Energy Efficient Back off Scheme with Adaptive Contention Window

D.Sharmila
PG Scholar
Anna University of Technology
Coimbatore, India

V.Bhanumathi
Assistant Professor
Anna University of Technology
Coimbatore, India

V.Femina
PG Scholar
Anna University of Technology
Coimbatore, India

R.Dhanasekaran
Director Research
Syed Ammal Engg. College
Ramanathapuram

ABSTRACT

Energy efficiency is a measure of the performance of IEEE 802.11 wireless multihop mobile ad-hoc networks. The operating life of the battery can be increased by controlling the contention window size at a node. A new backoff algorithm based on a dynamic adaptation of its maximal limit is proposed. This is a function of the number of nodes in the network and their mobility. In this algorithm, node's percentage of residual energy is also considered. The loss of packets due to the collisions in the MAC layer and mobility is reduced. Thereby the transport protocol performance can be improved. Our extensive ns-2-based simulation results have shown that the proposed scheme provides better performance in terms of energy goodput, throughput, packet delivery ratio, as well as the end-to-end delay.

General Terms

Mobile Ad-hoc Network (MANET), Backoff scheme, Performance Evaluation.

Keywords

Medium Access Control (MAC), CSMA/CA, Dynamic Source Routing

1. INTRODUCTION

Ad-hoc wireless networks are a comparatively new paradigm in multihop wireless networking. It can be defined as a wireless network formed by wireless nodes without the help of any established infrastructure. Each node can communicate directly with other nodes, so the network is characterized by the absence of central administration devices such as base stations or access points. Furthermore, nodes should be able to enter or to leave the network easily. The routes between nodes in an ad-hoc network may include multiple hops and, hence, it is appropriate to call such networks as "multi-hop wireless ad-hoc networks. In these networks, the nodes act as routers. They play an important role in the discovery and maintenance of the routes from the source to the destination or from a node to another one. This is the principal challenge to such a network. Because of the greater affordability of commercial radios, ad-hoc networks are likely to play an important role in computer communications.

The applications of ad-hoc networks are limited by problems such as mobility of nodes, shared broadcast channel, hidden and exposed terminal problem, and there are also constraints on resources, such as bandwidth and battery power. In ad-hoc networks, multiple nodes may contend for the channel simultaneously, thereby the probability of transmission errors is high. To reduce the collision problem, IEEE 802.11 ad-hoc network uses CSMA/CA protocol as its medium access control method.

IEEE 802.11 MAC layer has two medium access control methods: the DCF for asynchronous contention-based access and the point coordination function for centralized contention-free access. The DCF access scheme is based on a carrier sense multiple access with collision avoidance (CSMA/CA) protocol [2]. A station senses the channel for its idleness before transmitting. If the channel is found to be idle for Distributed Inter Frame Space (DIFS) time, then the station starts its transmission. Otherwise, if the channel is busy, the station continuously monitors the channel until it is found idle for a DIFS.

If two nodes transmit packets simultaneously, the packets are collided and more energy is consumed for retransmission. A node in CSMA/CA is required to sense the medium in randomly chosen back-off time duration before sending any packets. During this time, node remains in awake state. This timer is decreased as long as the channel is sensed idle and freezed when a transmission is detected and reactivated when the channel is idle again for more than a DIFS. When a receiver receives a successful data frame then it sends an acknowledgement frame (ACK) after a time interval called a short inter-frame space (SIFS) to the sender.

An optional four way hand-shaking technique, known as the request-to-send/clear-to-send (RTS/CTS) mechanism is also defined for the DCF scheme. Before transmitting a packet, a station operating in the RTS/CTS mode "reserves" the channel by sending a special RTS short frame. The destination station acknowledges the receipt of an RTS frame by sending back a CTS frame, after which normal packet transmission and ACK response occurs. Since collision may occur only on the RTS frame, and it is detected by the lack of CTS response, the RTS/CTS mechanism allows increasing the system performance by reducing the duration of a collision when long messages are transmitted. The RTS/CTS is designed to combat the hidden terminal problem.

A simulation analysis of the backoff mechanism in the IEEE 802.11 standard has been presented in [12]. Since the backoff and contention window are closely related, the selection of the contention window will affect the network throughput. Contention window must be chosen in such a way that the collision has to be minimized; thereby the network throughput gets increased. The authors in [4] showed the effective throughput and the mean packet delay versus offered load for different values of the contention window parameter and the number of contending stations.

Under a wide set of network and load conditions, multihop networks have lower performance than do single hop networks [2]. Data throughput is maximized when all nodes are in range of each other. The performance degradation in networks may be explained by the fact that channel contention in mobile ad hoc networks based on the 802.11 standard is not ideal.

A new backoff algorithm is proposed in [6], and the authors model it with a Markov chain; its saturation throughput is measured under several conditions and several sets of parameters which are to be adjusted according to the network condition, with the aim of approaching maximum throughput when the stations are saturated.

In [10], an adaptive, collision aware MAC protocol for wireless ad hoc networks, termed the Collision Based Contention (CBC) protocol, which depends on the current collision level on the shared medium contending nodes dynamically decides its Backoff value to avoid a blind random waiting before access to the medium is proposed.

Transmission Control Protocol (TCP) [5] is the transport protocol used in the most IP networks [15] and recently in ad hoc networks like MANET [13]. It is important to understand the TCP behavior when coupled with IEEE 802.11 MAC protocol in an ad hoc network. When the interactions between the MAC and TCP protocols are not taken into account, this may degrades MANET performance notably TCP performance parameters (throughput and the end-to-end delay) [11]. It is shown that the TCP parameters performance (notably throughput) degrades while the nodes number increase in a MANET using IEEE 802.11 MAC as access control protocol. Another parameter which is the mobility of nodes is taken into account in addition to the number of nodes.

It has been shown that TCP does not work well in a wireless network [12]. TCP associates the packet loss to the congestion, and then it starts its congestion control mechanism. Therefore, transmission failures at the MAC layer lead to the congestion control activation by TCP protocol then the number of packets is reduced. But this problem is more complex in MANET since there is no base station and each node can act as a router [13]. The TCP Performance parameters (like the throughput and the end-to-end delay) have been the subject of several evaluations. It has been shown that these parameters degrade when the interactions between MAC and TCP are not taken into account [11].

In [7], severe medium contention and congestion are intimately coupled, and TCP's congestion control algorithm becomes too coarse in its granularity, causing throughput instability and excessively long delay. Further, TCP's severe unfairness problem due to the medium contention and the tradeoff between aggregate throughput and fairness is illustrated.

The major source of these effects is the problem of hidden and exposed nodes. The most important solution which has been proposed to the hidden node problem is the use of RTS and CTS frames [12].

Likewise, there should be proper understanding between the MAC layer and the mobility parameter. When mobility increases, the backoff interval may also get increased. But this has to be avoided since the packet loss occurs due to the rupture of the connectivity and not due to collision.

Hamadani and Rakocevic [3] propose a cross layer algorithm called TCP Contention Control that it adjusts the amount of outstanding data in the network based on the level of contention experienced by packets as well as the throughput achieved by connections.

Lohier et *al*. [14] proposes a mechanism to adapt one of the MAC parameters, the *Retry Limit* (*RL*), to reduce the drop in performance due to the inappropriate triggering of TCP congestion control mechanisms. Starting from this, a MAC layer LDA (Loss Differentiation Algorithm) is proposed.

If the contention window control scheme does not consider the residual energy of a node, this may cause some nodes to have shorter life time than other nodes will. This situation will affect the establishment of a route and degrade the performance of the entire network. In order to increase throughput and save power, if a node has less residual energy, the node should have smaller backoff time to transmit its packets. On the other hand, if a node has higher residual energy , the node should have larger backoff time. In addition, we decrement the contention window size by just one unit instead of resetting *CW* to min *CW*. Therefore, we redefine the contention window control mechanism in IEEE 802.11 DCF as an efficient backoff scheme. The approaches presented suggest improvements to TCP performance based on MAC and TCP protocols.

This paper consists of following sections: Section 2 determines the calculation of backoff time. Section 3 explains the adaptive contention window maximum. Section 4 explains the result obtained by simulation. Section 5 represents the conclusion of the work.

2. CALCULATION OF BACKOFF TIME

2.1 IEEE 802.11

If the medium is busy, the station selects a random number called a back off time, in the range of 0 to CW (Contention Window). The back off timer decrements the BI (Back off Interval) each time the medium is sensed to be idle for an interval of one time slot. As soon as the BI becomes zero, the station can begin to transmit. If the transmission is not successful, a collision is considered to have occurred. Hence the contention window get incremented and this process will continue until the transmission is successful or discarded.

The back off time is computed as:

$$\text{Backoff Time} = \text{Random}\ (\ ) * \text{Slot Time} \quad (1)$$

Where Random ( ) is an integer drawn from a uniform distribution over the interval [0, CW]. CW is an integer within the range of values of the physical characteristics of the medium i.e. CWmin and CWmax (CWmin≤CW≤CWmax). Slot Time is also based on PHY characteristics. CW initial values would be CWmin.

The CW will take the next value in the series after each unsuccessful transmission, until CW reach the value of CWmax. Once it reaches the CWmax, it remains there until it is reset. This improves the stability of the system under high load conditions. The CW should be reset to CWmin after each successful transmission.

The algorithm used by IEEE 802.11 to make this contention window evolve is called binary exponential backoff (BEB). After each successful transmission, the contention window is set to [0, CW min − 1] (initial value). When node successive collisions occur, the CW is set to [0, min (1,024, $2^i * \text{CWmin} - 1$)], where ‘i’ is the number of retransmissions. If the number of retransmissions is greater than seven, then the contention window is reset to its initial value. One important thing is that the Random ( ) generated in each station should be statistically independent of Random ( ) in other stations.

The effect of this back off procedure is that multiple stations defer and go into random back off and a station with the smallest back off time will win the contention. The DCF does not differentiate the data traffic and stations. All stations and traffic classes have the same priority. The different delay and bandwidth requirements of the applications are not supported by the use of DCF.

2.2 Minooei 802.11

In [6], the authors proposed a Minooei 802.11 (M802.11) backoff algorithm and modeled it with a discrete-time Markov chain. The authors suggested choosing CW from the intervals:

$$[CW_{i-1}, CW_i],\ i = 1, 2... \tag{2}$$

$$[1, CW_0],\ i = 0 \tag{3}$$

Where CW_i is the contention window of the i^{th} backoff stage (i^{th} backoff stage means the station has collided ‘i’ times so far), and with the condition of the distances between the CW_i’s strictly increasingly. When a frame has collided i times, with increasing i the contending stations which are at the same stage as the station under consideration, are too many and the range of choosing CW ∗ Random( ) should become larger; this is accomplished by having the above mentioned condition and by having this lower boundary for CW∗ Random( ) in M802.11. In this way, the contending stations are also classified according to their backoff stages. The advantage of this method is classification of the stations by just incrementing the range of backoff times for a fixed number of stations. M802.11 decrements the backoff counter by just one unit instead of resetting CW to CWmin. M802.11 just reached a backoff stage which is optimal for traffic at that period of time, so it is better not to lose the frame and it seems that in this way delays will also decrease.The following equation is the backoff mechanism for M802.11.

$$\text{Backoff} = \text{Uniform}\ [(2^{i-1} * CW_{min} - 1),\ (2^i * CW_{min} - 1)] * \text{Slot Time} \tag{4}$$

2.3 Energy Efficient 802.11(E802.11)

The objective of the energy efficient backoff procedure is to save power and increase the throughput for a node with respect to those nodes in the two-hop contention area of the node. Let i denote the number of retransmission attempts made for a packet, and i_{max} represent the maximum number of retransmission attempts permitted.

Our proposed energy-efficient backoff mechanism is defined as follows:

$$\text{Backoff} = \text{INT}\ ((E) * CW_{min} + \text{Uniform}\ [(2^{i-1} * CW_{min} - 1),\ (2^i * CW_{min} - 1)] * \text{Slot Time} \tag{5}$$

Where, E is the node’s percentage of residual energy, and Uniform [∗] is the random number generation function with uniform distribution.

If a node had a higher residual energy in its two-hop contention region, then it will have a higher backoff time according to our efficient backoff mechanism; otherwise, it will have lower backoff time.

3. DYNAMIC CONTENTION WINDOW FOR MOBILE NODES

The MAC protocol is based on the backoff algorithm that allows it to determine which will access to the wireless medium in order to avoid collisions. The backoff time is calculated using (3), (4), (5) and when mobile nodes are considered contention window maximum is made adaptive thereby the performance of the network is increased.

The first parameter considered in this algorithm is the number of nodes in the network. When the number of nodes in the network increases, the performance of TCP deteriorates. The cause of this degradation is the frequent occurrence of collisions between nodes. These collisions become more frequent with a small backoff interval because the probability to have two or more nodes choose the same value in a small interval is greater than the probability that these nodes choose the same value in a larger interval.

For example, if ‘I’ be the interval, SI its size, and p (u, x) is the probability that the node ‘u’ chooses the x value in the ‘I’ interval. The problem then is how to ensure that for any two nodes u and v in the network with u! = v, we will have:

$$| p (u, x) – p (v, x) | = y$$

$$y != 0 \tag{6}$$

When the probability of collision increases, SI should also increases. Size of SI is adapted according to the number of nodes in the network and this can be achieved when the maximum contention window CW_{max} is adaptive.

$$CWmax\ (n) = CWmax0 + Log\ (n) \qquad (7)$$

Log ( ) is used here because we found in [14] that the effects of the large values of the nodes number on the TCP performance are almost the same.

The second parameter considered in this algorithm is the mobility of nodes because it participates in the degradation of TCP performance. In fact, node mobility often leads to the breakdown of connectivity between nodes, resulting in loss of TCP packets and then the degradation of the TCP performance. At the MAC protocol, when the packets losses are detected, they are associated to the collisions problem, which is not the case here. Then, more the mobility increases, more the backoff interval increases, which are not a real scenario, because these packets are lost due to the rupture of the connectivity and not by the collisions. Therefore, we will try to find a compromise between the effect of mobility and the size of the backoff interval.

Mobility is generally characterized by its speed and angle of movement, two factors that determine the degree of the impact of mobility on packets loss.

For a node u to communicate with another node v, the following factors have to be considered:

θ: the angle between the line (u, v) and the movement direction of node u,

S: the speed of mobile node u.

To consider the impact of mobility on the loss of packets it is necessary to study the effects of mobility parameters (S and θ). For the effect of speed W, as in the case of number of nodes, we use a logarithmic function because for large values of speed mobility the results converge. So this is expressed as follows:

$$H(S) = \begin{cases} 1 & \text{if } S = 0 \\ Log(S) & \text{else} \end{cases} \qquad (8)$$

Also, the degree of the influence of mobility on packets loss is determined using the direction of the node movement, it is given by G (S, θ):

$$G(S, \theta) = \begin{cases} 1 & \text{if } -\frac{\pi}{4} \leq \theta \leq \frac{\pi}{4} \\ \sqrt{S} & \text{else} \end{cases} \qquad (9)$$

G (S, θ) = 1 when S = 0 (without mobility). When the speed S of the node increases, the packets loss increase too and packet loss increases more when the node is moving in the opposite direction of communication. This kind of packets losses has a negative impact on backoff interval because they can be associated to the collisions, but is not the case here (as explained above). To make this impact positive, we must use the inverse, as like follows:

$$M\ (S, \theta) = 1 / (G\ (S, \theta) * H\ (S)) \qquad (10)$$

The equation (10) decreases with the increasing of G (S, θ) and H (S) (when S increases), it decreases more when the node is moving in the opposite direction of communication. M (S, θ) expresses the impact of the mobility on the packets losses; it is the probability that the cause of these losses is the mobility. With (10), we can guarantee that when the mobility of nodes is significant, the adaptation of the backoff algorithm is not important because this mobility is more probable to be the cause of many losses packets. But with weak mobility the same equation makes it possible to get a significant adaptation to the backoff algorithm because in this case the collisions between frames are more probable to be the cause of the packet losses.

By including the mobility of the nodes, contention window maximum is adapted and is written as

$$CWmax\ (n, S, \theta) = CWmax0 + (Log\ (n) * M\ (S, \theta)) \qquad (11)$$

$$CWmax\ (n, S, \theta) = CWmax0 + Log\ (n) * (1 / ((G\ (S, \theta) * H\ (S))) \qquad (12)$$

CWmax0: initial value of CWmax defined by the MAC protocol (with the 802.11 version, it is equal to 1024). Each node may determine the values of n, S and θ independently. So it can then calculate the value of CWmax according to the formula given in (12). The value of n is variable; it is updated always when a node is leaving from or entering into the network.

4 SIMULATION ENVIRONMENT

A simulated network with 100 nodes is considered and the random way point mobility scheme is employed to model the node movement. More specifically, at the beginning of the simulation, the nodes are randomly placed on a simulation area of 670 × 670 m^2 .Each node picks a random destination on the area and moves there at a random speed, uniformly chosen from a predefined range. Once the destination is reached, another random destination is targeted after a pause time. Results reported in this paper are performed under ns-2 network simulator. DSR (Dynamic Source Routing) is used as the routing protocol. In ref. [1], the authors compare the system performance with existing schemes by adjusting the speed of node mobility, the density of node. In this paper, we focus on the impact of network data traffic to energy consumption and system throughput by adjusting the contention window maximum when the nodes are mobile.

Communications between nodes are modeled using a uniform node-to-node communication pattern with CBR TCP traffic sources sending data in 512-byte packets at a rate 20packets/s. A total of 5, 10, 15, 20, 25, and 30 CBR connections were generated to represent different levels of loading, with a node being the source of only one connection. All CBR connections were started at times uniformly distributed during the first seconds of simulation and then remained active throughout the entire simulation run.

4.1 Simulation and Results

In this section, the performance of the proposed energy efficient backoff mechanism by considering the scalable nature of the wireless ad hoc network and mobility is evaluated.

The evaluation is made based on the following four parameters:

- Throughput: No of packets transmitted per unit time.
- Energy goodput: No. of packets delivered successfully per unit energy.
- Packet Delivery Ratio: Ratio of successfully delivered data packets to the data packets originated by the sources.
- End to End delay per packet: The total delay experienced by a packet that successfully reached the destination node.

Table 1. Simulation Parameters

Parameters	**Values**
Nominal bit-rate	2 Mb/s
Simulation time	150s
Packet size	512 byte
Data rate	20 packets/s
CWmin	32
Energy dissipated for transmit	2 J
Energy dissipated for receive	1 J
Energy dissipated for sleep	0.01 J
Sleep time	1 s
Initial energy	200 J
Preamble length	144 bits
RTS length	160 bits
CTS/ACK length	112 bits
MAC header	224 bits
IP header	160 bits
Slot time	20 µs

In this paper, the throughput evaluation is done by varying the pause time, the evaluation of energy goodput and packet delivery ratio is done by varying the number of connections and the end-to-end delay parameter is evaluated by varying the number of nodes.

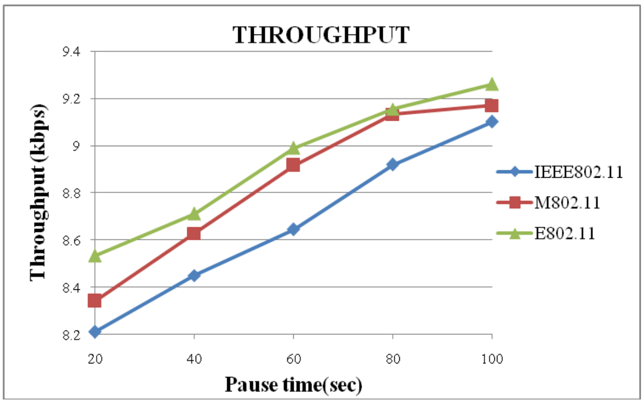

Figure 1. Throughput variation with pause time

Figure 1 shows the comparison of throughput for IEEE 802.11, M802.11, E802.11 with varying pause time. E802.11 improves throughput over M802.11 and IEEE 802.11 by approximately 2% and 3% respectively for the dynamic network.

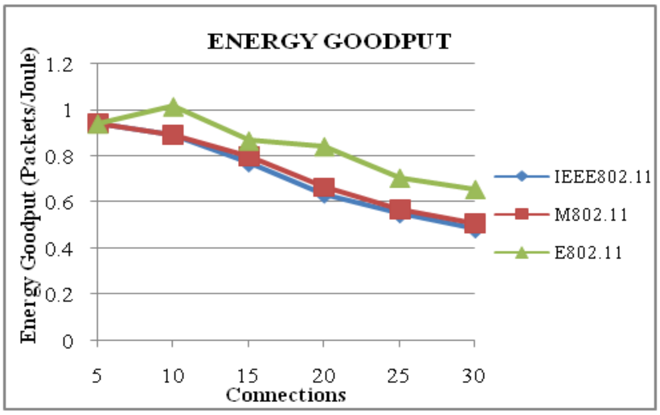

Figure 2. Comparison of Energy Goodput

Figure 2 shows the comparison of energy goodput for IEEE 802.11, M802.11 and E802.11 with mobile nodes. It is clearly seen that the successfully delivered packets per unit energy of E802.11 algorithm is improved over M802.11 and IEEE 802.11 approximately 12% and 14%.

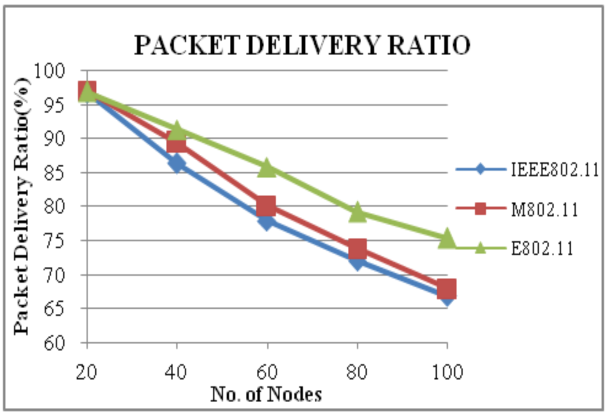

Figure 3. Comparison of Packet Delivery Ratio

Figure 3 shows the comparison of packet delivery ratio for IEEE 802.11, M802.11and E802.11 with mobile nodes.E802.11 improves the packet delivery ratio approximately 12% and 7% over IEEE 802.11 and M802.11 respectively.

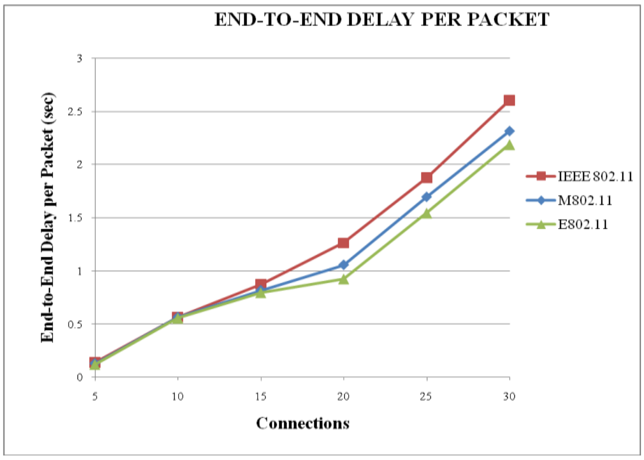

Figure 4. Comparison of End-to-End delay per packet

Figure 4 shows the comparison of End-to-End delay for IEEE 802.11, M802.11and E802.11 with mobile nodes. From this result, it is clear that E802.11 algorithm achieves a considerable reduction of End-to-End delay per packet.

5 CONCLUSIONS

Thus the TCP performance is improved by considering the interaction between TCP and MAC protocol. Energy efficient 802.11 achieves significant energy saving by taking into consideration percentage of residual energy of a node in the design of the backoff mechanism. By making the contention window maximum dynamic, the performance of the network with mobile nodes is still improved. When the connections are between 10 and 30, throughput of E802.11 is improved by 3% and 2% over M802.11 and IEEE 802.11. E802.11 of packet delivery ratio and energy goodput is improved by 7% and 12% over M802.11 and 12% and 14% over IEEE 802.11 respectively.

6 REFERENCES

[1] C.H.Chou , K.F.Su , H.C.Jiau , 2008 " Geographic forwarding with dead-end reduction in mobile ad-hoc networks", IEEE Trans Vehicular Technology, Vol. 57, No. 4, pp. 2375–2386.

[2] E.Dutkiewicz, 2001 "Impact of transmission range on throughput performance in mobile ad-hoc networks", IEEE Int'l Conf. on Communications, No. 9, pp. 2933–2937.

[3] E.Hamadani, Rakocevic, 2008 "A Cross Layer Solution to Address TCP Intra-flow Performance Degradation in Multihop Ad-hoc Networks", Journal of Internet Engineering.

[4] G.Bianchi, 2000 "Performance analysis of the IEEE 802.11 distributed coordination function", IEEE J Sel Areas Comm. Vol. 18, No. 3, pp. 535–547.

[5] G.Holland, N.Vaidya, 1999 "Analysis of TCP performance not over mobile ad hoc Networks", ACM Mobicom.

[6] H.Minooei , H. Nojumi, 2001 "Performance evaluation of a new backoff method for IEEE 802.11", Computer Communications, Vol. 30, pp. 3698–3704.

[7] Hongqiang Zhai, Xiang Chen, and Yuguang Fang, 2007 "Improving Transport Layer Performance in Multihop Ad-hoc Networks by Exploiting Mac Layer Information", IEEE Trans Wireless Comm, Vol. 6, No. 5, pp. 1692-1701.

[8] I.Karthigeyan , B.S. Manoj, C.S.R Murthy , 2005 " A distributed laxity-based priority scheduling scheme for time-sensitive traffic in mobile ad-hoc networks", Ad-Hoc Networks, Vol. 3, pp. 27–50.

[9] L.Munoz , M.Garcia , G.Choque , R.Aquero , 2001 "Optimizing internet flows over IEEE 802.11b wireless local area networks: a performance-enhancing proxy based on forward error correction", IEEE Communication Magazine, Vol. 39, pp. 60–67.

[10] M.Abdul Gafur, Niraj Upadhayaya, Syed Abdul Sattar, 2011 "Achieving Enhanced Throughput In Mobile Ad hoc Network Using Collision Aware MAC Protocol", International Journal of Ad-hoc, Sensor & Ubiquitous Computing, Vol. 2.

[11] M.Gerla, K.Tang, R.Bagrodia, 1999 "TCP Performance in Wireless Multihop Networks", WMCSA.

[12] M.Natkaniec , A.R.Pach, 2000 "An analysis of the backoff mechanism used in IEEE 802.11 networks", fifth IEEE symp. on computers and communications, pp. 444–449.

[13] R.Jiang, V.Gupta, C.Ravishankar, 2003 "Interactions between TCP and the IEEE 802.11 MAC Protocol", DARPA Information Survivability Conference and Exposition.

[14] S.Lohier, Y.G.Doudane, G.Pujolle, 2006 "MAC-layer Adaptation to Improve TCP Flow Performance in 802.11 Wireless Networks", IEEE Xplore, Canada.

[15] V.Kawadia, P.Kumar, 2005 "Experimental investigations into TCP performance over wireless multihop networks", SIGCOMM Workshop on experimental approaches to wireless network design and analysis (EWIND).