ENERGY EFFICIENT PACKET TRANSMISSION ALGORITHM IN A FADING CHANNEL ENVIRONMENT

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ABSTRACT: *This paper proposes an enhanced version of the dual parameter based cost function algorithm with additional features of adaptive rate/power to deal with varying channel conditions. The dual parameter based cost function algorithm adapts the transmission parameters of the IEEE 802.11 network devices to optimize the energy consumption of a WLAN transmitter in ideal channel condition. Based on the proposed cost function algorithm the transmission data rate varies from low to higher level based on traffic load. However, in fading channel similar approach could not be applied because of worst case scenario the received power values drop significantly where transmitting at a higher data rate would contributes to high percentage of packet loss. Due to that reason, this paper presented a combination of cost function algorithm with adaptive rate/power based on received power value to combat the fading channel. An OPNET based simulation model was developed to analyses the performance of the propose algorithm. Simulation results show the proposed algorithm can significantly improve the energy efficiency of a WLAN while maintaining the network QoS in fading channel environments*.

Key words: adaptive rate/power, fading, energy efficiency, QoS performance, cost function.

1. INTRODUCTION

In recent years, the conservation of energy has become one of the critical current research areas due to rising demands of Information and Communication technology (ICT) services. Based on recent surveys published by [1,2], from 2012 to 2017, global average internet traffic growing at an annual rate of 23%. According to energy efficiency studies by [3], the carbon footprint contributed by the ICT sector is estimated around 1 to 2% globally. In addition to a rise in greenhouse gases, the business operation cost could also increase. Hence, it is important to develop energy efficient techniques for future communication networks.

The link adaptation mechanism offers the ability to adapt the modulation and coding scheme (MCS) and transmit power according to the channel conditions on the radio link. Traditionally in WLANs, the link adaptation technique is used to maximize the throughput by transmitting at the maximum possible transmission data rate as stated by [4]. However, in real environment due to varying channel conditions, the data rate need to be adjusted based on channel condition. In the literature, various techniques have been used to quantify the fading conditions [5] proposed a scheme to maximize the network throughput using a Physical (PHY) rate adaptation in Mobile Environments (RAM). The RAM adapts the transmission rate using the SNR prediction algorithm. [6] present an analytical model of the automatic rate fallback (ARF) rate adaptation technique with the 802.11 distributed coordination function (DCF) in a Rayleigh fading channel. The ARF rate adaptation of a station is modelled as a Markov chain. [7] presents a new rate adaptation algorithm based on the MAC layer frame error rate (FER).

This paper proposes the link adaptation based dual parameter cost function algorithm to deal with fading environments. The paper aims to apply the previously developed cost function algorithm (as applied in ideal channel condition) published by [8] with additional features to combat with the varying channel conditions. The main objectives of the algorithm are to improve the energy efficiency while maintaining the QoS performances. These are achieved by limiting the data rate and transmit power which results from the cost function algorithm to an appropriate level to ensure successful packet transmission at the receiver site.

2. PROPOSED ALGORITHM

This section describes in detail enhance dual cost function algorithm with additional features to overcome the fading environments. The enhanced technique apply the previously developed cost function algorithm with additional features of adaptive rate/power according to the channel condition which represents by the value of received signal strength.

2.1. Dual Parameter Cost Function in ideal channel condition

The dual parameter cost function algorithm [9], initially was developed for ideal channel conditions. In ideal channel condition, the decision of the rate/power selection is solely depends on the value of the cost function, F(t,Q). The cost function F(t,Q) incorporates the values of measured delay, current queue, queue threshold and a tunable parameter, which is the rate adaptation sensitivity parameter. The function F(t,Q) is represented as:

$$F(t,Q) = \begin{cases} C\left(\frac{1}{T_{target} - T_{current}} \times \left(\frac{Q_{current},j}{Q_{threshold,j}}\right)\right) & for\ T_{crt} < T_{target} \\ 1 & for\ T_{crt} \geq T_{target,j} \end{cases} \quad (1)$$

The novelty of the cost function algorithm is a rate selection based on dual parameter approach, where a cost function takes account an average measured delay of the traffic and the queue length of an individual transmitter. From the equation, *C* is a rate adaptation sensitivity factor, $T_{target}$is the target delay, $T_{current}$ is the measured delay in the network. $Q_{current,j}$ is the *jth* terminal transmission queue length. The queue threshold $T_{threshold}$ was measured as a short-term average queue length calculated in the past averaging period. The short-term average queue size is updated for every *N* packets, based on equation (2). Q*i*is an instantaneous queue length forpacket *i*.

$$Q_{threshold} = \frac{1}{(N-1)}\sum_{i=1}^{N-1} Q_i \quad (2)$$

The cost function algorithm adjusts the transmission data rate according to dual transmission parameters, where the end to end delay and the queue length are the parameters used. This is achieved by mapping the function of F(t,Q) based on the data rate mapping table, as in table 1[9]. At very light loads, the function of F(t,Q) results in lower values, thus adapting to a range of lower data rates. As the traffic increases, function F(t,Q) shows significant rises, thereby adapting to higher levels of the transmission data rates. Following that, an appropriate transmission power which corresponds to the selected data rate is applied. However, the same concept of adapting the transmission data rate in ideal channel conditions could not always be performed in a non-zero BER channel due to rapidvariations of the received signal power caused by the fading conditions.

2.2. Enhance Feature: Adaptive Rate/Power for fading channel.

When the cost function is executed in a fading channel, sometime it is not possible to transmit at the same data rate as the ideal channel condition. This is because there are instances when the transmitted signal experience destructive fading where the received signal strength could significantly reduce. Based on the proposed cost function algorithm, an increase in the traffic load leads to a higher F(t,Q) value, thus adapting to a much higher level. During this fading condition, transmitting at a higher data rate as selected by the cost function algorithm would result in excessive packet loss because the received power value of some of the packet is below the threshold power level for the specific higher transmission data rate. Due to this reason, an opportunistic scheduling packet transmission technique is developed by combining the cost function approach and adaptive rate/power algorithm based on received signal strength to overcome the fading channel.

Additional feature of the combined algorithm is developed by adjusting the data rate and the transmit power according to short term channel conditions. Based on channel estimation, the data rate is adjusted according to the received signal strength where in the case of destructive fading, lower order modulation schemes is selected. The adaptive rate for fading channel limit the data rate which results from the cost function algorithm as applied in ideal channel condition to an appropriate level to ensure successful packet transmission at the receiver site, which also contributes to retain the energy efficiency and QoS performances. This is because as the channel deteriorated, the transmission data rate is adjusted towards lower levels. As known, lower order modulation and coding (MCS) values are more robust as compares to higher order modulation schemes. These results in lower error probability which leads to higher packet success rate at the receiving site. Lower percentage of packet loss reduces the number of retransmission required, thus reducing the energy consumption.

Value of average received power is used as an estimator to limit the ceiling of the data rate. Therefore, in fading channel, results of data rate from the cost function algorithm (as in ideal channel condition), R_{cf} is again adapted according to the fading channel environment (represented by the average received power value) and new data rate (R_{fading})varies from the minimum level up to the ceiling rate (R_{max})only. The rate adaptation is performed using a threshold based scheme which switches between different data rates depending on the received signal level. The received signal level threshold for the rate selection is based on the minimum required power level for each of the MCS values. The received signal threshold is set according to minimum required power level for each of the MCS values. Based on the rate adaptation (threshold scheme), the new data rate (R_{fading}) is the minimum data rate which determined by both the cost function and adaptive rate/power algorithm. Details of the proposed adaptive rate adaptation for fading conditions are demonstrated in pseudo code:

Adaptive Rate/Power Algorithm

1: avg_{prx}→average received power
2: R_{max}→average received power
3: R_{cf}→ transmission data rate based on cost function
4: for each bock of packet (short term average)
5: check avg_{prx} to limit the data rate
6: if avg_{prx} *<-82dBm, packet will be dropped;*
7: if *(-82dBm<=* avg_{prx} *<= -81dBm),* R_{max}*=6Mbps;*
8: if *(-81dBm<=* avg_{prx} *<= -79dBm),* R_{max}*=9Mbps;*
9: if *(-79dBm<=* avg_{prx} *<= -77dBm),* R_{max}*=12Mbps;*
10: if *(-77dBm<=* avg_{prx} *<= -74dBm),* R_{max}*=18Mbps;*
11. if *(-74dBm<=* avg_{prx} *<= -70dBm),* R_{max}*=24Mbps;*
12: if *(-70dBm<=* avg_{prx} *<= -66dBm),* R_{max}*=36Mbps;*
13: if *(-66dBm<=* avg_{prx} *<= -65dBm),* R_{max}*=48Mbps;*
14: if *(*avg_{prx}*>-65dBm),* R_{max}*=54bps;*
15: From adaptation based on cost function → R_{cf}
16: R_{cf} is compare with R_{max} and $R_{fading}$is determined as minimum values for both.
17: R_{fading}= Min(R_{max}, R_{cf})
18: end if

In fading channel, to overcome the adverse effects of the varying channel condition, higher transmission of power would be required. Thus, extra feature of power adaptation added a new parameter where the new transmit power is adapted based on the short term average signal level. Due to the effects of multipath fading, the adaptation of the transmit power can either be increased or decreased from the original transmit power selected with a specific margin, *Δmargin* according to the fluctuations of the received signal power, as in equation (3):

$$Ptx_{fading} = P_{Rx}(dBm) + L_p(dB) \pm \Delta margin \quad (3)$$

The *Δmargin* can have positive or negative values, depending on either constructive or destructive fading. If destructive fading, then the *Δmargin* will be a positive value, which indicates that the transmit power needs to be increased to overcome the adverse effects of the fading. In contrast, if constructive fading occurs, where the average received power is more than the minimum received power at that data rate $Prx_{avg} > Prx_{min}$, which specifies a good channel condition, then transmit the new power either remains at the existing power level or is set to lower values to gain an advantage of lower energy consumption. For this algorithm, in the case of constructive fading the existing transmit power value (as for the cost function algorithm) is selected.

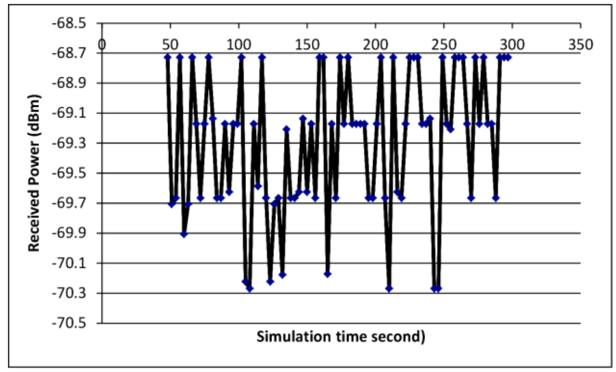
3. SIMULATION RESULTS AND ANALYSIS

Performances of the proposed technique are evaluated using an OPNET based simulation model. The network model consists of ten user terminals (UE) and one Access Point (AP) placed randomly in a 200m x 200m area. The parameters used in simulations are summarized in table 1. Simulation results are averaged over 3 simulation runs.

Table 1: Simulation Parameters

Parameter	Value
WLAN Standard	IEEE802.11g
Operating Frequency	2.4 GHz
Number of UEs	10
Transmission Range	100m-300m
Propagation Model	Free space path loss
QoS delay threshold	200ms
Packet delay threshold	1-3%
Packet Generation	Exponentially distributed
Noise density	-163dBm/Hz
Packet length	1000 bytes
Transmit power *(Ptx)*	745.2 mW
Receive power *(Prx)*	370.8mW
Idle power *(Pidle)*	18µW

Figures (1) to (4) show how the new data rate in fading channel (R_{fading}) is adapted based on fluctuation of received power values. Figure (1) plots the variation of received power values for fading channels with (k=3). For fading condition, the proposed combined algorithm limits the transmission data rate, according to the fluctuation of received power values, where the new transmission data rate cannot exceed the threshold level (R_{max}) as shown in figure (2). Figure (3) presents the transmission data rate which result from the cost function algorithm. Figure (4) depicts the new transmission data rate which adapting towards more robust rate according to the variation of received power values. Figure (5) shows the corresponding transmit power values. Values of transmit power for the combined algorithm in fading channel is higher than those values in ideal channel condition and this is achieved according to equation (3) which are based on the fluctuation of received power values, the path loss as well as the *Δmargin* values.



Fig(1): Variation of received power value for fading channel

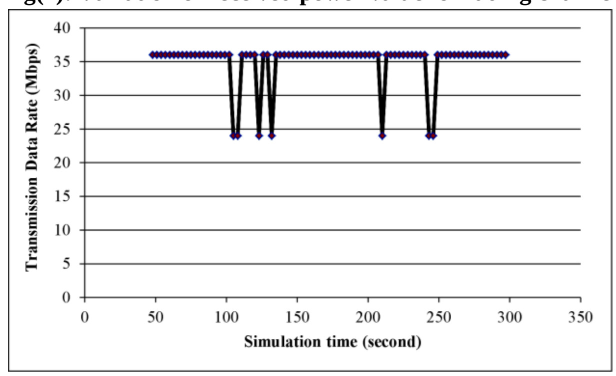


Fig (2): Maximum threshold level for transmission data rate (R_{max}) limits by the combined algorithm

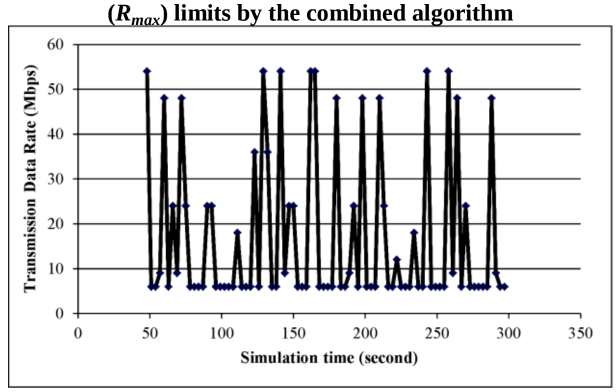


Fig (3): Transmission data rate using the cost function (R_{cf})algorithm
(for zero BER channel condition)

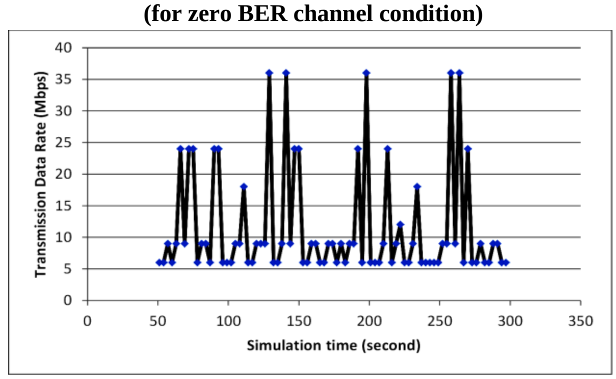


Fig (4): Transmission data rate (R_{fading}) using the combined algorithm.

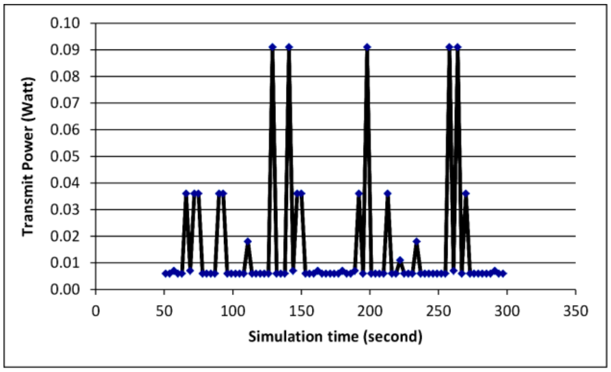


Fig (5): Transmit power values using the combined algorithm.

Figure (6) shows the distribution of data rates at (p=0.25). It can be observed that the combined algorithm shows higher percentages at lower data rates than the adaptation cost function. This is because, the combined algorithm adapting the data rate according to the short term average of received signal power. As known, in fading channel, most of the time the received power values deteriorated, thus adapting towards lower data rates. For the cost function algorithm without any extra feature, the data rate is not adapted based on current channel condition, but it is adjusted according to the traffic load which influences by the delay and the queue length. Higher BER in fading channel degrades the QoS performances which contributes to rise of ete delay and the queue utilization, thereby results in higher F(t,Q) values, thus map to higher data rates as shown in figure (6).

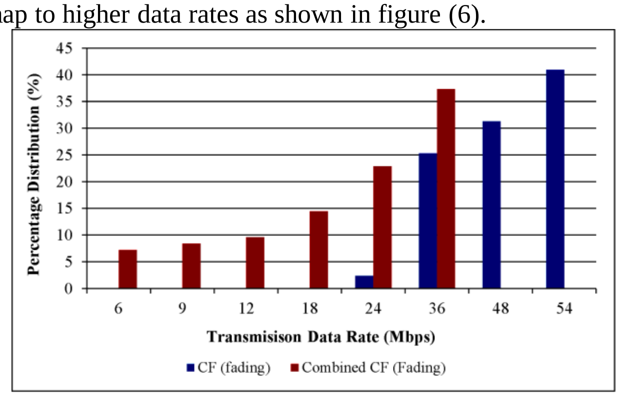


Fig (6): Distribution of transmission data rates for both cases

Table 1 summarizes the percentage of packet loss for both algorithms. It can be extracted from the table that the packet loss rate for the combined algorithm in fading conditions is less than the packet loss rate which applied the cost function algorithm only. Such difference of performance is achieved since the cost function algorithm is executed in a fading channel without taking any consideration of channel conditions. As mentioned before, when the cost function algorithm is applied in fading channel without any additional modification, due to higher BER which degrades the QoS performances results in higher F(t,Q) values thus adapting to much higher data rates. These conditions result in excessive packet loss because the received power value of some of the packets is below the threshold for the specific higher transmission data rate.

Table 2: Comparison of packet loss rate

Network Load	Packet Loss (%)	
	CF(non ideal channel)	Comb CF (non ideal channel)
0.05	2.5	0.5
0.1	6	2
0.2	4	1.5
0.25	8	3
0.3	6.5	2
0.4	9	3

In order to overcome the varying channel condition, the combined cost function with adaptive rate/power adaptation algorithm based on received signal strength is executed. The main objective of the proposed approach is to limit the data rate which results from the cost function algorithm to an appropriate level to ensure successful packet transmission. As can be seen from figure (6), the combined algorithm shows high percentage of staying at more robust rate compares to the cost function algorithm which is unaware of the channel condition. Transmitting at lower data rate reduce the packet error rate which leads to lower packet loss. When a packet is lost the packet needs to be retransmitted. When the percentage of packet loss increases in fading conditions, consequently number of retransmissions increases proportionally which consumes more transmission energy, as can be seen from figure (7) and figure (8) respectively.

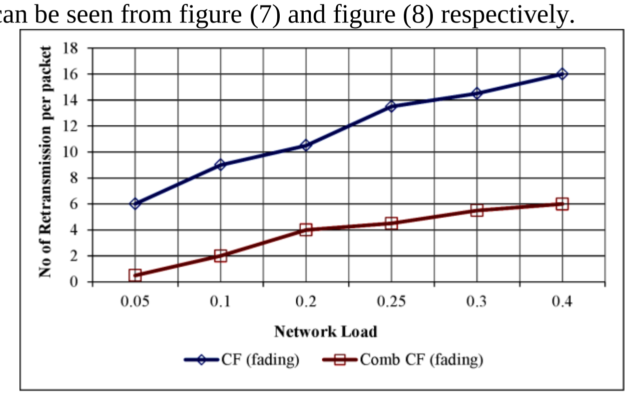


Figure (7): Number of retransmission per packet for all load conditions

By adapting to more robust rates in a fading channel, the probability of packet loss and retransmissions are reduced. Fewer number of packet loss reduces the number of retransmission required, which also leads to lower energy consumption, as can be seen in figure (8).

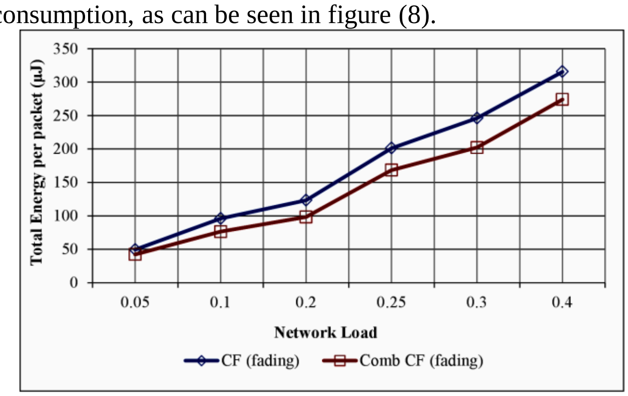


Figure (8): Total energy per packet for both cases

In fading channel, high BER causes unsuccessful packet transmission, which leads to higher packet loss, thereby increasing the number of retransmissions. These conditions directly degrade the QoS performance. Higher packet loss rates increase energy consumption because for each loss of packets enforcing packet retransmissions. Energy is wasted because of the packet retransmission, where the energy expenditure for an unsuccessful transmission has to be multiplied by the number of unsuccessful transmission attempts. Table 3 detailed out components of energy consumption. From the table, it is clearly show that although the transmit power is increased for the combined algorithm, but total energy consumption per packet is reduced due to lower number of retransmission as well as lower ete delay.

Table 3: Breakdown components of energy consumption for both techniques at (p=0.4)

Mode	Energy (Idle Mode) Pidle(Tdifs+Tsifs+Tbo)	Avg Ptx (Watt)	Energy (Transmit	Energy (Receiving	Energy per packet	No of Retx/pkt	Tot Energy per pkt (mJ)
CF only	0.00495μJ	0.12	17.78μJ	0.769μJ	18.55μJ	16	0.315mJ
Comb CF	0.00114μJ	0.125	37.53μJ	1.597μJ	39.13μJ	6	0.271mJ

As mentioned, the main contribution of the proposed combined algorithm is reducing the packet error rate by transmitting using robust MCS values. As packet error rate reduces, more packets are successfully transmitted which reduces the number of re-transmissions. As a result, packet is delivered quicker which contributes to lower end to end (ete) delay. The total ete delay consists of several delay components. For the combined algorithm, fewer number retransmission of packets leads to lower backoff delay as well lower queuing delay which contributes to lower ete delay.

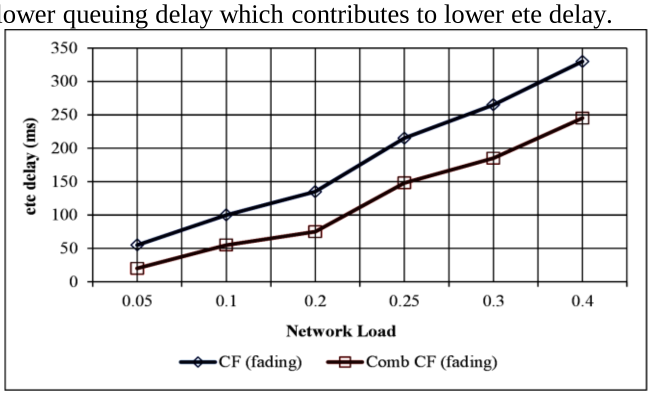


Figure (9): Comparison of the ete delay for both cases

4. CONCLUSIONS

The main objective of the proposed adaptive rate/power is to improve the energy efficiency in fading conditions by adapting the transmission data rate to more robust rate values which reduce the packet error rate. These conditions directly improves the QoS performances where the throughput could increase due to a reduction in packet loss rate and the ete delay is reduces due to faster packet transmission time as well as lower backoff and queuing delay. Apart from that, higher packet success rates reduce the energy consumption because fewer number of packet loss reduces the number of retransmission packet where the energy expenditure for an unsuccessful transmission is less than the previous.

5. ACKNOWLEDGMENT

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