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Contention Window Optimization: an enhancement to IEEE 802.11 DCF to improve Quality of Service

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ABSTRACT

Wireless communication technology has gained widespread acceptance in recent years. Wireless Local Area
Networks (WLANs) are becoming more and more popular and widely used, since they provide high data rates. The main characteristics of this technology are simplicity, flexibility and cost effectiveness.
Recent applications include media streaming, interactive collaboration, videoconferencing and multimedia messaging. However, multimedia applications require a certain quality of service (QoS) support such as guaranteed bandwidth, reduced delay, high throughput and error rate. Guaranteeing those QoS requirements in the existing WLANs characterized by mobile stations with a low bandwidth and high rate error is a challenging task.
Distributed Coordination Function (DCF) is the basic Medium Access Control (MAC) method. It is based on the Carrier Sense Multiple Access (CSMA) that works as Listen-before talk scheme.
After collisions during competitive access to the channel in DCF scheme, packets must be retransmitted. These retransmissions consume enough bandwidth and increase the end-to-end delay for these packets. To address this, we propose to extend DCF with a new calculation method to increment contention window (CW) that enables each station to access the channel after a small number of attempts. Otherwise, it declares failure case early, if collision still occurs. The purpose of our scheme is to reduce delay and packet loss ratio and increase the efficiency of the transmission channel.
To show the performance of the proposed solution, simulations were conducted under Network Simulator (NS2) to measure the traffic control and packet loss ratio under various constraints

KEYWORDS

Wireless Local Area Networks (WLAN), Quality of Service (QoS), Distributed Coordination Function (DCF), Medium Access Control (MAC) layer, Contention Window (CW), Network Simulator NS2.

1 INTRODUCTION

Wireless Local Area Networks (WLANs) are becoming more and more popular attracting the interest of researchers, system integrators and manufacturers of wireless devices. They provide high data rates while maintaining a relative low price. It is one of the most deployed wireless networks in the world and is high likely to play a major role in multimedia home networking and next-generation wireless communications.

In Recent years, IEEE 802.11 [1] standard has emerged as the dominating technology for WLAN and is deployed almost everywhere including offices, public places and homes. Low cost, ease of deployment and mobility support has resulted in the vast popularity of IEEE 802.11 WLANs.

The architecture of IEEE802.11 standard includes the definitions of Medium Access Control (MAC) sublayer and Physical Layer (PHY). Its MAC layer has two access mechanisms: DCF (Distributed Coordination Function) and PCF (Point Coordination Function).

DCF is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique and adopts a slotted Binary Exponential Backoff (BEB) scheme to reduce collisions due to stations transmitting simultaneously. It is best known for asynchronous data transmission (or best-effort service). PCF uses a central-controlled polling method to support synchronous data transmission (QoS for real-time traffic).

Current applications such as video, audio, email, and data transfer have different requirements in bandwidth, delay, jitter, and packet loss. So, the standard WLAN that use the traditional best effort service in not able to support this kind of applications. Applications with QoS support are very important for IEEE802.11 WLAN in future wireless communications.

However, in DCF mechanism of IEEE802.11, all the stations and data flows have the same priority to access medium. There is no differentiation mechanism to support the transmission of data streams with different QoS requirements. So, in order to support applications with QoS requirements, some priority schemes have been proposed [2], [3]. The support of QoS for IEEE802.11 becomes critical for its success in multimedia applications.

The new developed standard called 802.11e [4], which enhances the current 802.11 MAC to support applications with QoS requirements (i.e. defined to support QoS) that providing differentiated classes of service in the MAC layer [5], it also enhances the physical layer so that it can delivery time sensitive multimedia traffic, in addition to traditional data packets..

The QoS is a primary factor which gives great satisfaction to the customer and great benefice to the providers.

Several studies has been done to improve QoS in network domain and particularly in Ad hoc network. QoS has to be guaranteed in reality at different levels of protocol architecture i.e. in different network layers (physical, network, etc.).

The remainder of the paper is organized as follows: In section 2, we briefly review the DCF mechanism [6] and backoff scheme used in IEEE 802.11 MAC layer. In section 3 we present a major thread of research has focused on enhancing IEEE 802.11 protocol performance by proposing various QoS improvements on DCF scheme.

A detailed description of the proposed solution is the subject of section 4. Section 5 presents performance results of our solution Vs basic DCF. Finally section 6 concludes and outlines open research directions.

2 DISTRIBUTED COORDINATION FUNCTION AND BACKOFF ALGORITHM

2.1 DCF description

DCF is the basic medium access mechanism for both Ad hoc and infrastructure modes. It works as a listen-before-transmission scheme. In DCF mode, each station checks whether the medium is idle before attempting to transmit. It is based on a CSMA/CA mechanism. The CSMA/CA constitutes a distributed MAC that use a local assessment of the channel status, i.e. whether the channel is busy or idle.
In this mode, if the medium is determined to be idle for DIFS (Distributed InterFrame Space) interval, the station transmits a packet immediately. Otherwise, the station shall defer until the end of the current transmission and starts the backoff process by selecting a random backoff counter. For each slot time interval, during which the medium stays idle, the random backoff counter is decremented. If the medium is busy, stations freeze their backoff counter.
If a certain station does not get access to the medium in the first cycle, it stops its backoff counter, waits for the channel to be idle again for DIFS and starts the counter again. Once the backoff counter expires, the station is authorized to access the medium (i.e. starts transmission immediately).
Stations that have waited longer have the advantage over stations that have just entered, in that they only have to wait for the remainder of their backoff counter from the previous cycle(s).
In the case of unsuccessful transmission (i.e. a collision occurred), the CW is doubled, and a new backoff procedure starts again. This process will continue until the transmission is successful or discarded.
Stations that have waited longer have the advantage over stations that have just entered, in that they only have to wait for the remainder of their backoff counter from the previous cycle(s).
Each station maintains a (CW), which is used to select the random backoff counter. The backoff time is a random number in the range of 0 and CW (i.e. interval [0, CW]).
The larger CW generates bigger overhead and small CW increases the number of collisions but ensures shorter access delays. The timing of DCF channel access is illustrated in Figure 1.

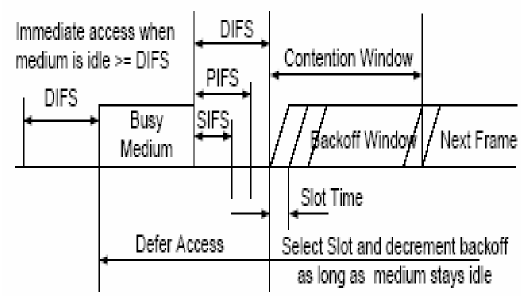

Figure 1: the timing relationship for DCF or basic access method

An acknowledgement (ACK) frame is sent by the receiver to the sender for every successful reception of a frame. The ACK frame is transmitted after a short IFS (SIFS), which is shorter than the DIFS. As the SIFS is shorter than DIFS, the transmission of ACK frame is protected from other station’s contention. The CW size is initially assigned to CWMin and if a frame is lost i.e. no ACK frame is received for it, the CW size is doubled, with an upper bound of CWMax and another attempt with backoff is performed. After each successful transmission, the CW value is reset to CWMin.

An additional RTS/CTS (Request To Send / Clear To Send) mechanism is defined to solve a hidden terminal problem inherent in WLAN. The successful exchange of RTS/CTS ensures that channel has been reserved for the transmission from the particular sender to the particular receiver. This is made possible by requiring all other mobile stations set their Network Allocation Vector (NAV) properly after hearing RTS/CTS and data frame. So they will refrain from transmitting when the other mobile station is in transmission. Use of RTS/CTS is much helpful when the actual data size is large compared to size of RTS/CTS. When the data size is comparable to size of RTS/CTS, the overhead caused by the RTS/CTS would compromise the overall performance [6], [7]. All of the MAC parameters including SIFS, DIFS, SlotTime, CWMin, and CWMax are dependent on the underlying physical layer (PHY).

2.2 Backoff scheme

In 802.11 DCF, a binary slotted exponential backoff is used with CSMA/CA. The backoff time is computed as follows [8]: Backoff Time = Random() * SlotTime, where Random() is a pseudorandom integer drawn from a uniform distribution over the interval [0,CW].

CWMin and CWMax are respectively minima and maxima value of CW.

CW parameter shall take an initial value of CWMin. After each unsuccessful transmission, CW is doubled, up to a maximum value 2m.W, where W is equal to (CWMin+1) and 2m.W is equal to (CWMax+1). Once the CW reaches CWMax, it will remain at the value of CWMax until it is reset. The CW will be reset to CWMin after every successful attempt of transmission of a data frame or a RTS frame, or where a retry counter reaches its limit.

Since a station use CW to control the backoff window of packet transmission, the optimal setting of CW will affect the performance of DCF. The backoff procedure of CW can be considered as a progress to probe the optimal value of CW, however, the resetting scheme in 802.11 breaks this progress, which will degrades the performance of DCF. Then the question is how to control the backoff counter, or CW optimally or near optimally.

3 THE QUALITY OF SERVICE

3.1 QoS and model

The QoS is a set of mechanisms capable to distribute the network resources on different applications in order to maximize the degree of satisfaction of each one [9]. It is characterized by a number of parameters (flow, latency, jitter and loss). Qos is the ability of a network element (e.g. an application, a host or a router) to provide some level of assurance for consistent network data delivery. From the user point of view, the QoS can be defined as the degree of its satisfaction.

A QoS model defines an architecture which provides the best possible service. This model must take into consideration all the challenges imposed by ad hoc networks, such as change of topology and constraints of energy and reliability. It describes a set of services that enable customers to select a number of warranties on some properties such as time, reliability, etc... Several QoS models are proposed in the literature: The conventional models Intserv [10] and DiffServ [11] used in wired networks are not suitable for WLAN.

Many others solutions are proposed such as IEEE 802.11e [4], MACA (Multihop access collision avoidance) [12], MACAW (Media Access Protocol for Wireless LANs) [13], MACA/PR (Multiple Access Collision Avoidance with Piggyback Reservation) [14], and different QoS improvements based on IEEE 802.11 DCF

Each of these solutions attempts to improve one or more parameters of the QoS.

3.2 QoS techniques in 802.11

We found two basic types of QoS. Integrated services, were network resources (i.e. bandwidth) are apportioned according to an application's QoS request (i.e. resources reservation), and differentiated services that classify network traffic according network resources (Prioritization).

To characterize these types of QoS, we can apply it to individual application flows [15] or to flow aggregates.

A flow is defined as an individual, uni-directional, data stream between two applications (sender and receiver), but an aggregate is simply two or more flows.

A lot of works and techniques are developed to obtain differentiated services in a 802.11 base network [16]. They can be achieved by modifying the parameters that define how a station or node would access the wireless medium based on DCF.

Although the contention-free service in the PCF is designed in 802.11 networks to provide QoS for real-time traffic, this service presents some limitations and cannot meet the requirements of real-time traffic. The main limitations related to PCF are:

- Introducing unpredictable beacon delay for each contention-free period, this problem is related to the uncontrolled length of the CP.
- Unknown transmission time of polled stations, this may destroy any attempt to provide QoS to other stations that are polled during the rest of the CFP.
- No knowledge of the offered traffic at the polled stations: with CFP.

Solutions using the DCF that introduce priorities are [3]:

The access scheme called Distributed Fair Scheduling (DFS) [17] (i.e. Backoff Increase Function) use modified backoff mechanism to determine which station should send first. In this approach, the backoff interval calculated is proportional to the size of the packet to send and inversely proportional to the weight of the flow.

Before transmitting a frame, the backoff process is always initiated, and when a collision occurs, a new backoff interval is calculated using basic backoff algorithm of IEEE 802.11 standard.

The Varying DIFS scheme [16] (DIFS differentiation) is based on the same idea used to introduce priorities for data frames (in the basic scheme) and for RTS frame (in the RTS/CTS scheme). In this approach each priority level is given a different DIFS (i.e. DIFSj) used by the associate station having priority j, to stay idle for a DIFSj before transmitting data. To avoid collision, the maximum contention window size in backoff mechanism is determined on the DIFS difference between stations having the same priority frames.

This technique maybe useful for real-time application, where we have more constraints on delays than on packet drops.

The third mechanism that can be used is to limit the maximum frame length [2] used by each station. In this differentiation mechanism, different priority stations are allowed to transmit frames with different maximum frame sizes. The station with higher priority can send larger frames than a station with a lower priority. Here, the station can either to drop packets that exceed the maximum frame length assigned to a given station (or simply configure it to limit its packet lengths), or to fragment packets that exceed the maximum frame length. This mechanism is actually used to increase transmission reliability, and it can be used for differentiation.

The differentiation mechanism called Extended DCF [18] involves using the Contention Window as a way to give higher priority to some stations than to others. Assigning a short contention window to those stations that should have higher priority ensures that in most (though not all) cases, the higher-priority stations will be able to transmit ahead of the lower-priority ones.

The contention window is a time window following the transmission of a frame. During this time window, the various stations on the network contend for access to the network.

The last differentiation scheme is BlackBurst (BB) [19]. Its main goal is to minimize the delay for real-time traffic. To do this, BB imposes certain requirements on the high priority stations. So, this stations, try to access the medium with equal, constant intervals, and the ability to jam the medium for a period of time by transmitting the black burst packet.

By using slotted time, and imposing a minimum frame size on real-time frames, it can be guaranteed that each BB contention period will yield a unique winner.

On the other hand low priority stations use the CSMA/CA access method defined in IEEE 802.11 [8].

Due to these limitations, new mechanisms are designed and under standardization in order to support QoS for 802.11 wireless networks. The following section will detail the main concepts and mechanisms for MAC enhancements for supporting quality of service.

4 PROPOSED MODIFICATIONS

4.1Motivations

The idea used to modify DCF procedure is based on mechanisms that generated packets loss and inutile bandwidth consumption. Packets loss may occur when collisions take place in channel contention mechanism. After these collisions, retransmissions are reinitiated, so they consume bandwidth and increase latency packets between communicating pairs.

4.2 Proposed solution

Our proposal solution is made by changing CW (Contention Windows) increment function in medium access procedure DCF that use RTS and CTS at MAC layer to improve some QoS parameters such as: loss, delay and throughput.

In DCF procedure, backoff mechanism reduces the risk of collision but it does not remove this phenomenon completely and when a collision occurs again (no response of ACK packet), a new backoff will be generated randomly. At each collision, window size increase in order to reduce the probability of such collisions to happen again. In the standard solution, CW values will change between given CWMin and

CWMax values. When a packet is successfully transmitted, the CW is reset to CWMin.

In this paper, we propose two functions (noted function 1 and 2) to increment the CW value by two new calculation types (i.e. left shift).

Our solution is based on the two following ideas:

Incrementing CW will cause "large CW" and larger Backoff which generates a bigger overhead

But when CW is decremented, it will give a "small CW" that increases the number of collisions.

Backoff time for basic DCF is βi * (SlotTime) where βi is given by the following mathematical formula: $\beta i = 2^{i+k} - 1$ where i (initially equal to 1) is the transmission attempt number and k depends on the PHY layer type and SlotTime is function of physical layer parameters.

When the value of "i" reaches an upper limit, the random range (CWMax) remains the same and when a packet is successfully transmitted, the CW is reset to CWMin.

In 802.11 standard, the chosen value are CWMin = 31, CWMax = 1023 and for k we take the value 4 because the CWMin value is equal to 31 (i.e. 2i+4 for i=1 is 31) so βi becomes $(\beta i = 2^{i+4} - 1)$ and i takes values from 1 to 6 (i = {1, 2, 3, 4, 5, 6}) (i.e. i=6 gives the CW=1023). In this case βi is the result of adding 1 to the one bit left shift of the variable CW. So after each collision, possible CW values are: {31, 63, 127, 255, 511, 1023} (see fig.2.a).

Our first function (function 1) is based on adding 3 to two bits left shift of the variable CW, where the number 3 is used to replace the two bits equal to zero after shift operation and βi becomes $(\beta i = 2^{2i+3} - 1)$.

The number of retransmissions attempts after each calculation is (04) (i= {1, 2, 3, 4}), and when i becomes greater than 3, CW is reset to 1023 (i.e. the max value of CW). So after each collision, possible CW values are: {31, 127, 511, 1023} (see fig.2.b).

Fonction1: adding 3 to two bits left shift

```
void inc_cw ( )
    {
      CW = (CW << 2) +3
          If (CW > CWMax )
             CW = CWMin;
    }
```

For example, if CW = CWMin =31, the next new value after is CW = 127.

Our second function (function 2) is based on adding 7 to three bits left shift of the variable CW, where the number 7 is used to replace the three bits equal to zero after shift operation and βi becomes $(\beta i = 2^{3i+5} - 1)$.

The number of retransmissions attempts after each calculation is (03) (i= {0, 1, 2}), and when i becomes greater than 1, CW is reset to 1023. So after each collision, possible CW values are: {31, 255, 1023} (see fig.2.c).

Fonction2: adding 7 to three bits left shift

```
void inc_cw ( )
    {
      CW = (CW << 3) +7
          If (CW > CWMax )
             CW = CWMin;
    }
```

For example, if CW = CWMin =31, the next new value after is CW =255.

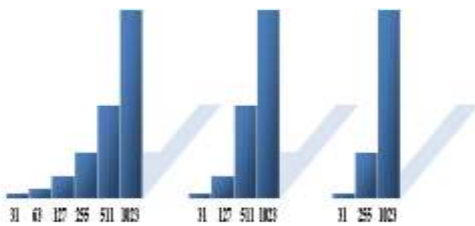

Fig. 2.a Fig. 2.b Fig. 2.c

Fig. 2: Possible CW values for (basic DCF, function 1and function 2)

5 SIMULATIONS AND EVALUATION

Measures in a simulation must be made on a set of parameters under certain conditions.
In WLAN, all nodes are mobiles and routes between these nodes may change frequently. So, we are obliged to recalculate very often routes between nodes which needs an additional control load and more bandwidth consuming. Nodes have limited energy, so it is imperative to best manage it as long as possible.
Energy consumption (is proportional to the number of packets processed and the type of treatment (Tx / Rx)) and Density (The average number of neighbors per node) have very important impact on the performance of mobile wireless networks (WLAN).
Evaluate network performances is to find if it is able to minimize packets loss, i.e. eliminate if possible the transfer loss (quality criterion). Packets Control are required for network management but they consumes some bandwidth. If the packets control rate is high, performances network degrades but conversely they are better (efficacy endpoint). Taking into account the characteristics of physical links (capacity) and current flow sharing them, when throughput (quantity of information per unit time) is higher, bandwidth is used efficiently.
For some applications, it is not enough to transmit large data quantity (high speed) without loss, but it is imperative to transmit it if possible faster, i.e. short (reduced) delay in real-time applications
To study and analyze our proposed solution based on DCF, we used Network Simulator (NS2) [20] version 2. The table below (Table 1) shows parameters used in our simulation model. They represent values used in NS2 for layer IEEE 802.11b.

Table 1: Simulation parameters

Parameters	Value
Simulation time	100s
Access medium	Mac/802_11
Routing protocol	AODV
Buffer size	50
Simulation grid	1200×1200 m
SlotTime	20 µs
SIFS	10 µs
CWMin	31
CWMax	1023
Flow	11Mb

5.3 Results and Discussions

The desired parameters to be evaluated by simulation under different contexts (mobility and density) are: average throughput in kbps that indicates data transfer rate.
Packets lost ratio is the rapport among successfully received and sent packets. This ration expresses network reliability.
To compare the efficiency of these three functions (Function 1, 2 and the basic DCF), we have considered six different scenarios in our simulation depending on the constraint of mobility (low and high) and the number of nodes (mobile station) with low value (10 nodes), medium value (20 nodes) and high value (50 nodes).

For each scenario, we have analyzed the found results (The packets lost and sent number, packet loss ratio and data throughput) of our two functions with the basic DCF

5.3.1Packets sent

We have obtained the following results (Fig.3) by measuring the total number of packets sent in the different scenarios for the tree functions.

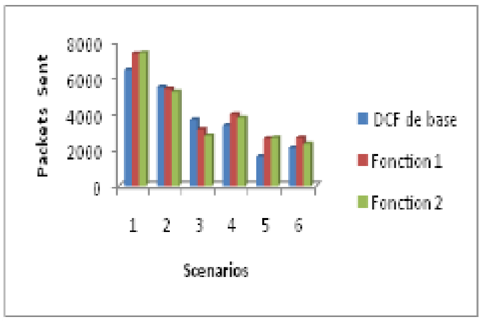

Fig.3: Packets sent

We have noted in the case of transmitted packets, the three functions have the same performance except for a high number of nodes and high mobility, where the DCF basic is better than our two proposed functions

5.3.2 Packets lost

We have obtained the following results (Fig.4) by measuring the total number of packets lost in the different scenarios for the tree functions.

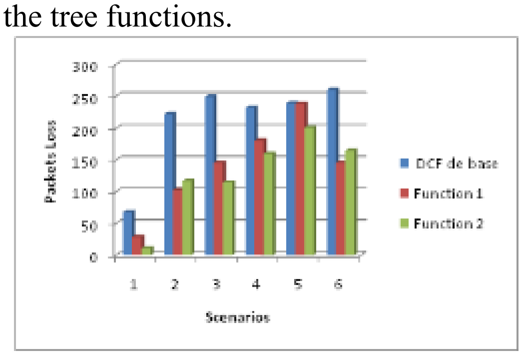

Fig.4: Packets lost

In the case of packets lost, we have noted, the contribution of our two proposals (function 1 & 2) is significantly better then the DCF basic in all scenarios.

5.3.3 Packet Loss ratio

We have obtained the following results (Fig.5) by measuring the packet lost ratio in the different scenarios for the tree functions. Note that Packet Loss ratio = (received packet number / sent packet number) * 100.

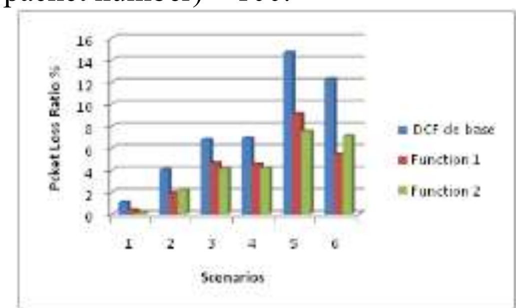

Fig.5: Packets Loss ratio

In the packet loss ratio case, we have noted that the proposed our two functions reduce significantly the packet loss parameter.

5.3.4 Average throughput

We have obtained the following results (Fig.6) by measuring average throughput (kbps) for all scenarios for the tree functions.

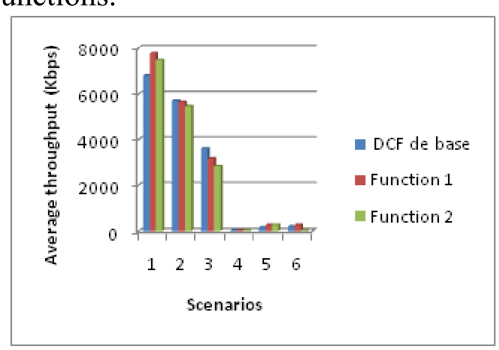

Fig.6: Average throughput

In the case of average throughput, our two functions give better results than basic DCF in almost all scenarios.

6 CONCLUSION

In this paper, we have proposed and evaluated the performance of a new solution (function 1 and 2) mechanism for QoS support in IEEE 802.11 WLAN. We have shown by simulations that the proposed solution improves QoS requirements (rate packet loss and throughput) in two constraints (mobility and density).

Based on results of the different scenarios and parameters, we can conclude that the proposed two functions have shown very encouraging results compared to basic DCF for measured parameters (packets sent, packets loss and average throughput) under the two constraints (mobility and number of nodes). So, better results can be obtained if we can apply the proposed solution in the real word. In the forthcoming work, we plan to some investigation about our solution specially:

- Comparing our solution to EDFC of 802.11.e designed for QoS in WLAN,
- Using our solution in a real WLAN,
- Implementing the admission control to complete service differentiation that gives certain QoS guarantees.

7 REFERENCES

1. Cali, F., Conti, M., Gregori, E.: Dynamic Tuning of the IEEE 802.11 Protocol to Achieve a Theoretical Throughtput Limit. In: IEEE/ACM Trans. Networking, vol. 8, no. 6, December 2000, pp. 785-799 (2000).
2. Aad, I., Castellucia, C.: Differentiation mechanisms for IEEE 802.11. In Proceedings of IEEE Infocom 2001, Anchorage, Alaska, April (2001).
3. J. Deng and R. S. Chang, A priority Scheme for IEEE 802.11 DCF Access Method, IEICE Trans. in Comm., vol. 82-B, no. 1, January 1999.
4. IEEE 802.11e draft/D4.1, Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS), Feb. (2003).
5. Wu, H., Peng, Y., Long, K., Cheng, S., Ma, J.: Performance of Reliable Transport Protocol over IEEE 802.11 Wireless LAN: Analysis and Enhancement. In Proceedings of IEEE INFOCOM 2002, New York, NY, June (2002).
6. Chen, Z., Khokhar, A.: Improved MAC protocols for DCF and PCF modes over Fading Channels in Wireless LANs. In Wireless Communications and Network Conference (WCNC) (2003).
7. Anastasi, G., Lenzini, L.: QoS provided by the IEEE 802.11 wireless LAN to advanced data applications: a simulation analysis. In ACM/Baltzer Journal on Wireless Networks, 6, 2000, pp. 99-108 (2000).
8. IEEE std 8802.11-1999, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. (1999).
9. Kay, J., Frolik, J.: Quality of Service Analysis and Control for Wireless Sensor Networks. Submitted to the 1st IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS 2004), Ft. Lauderdale, FL., Oct. 25-27, (2004).
10. Braden, R., Zhang, L., and al.: Integrated Services in the Internet Architecture: an Overview. Juin 1994. RFC 1633 (1994).
11. Blake, S., Black, D., Carlson, M., Davies, E., Wang, Z., Weiss, W.: An Architecture for Differentiated Services. Déc.1998. RFC 2475 (1998).
12. Karn, P.: MACA -a New Channel Access Method for Packet Radio. ARRL/CRRL Amateur Radio 9th Comp. Net. Conf., 1990, pp. 134–40 (1990).
13. Bhargavan, V. et al.: MACAW: A Media Access Protocol for Wireless LANs. In Proc. ACM SIGCOMM (1994).
14. Lin, C. R., Gerla, M.: Asynchronous Multimedia Multihop Wireless Networks. In IEEE INFOCOM (1997).
15. Aad, I., Castelluccia, C.: Remarks on per-flow differentiation in IEEE 802.11. In European Wireless 2002, Florence, Italy, February 25th-28th, (2002).
16. Drabu, Y.: A Survey of QoS techniques in 802.11. Available at: http://trident.mcs.kent.edu/~ydrabu/research/wmac/mac.pdf
17. Vaidya, N. H., Bahl, P., Gupta, S.: Distributed fair scheduling in wireless LAN. In Sixth Annual International Conference on Mobile Computing and Networking, Boston, August (2000).

18. Veres, A., Campbell, A.T., Barry, M., Sun, L-H.: Supporting service differentiation in wireless packet networks using distributed control. In IEEE Journal of Selected Areas in Communications (JSAC), Special Issue on Mobility and Resource Management in Next-Generation Wireless Systems, vol. 19, No. 10, pp.2094-2104, October (2001).
19. Sobrino, J. L, Krishnakumar, A. S.: Quality of Service in ad-hoc carrier sense multiple access networks. In IEEE Journal on Selected Areas in Communications, 17(8): 1353-1368, August (1999).
20. Fall, K., Varadhan, K.:The NS Manual. Vint Project, UC Berkeley, LBL, DARPA, USC/ISI, and Xerox PARC. April 14, (2002).