Performance Improvement Using Contention Window Adaptation in IEEE 802.11 WLANs

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Abstract

In trending technology, we need to concentrate on very important issue to find out optimal solution for communication between several wireless devices with avoiding the obstacles such as the traffic in network, message collision, retransmission of messages and many other issues. And for avoiding such problems in the network, there must be some optimal solution. Most algorithms cannot give best solution for the optimal output for communication in terms of choosing best data rate available and packet delivery ratio. In our algorithm we are going to use rate adaptation mechanism with contention window parameter. Specially it is receiver assisted protocol, it means decision depends on receiver to negotiate rate and backoff value. It reduces the extra controlling overhead and as well as selects best rate with contention window value.

Keywords: *Rate adaptation, backoff parameter, contention, IEEE 802.11, BEB.*

1. Introduction

In wireless networks, successful data reception is mainly dependent on the Signal-to-Interference-and-Noise Ratio at the receiver. IEEE 802.11 supports more than link rates. Every link rate is associated with a certain required SINR starting point for decoding received packets successfully. Collectively, we define the sum of interference and noise power (N + I) as the accumulated environmental energy E. Suppose no power adjustment exists, apparently SINR is solely affected by the environmental power level E. When we apply conventional link rate adaptation schemes network faces several problems like on communication failure it decreases channel access attempts and on communication success it minimizes contention window value to increases the channel access, parallel it may also increases the data rate. Due to this irregular interaction IEEE 802.11 system came across poor performance.

Motivated by the above observations, instead of separately dealing with the these parametric quantities, we consider the combined link rate and contention window adaptations in a unified framework. In particular, rate adaptation strategy that also takes contention window adjustment into consideration, entitled MARC, is developed to improve IEEE 802.11 system capacity. As 802.11 DCF is essentially a CSMA scheme, which mandates a station sense (detect) the wireless channel before attempting to transmit. Only when the sensed (detected) energy is below carrier-sense threshold does a station prepare to carry out its access attempt. MARC taps into this characteristic and lets each station constantly keep track of detected energy levels. In this way, environmental energy E can be received based on recent energy statistics averaged in a certain time interval. For some communication pair tx (transmitter) and rx (receiver), define Etx and Erx as the environmental energy level at the transmitter and receiver, respectively. By comparing Erx to Etx, a receiver is able to infer the medium congestion difference between the two sides, further utilized to assist in rate selection and contention window adjustment.

This energy information is only approximate, yet useful for resolving the problem of asymmetric (different) congestion views comprehended by tx and rx. Therefore, we propose to piggyback the Etx information in DATA packet, as shown in our MARC algorithm at the receiver can utilize this information to perform contention window tuning for transmitter.

Reply from the receiver is then carried by the ACK packet back to the sender. Instead of creating more overhead, MARC uses the reserved fields (5 bits in total) in PLCP header to carry the feedback. On acquiring the feedback from receiver, our MARC algorithm at the transmitter alters the transmit rate or contention window size accordingly.

When performing rate and contention window (CW) adaptations at the receiver, MARC first estimates whether the current transmit rate is the best sustainable choice under the latest observed environmental energy Erx. A new rate will be suggested if the current rate is not the best one. Otherwise, MARC moves on to evaluate whether the CW needs to change based on the difference of Etx and Erx.

2. Related Work

The Auto rate fallback (ARF)[6] was originally used in WaveLAN-II devices, one of the previous 802.11 products. ARF is the most widely implemented rate-adaptive scheme. The concept was proposed by A. Kamerman and L. Monteban in 1997. Although ARF is easy to implement, it has one attendant drawback: ARF cannot work efficiently under stable or fluctuated channel conditions.

Receiver based Auto-rate (RBAR)[4] is a receiver-based rate-adaptation mechanism, which makes the rate adaptation decision based on channel quality estimated at the receiver and informs the sender via RTS/CTS handshaking mechanism. This mechanism was proposed by G. Hollan, N. Vaidya, and P. Bahl, in 2001. Two main drawbacks exist in the RBAR protocol. One is the controlling overhead caused by rate negotiation on a per-packet basis. The other is the fact that RSSI estimation is not precisely supported in most wireless devices.

Adaptive Thresholds (AT)[15] aims to enhance the performance of ARF rate adaptation protocol for mitigating the problem of using fixed up/down-thresholds without considering time-varying wireless channel characteristics and the impact of link-layer collisions. In 2007 J. Choi, J. Na, K. Park, and C.-K. Kim proposed a run-time adaptive algorithm to dynamically adjust the up/down-thresholds in ARF based on link-layer measurements. Since frame collisions cannot be easily distinguished from channel errors according to missing IEEE 802.11 ACKs, chances are the ARF rate control usually results in unnecessary rate downshifts when channel noise is actually low.

AC (ARF with COLLIE (Collision Interferencing Engine))[16] targets on wireless packet loss diagnosis so that transmission failures caused by link-layer collisions or channel errors (weak signal) can be distinguished. So that AC can improve ARF performance. S. Rayanchu et al. proposed this work in 2008. The essential operation of AC greatly depends on the AP module's capability of identifying the true cause of a packet loss and invoking the correct method of adaptation in actual, which incurs significant per-packet overhead and considerable bandwidth waste when inaccurate diagnosis takes place. Adaptation of data rate and contention (ARC)[17] is an open-loop rate adaptation protocol that jointly considers the contention window adjustment. The ARC protocol estimates the optimal contention window (optCW) based on Cal`i's approximation methods. This work was projected by A.-C. Li, T.-Y. Lin, and C.-Y. Tsai in 2009. Due to its open-loop nature and tuning contention window first, ARC may encounter several transmission failures before reaching a proper backoff and rate setting. In addition, the transmitter-estimated optCW in ARC does not always reflect the contention level at the receiver under asymmetric networking environments.

3. System Design and Working

Here, a system needs to develop in such a way that, which will reduce the number of collisions in the network. This improper interaction of data rate and backoff that harms the 802.11 system performance, due to separate consideration of those two parameters. Modified MARC subject to very negligible overhead due to controlling information sent via packet regardless of its receiver aided nature. SINR data is practically not possible thats why RSR table is used which derived by trial and error basis by continuously remarking the environmental variable. The RSR table then guides the recipient to choose the best suitable rate for the transmitter.

3.1 Mathematical Model

Let S be a system that describes 802.11 performance measures.
S= {Rate, CW, Control, Energy}
Rate= {x | x is true or false, which shows MARC RATE Flag is enable or disable }
CW= {x | x is true or false, which shows MARC CW Flag is enable or disable}
Control= {B1B2B3 | 8 combinations of data rates}
B1={0, 1}
B2={0, 1}
B3= {0, 1}
Energy={Erx, Etx, Ediff}
Erx= Energy Level of Receiver
Etx= Energy Level of Transmitter
Ediff = (Erx – Etx)/Etx

3.2 Receiver Operation

Suppose the current transmit rate is r_i and receiver suggested rate is r_j. If r_i is not equal to r_j, then the receiver sets MARC Rate Flag true, and corresponding 3-bit MARC Control, defined as b1b2b3, with value(b1b2b3) = j - 1. On the other hand, if $r_i = r_j$, meaning that the best rate is already in use, the receiver then looks at the energy difference E_{diff} between E_{rx} and E_{tx}. Define $E_{diff} = \frac{Erx - Etx}{Etx}$. Generally speaking, rate adaptation is effective in resolving the collisions due to concurrent transmissions (with transmitters locating outside of each other's carrier-sense range), but ineffective in reducing collisions due to simultaneous transmissions (inside carrier sense range). The latter can be alleviated by increasing the contention window size to discourage transmission attempts in the collision zone. Thus contention window tuning is also critical for system performance. An optimal contention window ($optCW_{ri}$) at rate r_i can be approximated based on Cal'i's analytical model. However, the transmitter-estimated $optCW_{ri}$ does not necessarily reflect the contention status at the receiver. As a result, the receiver utilizes E_{diff} to assist in tuning transmitter's CW value to further increase the transmission success probability. Specifically, when Ediff is positive, indicating energy (contention) level at the receiver is higher than that at the transmitter, the CW value should be increased to reduce contention. In contrast, when Ediff is negative, implying contention level is lower at the receiver than that at the transmitter; the CW value can be decreased to encourage more aggressive transmission attempts. Consequently, the receiver sets MARC CW Flag true and the first bit (b1) of MARC Control as follows,

$$b1 = \begin{cases} 1 & if\ E_{diff} > 0 \\ 0 & if\ E_{diff} < 0 \end{cases}$$

Next, the rest two bits (b2b3) of MARC Control are utilized to indicate the CW adjustment quantity for transmitter. Suppose K values can be represented (in our case K = 2^2 = 4 given two bits $b_2 b_3$ are available). K boundaries (0, 1, $\frac{1}{K}$, $\frac{2}{K}$, . . . , $\frac{K-1}{K}$) are defined for possible E_{diff} values. When $|E_{diff}|$ lies between any two boundaries or beyond the largest boundary, the receiver configures the value of b2b3 in MARC Control.

The pseudo code for receiver MARC operations in Algorithm 1. Based on the values of MARC Rate Flag, MARC CW Flag, and MARC Control contained in ACK packet, the transmitter is able to perform the rate and contention window adjustment accordingly.

Table 1: All Cases Of E And Corresponding MARC CW Flag & Control Bits When Rate Flag = False

Possible Cases	EARC CW Flag	EARC Control		
		b_1	b_2	b_3
$0 < E_{diff} \le 25\%$	true	1	0	0
$25\% < E_{diff} \le 50\%$			0	1
$50\% < E_{diff} \le 75\%$			1	0
$75\% < E_{diff}$			1	1
$-25\% \le E_{diff} < 0$		0	0	0
$-50\% \le E_{diff} < -25\%$			0	1
$-75\% \le E_{diff} < -50\%$			1	0
$E_{diff} < -75\%$			1	1
$E_{diff} = 0$	false	don't care		

3.2 Transmitter Operation

Once the ACK packet successfully returns from the receiver, the transmitter first checks if MARC Rate Flag is set true. If yes, rate and CW are configured to rb+1 and optCWrb+1 respectively, where b = value (b1b2b3). If MARC Rate Flag is set false, then transmit rate remains at ri, and the transmitter moves on to check the MARC CW Flag. If MARC CW Flag is false, then present CW value, denoted cwp, remains. Otherwise, the transmitter should adjust the CW value.

If, unfortunately, ACK does not return (or DATA packet simply fails to reach the receiver), the transmitter has no receiver feedback to assist in the rate and CW adaptation. In this case, the transmitter compares cwp with optCWri , and increases cwp to optCWri if cwp < optCWri , letting rate stay at ri. The design rationale is trying to impose a larger backoff window on future transmission, hoping the next transmission can succeed without the need to decrease rate. However, if cwp ≥ optCWri , then the transmitter should decrease rate to the next lower one (or maintain the rate if it is already the lowest). Meanwhile, cwp is set to the optimal CW value at the lower rate.

Algorithm 2 summarizes MARC operations at the transmitter. Note that the feedback from the receiver takes effect on the next DATA packet (including retransmitted packet) to be sent by the transmitter within a certain time interval (*timeout*). In case the next DATA packet arrives after *timeout* expires, the corresponding rate and CW settings become invalid, and the transmitter resets transmit rate to the default rate r_R (the highest supported rate) and CW at $optCW^r_R$.

Algorithm 1:- MARC Algorithm at Receiver

while (DATA packet transmitted at rate r^i received) **do**

Look up the RSR table and decide a best sustainable rate r^j based on E^{rx};
if (i != j) **then**
MARC Rate Flag set to *true*;
Set value($b1b2b3$) = j - 1 in the **MARC Control** field;
else
MARC Rate Flag set to *false*;
Compare *Erx* with *Etx* and calculate *Ediff* ;
if (*Ediff* == 0) **then**
MARC CW Flag set to *false*;
else
MARC CW Flag set to *true*;
if (*Ediff* $<$ 0) **then**
Set $b1$ = 0; // to decrease CW
else
Set $b1$ = 1; // to increase CW
if (($\frac{k}{K} < |E^{diff}| = \frac{k+1}{K}$) && ($0 = k < K - 1$)) **then**
Set value($b2b3$) = k;
else
Set value($b2b3$) = K - 1;
Return ACK packet back to transmitter;

Algorithm 2:- MARC Algorithm at Transmitter After DATA Has Been Sent to Receiver Using Rate *ri*
Suppose *cwp* is the current CW setting for this particular receiver;
if (ACK returned) **then**
if (**MARC Rate Flag** == *true*) **then**
Obtain b = value($b1b2b3$);
Set $r^{next} = r^{b+1}$;
Set $cw^p = optCW^{r^{b+1}}$;
else
Set $r^{next} = r^i$;
if (**MARC CW Flag** == *true*) **then**
switch ($b1b2b3$)
case 100: Set $cw^p = optCW^{r^i} \times (1 + 12.5\%)$;
case 101: Set $cw^p = optCW^{r^i} \times (1 + 37.5\%)$;
case 110: Set $cw^p = optCW^{r^i} \times (1 + 62.5\%)$;
case 111: Set $cw^p = optCW^{r^i} \times (1 + 87.5\%)$;
case 000: Set $cw^p = optCW^{r^i} \times (\alpha + (1 - \alpha)(1- 12.5\%))$;
case 001: Set $cw^p = optCW^{r^i} \times (\alpha + (1 - \alpha)(1- 37.5\%))$;
case 010: Set $cw^p = optCW^{r^i} \times (\alpha + (1 - \alpha)(1- 62.5\%))$;
case 011: Set $cw^p = optCW^{r^i} \times (\alpha + (1 - \alpha)(1- 87.5\%))$;
else
if ($cw^p < optCW^{r^i}$) **then**
Set $cw^p = optCW^{r^i}$;
Set $r^{next} = r^i$;
else
if ($i > 1$) **then**
Set $r^{next} = r^{i-1}$;
Set $cw^p = optCW^{r^i}$ -1 ;
else
Set $r^{next} = r^i$;
Set $cw^p = optCW^{r^i}$;
if (next DATA packet destined for this particular receiver arrives before *timeout* expires) **then**
Pick up the backoff timer from [0, cw^p -1] and starts to count down;
Transmit the DATA packet at rate r^{next};
else
Pick up the backoff timer from [0, $optCW^{r^R}$ -1] and starts to count down; // r^R is the highest supported rate
Transmit the DATA packet at rate r^R;

4. Results and Discussion

4.1 Symmetric Environment:

In the environment, where the contention level at the transmitter is consistent with that comprehended by the receiver, referred as a symmetric environment. ARF-based approaches (AT and AC) perform slightly better than BEB. By jointly adjusting the rate and CW parameters, ARC yields the second best throughput. Because of its open-loop nature, ARC is unable to react to the varying channel as quickly as MARC does. On the other hand, although RBAR incorporates receiver feedback to assist in rate selection, the system throughput achieved by RBAR is not as high as MARC due to the controlling overhead and binary exponential backoff mechanism used by RBAR. This result demonstrates the importance of designing the rate and CW parameters in a unified framework at the cost of moderate controlling overhead (only one extra byte to carry Etx in our MARC design). Consequently, MARC improves the performance of ARC and RBAR. Mostly MARC and RBAR uses the largest proportion of rate setting is both at 2 Mbps regardless of the rate selection mechanisms adopted by RBAR and MARC are different. In RBAR, the best rate is selected based on SINR value, which is obtainable in simulator but not accurately supported by current hardware. In contrast, MARC decides on the best sustainable rate according to the RSR table derived from actual reception past, which is practically implementable. This result implies that the RSR table introduced in MARC does good judgment without the need to obtain SINR, and thus represents a promising option for rate determination.

4.2 Asymmetric Environment:

If hidden terminals exists in network, then observed contention status at the transmitter is different from that at the receiver, to which we refer as the asymmetric environment. Such inconsistent contention comprehension can invalidate the transmitter-estimated CW setting. Although having receiver feedback, performance achieved by RBAR is limited by its communication overhead and lack of incorporating appropriate CW adjustment. Collectively, MARC performs better than ARC and RBAR by around 21percent, and has the potential to improve the performance of ARF-based approaches by 1.8 times in average. The joint CW adjustment effectively maintains rate stability, preventing unnecessary rate fluctuations. Specifically, if the medium congestion level can be minimized by enforcing larger backoff on communications, then there is no need to decrease the link rate. Conversely, if there is extra interference that may be tolerated, a smaller backoff can be used to increase more transmission activities with keeping the rate intact.

5. Conclusion

This system is a practical implementable solution for tuning the rate and backoff parameters in an IEEE 802.11 multi-rate environment. By utilizing reserved bits in 802.11 PLCP header and one extra byte carried in DATA packet, MARC incurs little communication overhead despite its closed-loop (receiver assisted) nature. Instead of trying to obtain the SINR value (which is not practically obtainable), MARC decides on the best rate according to an empirically derived rate selection reference table at the receiver. In addition, the receiver also assists in tuning the transmitter-estimated optimal contention. With proper interaction of these two parametric values, results show that the proposed protocol effectively improves the IEEE 802.11 system performance through its unified design intelligence.

Acknowledgment

I feel immense pleasure in thanking my guide Prof. Jyoti B. Kulkarni, for her technical support, constant encouragement, consistent guidance and inspiration throughout this seminar topic. Her willingness to motivate me contributed tremendously to my project. Her guidance and discussions with her are invaluable in realization of this report.

I express my sincere thanks to our H.O.D, Prof. P. R. Futane, Department of Computer Engineering for providing all the facilities towards completion of this seminar.
I wish to thank Prof. Mrs. S.A. Joshi, M.E.Co-ordinator, Sinhgad College of Engineering Vadgaon (Bk), Pune for her valuable suggestion regarding this seminar work.

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