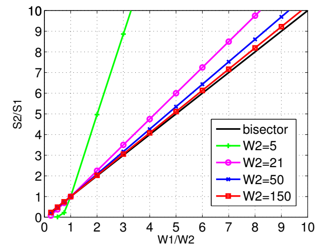

Figure 2: Allocation ratio vs CW ratio

on link i which is the aggregation of the flow rates passing through link i ($s_2 = r_1 + r_2$). Consequently, $G(\gamma_2)\,(1-\gamma_2)$ must be as twice as $G(\gamma_1)\,(1-\gamma_1)$ where $G(\gamma_2)\,(1-\gamma)$ and $G(\gamma_1)\,(1-\gamma_1)$ are the successful attempt rates on links 2 and 1 respectively. For achieving this, we propose to assign for each node a CW that is a function of the total number of flows passing through this node. It is intuitive to assign smaller CW_{min} and CW_{max} to the node that has more traffic. We solve the fixed point equations (1) numerically using Matlab for several values of CW_{min} and we find $G(\gamma_i)$ and γ_i. Then we plot the ratio s_2/s_1 in function of W_1/W_2 where W_i refers to CW_{min} for node i and s_2/s_1 is calculated, for the same packet length, in terms of $G(\gamma_i)$ and γ_i as follows: $\frac{s_2}{s_1} = \frac{G_2(\gamma_2)(1-\gamma_2)}{G_1(\gamma_1)(1-\gamma_1)}$.

We varied the values of CW_2 from small values 5 until very large values 150 (results are in figure 2). We find that s_2/s_1 is almost proportional to CW_1/CW_2 for all values of CW_2. In other words: $\frac{s_2}{s_1} = k \times \frac{CW_1}{CW_2}$.

The obtained results show that the larger the values of CW_1 and CW_2 are, the more the curve approaches to the bisector. Nevertheless, increasing these values, while implying a better throughput ratio, reduces the actual throughput for both and therefore the overall capacity. Hence since we search at maximizing fair-capacity, we choose the values of CW_i so as to conserve an average value which is equal to the default CW (usually 32). This increases capacity and improves fairness.

So we now have two conditions for choosing the values of CW_i, the first one is to maintain the initial contention window values which is represented as:

$$CW = \frac{\sum_{k=1}^{N} CW_k}{N} \,. \tag{2}$$

where N is the number of nodes in a certain neighborhood (we will explain later how to choose N). CW is a basic value of CW_{min} adopted in Wi-Fi cards. Second, we choose the values of CW_i inversely proportional to the traffic state and we set k to 1 since the ratio is almost 1 with a bigger error for small CW (figure 2).

$$\frac{s_i}{s_j} = \frac{CW_j}{CW_i} \,. \tag{3}$$

If we return back to figure 1(a), the fair allocations correspond to (B/3, 2B/3) on each link, hence we must choose the values of CW_1 and CW_2 that gives this ratio. Since $s_2 = 2 \times s_1$, then $CW_1 = 2 \times CW_2$ and $(CW_1 + CW_2)/2 = 32$. (32 designates the default value for CW_{min}). We use the obtained values of CW_1 and CW_2 , and calculate the attempt rates and collision probabilities on Matlab using fixed point anaylsis, and we find then the successful attempt ratio. Knowing that the ideal ratio corresponds to 1:2, we obtain a ratio 1:2.2. This obtained result can be observed by looking at figure 2 for $W_2 = 21$ and $W_1/W_2 = 2$.

4. DISTRIBUTED ALGORITHM

Hereafter, we propose a distributed algorithm that ensures fairness based on the solution discussed in section 3. Each node exchanges its load information and its k-hop neighbors list in the k-hop neighborhood. Since we account for the hidden node problems, we choose k as the upper integer value of the carrier sensing range R_{CS} divided by the transmission range R_{trans}.

$$K = \lceil \frac{R_{CS}}{R_{trans}} \rceil \,.$$

Then every node locally calculates its CW, satisfying the 2 previously discussed conditions (see equations 2 and 3). In fact, it corresponds to the value obtained from the maximal weighted clique that it participates to. We use weights on the network graph for representing the load information at each link (Further discussion about weighted clique calculations is escaped for space limitations, refer to [3]). As an example, if $R_{CS} = 550$ and $R_{trans} = 250$, then $k = 3$. This means that each node must exhange the neighboring information and load information with its 3-hop neighbors. The whole procedure runs upon receiving a beacon that is broadcast by the gateway GW. The interval between 2 beacons is assumed to be relatively long since the traffic state in WMNs does not change frequently.

5. CONCLUSION

We addressed throughout this paper the fairness problem in WMNs. We proposed a solution that is based on varying the CW values to differentiate user's probability to access the medium, and on using a queue per flow per node. We also proposed a distributed version of the algorithm. Numerical results show a significant enhancement in fairness.

6. REFERENCES

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