A proactive, terminal based best Access Point selection mechanism for Wireless LANs

Nikolaos Papaoulakis and Charalampos Z. Patrikakis, *Senior Member IEEE*

***Abstract*— In IEEE802.11 WLAN networks, Radio Resource Management (RRM) is necessary for the efficient use of scarce radio resources and to balance the telecommunication traffic load, among all the Access Points (APs) of the infrastructure network. In these networks, the mobile station MS has the functionality to select an AP, based on specific criteria. A key challenge is how to achieve overall load balancing in the network, during the AP reselection procedure in a way that will achieve the optimum utilization of network resources. The conventional approaches typically use the strongest received signal from the side of MS (RX Level) as the criterion, without considering the traffic load of each AP. In this work, we present two easy to implement WLAN resource management mechanisms that are fully compatible with the existing standards and mechanisms already supported by IEEE802.11 networks.**

***Index Terms*— 802.11, dynamic AP selection, reconfiguration**

I. INTRODUCTION

Wireless Local Area Networks (WLANs), are continuously expanding not only in terms of coverage but also in terms of supported traffic and services. This tremendous growth is ought to the flexibility that IEEE 802.11 networks offer and also to the extremely low cost of those network's implementation. The initially deployed applications consisted of legacy IP services, like HTTP browsing, FTP and email retrieval with specific Quality of Service (QoS) requirements, like low packet loss and specific throughput availability [1]. The IEEE 802.11 networks have well-tested MACs mechanisms in order to satisfy these requirements such as CSMA/CA, RTS/CTS and the Fragmentation mechanisms. Today, IEEE 802.11 networks have become became a prevailing technology for broadband wireless Internet access. Thus, we have WiFi devices with much wider applications, like as VoIP phones (VoWLAN), wireless cameras for home surveillance and multimedia adapters/bridges that could deliver real time media streams to the end user.

These new applications introduce new traffic, schemes profiles and of course much more restricted QoS requirements [2]. Without sophisticated Quality of Service (QoS) mechanisms, the conventional 802.11 standard cannot meet the demands of real time voice and video services in terms of jitter and delay of packet delivery. The requirement for guaranteed QoS in modern WLANs, brings to the foreground the need for enhancing the WLAN MACs protocols with the appropriate QoS support mechanisms. Trying to meet these challenges, in this work we present and analyze a mechanism, which could be easily integrated in all IEEE 802.11 Wireless LANs in order to increase the efficiency and performance in all traffic load scenarios.

Manuscript received July 22, 2008.
The authors are with the School of Electrical & Computer Engineering, National Technical University of Athens, Greece, GR 15773 (e-mail: {npapaoul, bpatr}@telecom.ntua.gr).

II. CONGESTION AVOIDANCE MECHANISM IN WLANS

A. Description of conventional AP reselection mechanism for IEEE 802.11x - WLAN

In IEEE 802.11 and almost all WLANs, the selection of the serving (dominant) AP from the MS in an infrastructure topology is based upon the idea that the MS should associated within the AP offering the best coverage, by means of strongest received RF energy level (RX Level) [3], [4]. In receiving mode, each MS has to search for the best dominant access point in its area for a determined Extended Service Set Identification (ESSID). This process (called access point reselection [3]) is based on the comparison of the received RX level from the access point with the same ESSID that the MS receives. In particular, the formula that describes the access point selection process is the following:

RX level(new) > RX level(old) + APRH (1)

The parameter APRH (Access Point Reselect Hysteresis) is controlled by the WLAN client and is different for each Wi-Fi vendor. Some vendors provide predefined values for this parameter with the parameter "density of access point" such as: High, Medium and Low. Also the use of the Fast Roaming parameter determines how fast a user reselects from on AP to another. Particularly, this parameter determines the minimum RX level from the serving AP in order to enable the mechanism of equation (1).

B. State of the art techniques for traffic balancing

Minimizing congestion in large scale WLANs has received significant attention in the past few years [5],[6]. There are a lot of proposed methods and algorithms for traffic balancing based on power management of Access Points (AP) in order to eliminate congestion. In [5],[6], the authors propose an approach of traffic balancing in WLANs by adjust the RF power of APs, according to the traffic load. By altering the RF power you could control the dominance area of an AP and correspondingly the offered traffic load. These techniques demand from the AP infrastructure, the existence of a Network Management System (NMS) that will perform the monitoring of traffic load per AP and control the transmit power of each one accordingly. A big disadvantage of these techniques is that they react after the congestion occurrence. This means that the network is being congested until the NMS fine-tunes the power of the congested APs in order to perform the network balancing. These conditions are very unfavourable for real time services like VoWlan, video streaming etc, which require real time and preventing QoS support. In order to provide a suitable solution that overcomes the obstacle of post reaction to congestion, we introduce a technique that tries to achieve load balancing following a proactive approach. Furthermore, the proposed technique is terminal based, and can therefore be used in any existing infrastructure without the need of modification or use of special mechanisms.

C. The proposed reselection mechanism for traffic balancing

The proposed AP reselection mechanism follows the approach proposed in [8], [9]. The reselection criterion is not limited to the RX level, but includes also to the traffic load of the AP. For this, we enhance formula 1 by adding a traffic dependable value, which corresponds to the Average_throughput_utilization. Therefore, the new AP reselection mechanism is described in the following formula,

$$Q_{WLAN}(new\ AP) > Q_{WLAN}(old\ AP) + APRH \quad (2)$$

where Q_{WLAN} is the parameter measuring the expected quality that can be offered by each AP, measured over the utilization of the AP, over throughput:

$$Q_{WLAN} = RX\ level(dBm)/APUtil \quad (3)$$

The value *APUtil* is the measurement of the level of utilization of the Access Point, which is calculated over the traffic status of the AP.

The AP within the same ESSID and with the biggest Q_{wlan} will be the dominant in the determined area. The difference that our approach introduces compared to [8], [9], is that the above calculations are performed at each terminal and not at the APs. In this way, the WLAN network needs no enhancements in order to support the proposed mechanism, while the process of calculating the best access point is performed only at the terminals, thus reducing the calculations required.

In order for the terminals to be able to use the new AP reselection algorithm, the accessory information of the traffic indicator *APUtil* needs to be communicated. Therefore, we need a "carrier" for *APUtil.* As we know the IEEE 802.11 protocol has specific manage frames, which called beacons. These «small» frames are being sent periodically by each AP in order to announce its presence and provide relevant information, such as timestamp, SSID, and other parameters regarding the access point to MSs that are within range. The MSs continuously scans all 802.11 radio channels and listens for beacon frames, which will be the basis for selecting an AP. The period that these frames are being transmitted is basically 100ms. This means that every 1 sec the AP has send 10 beacon frames but this is happens only if the AP hasn't to transmit anything in this time period. The typical length of beacon frame is 50 bytes and its header contains two addresses. The source address which is the MAC address of AP and the destination address which is FF:FF:FF:FF:FF. Also, it contains a tail, which is the CRC of the frame.

The other fields are being described below:

- Beacon interval
- Timestamp
- Service Set Identifier (SSID)
- Supported rates
- Parameter Sets
- Capability Information
- Traffic Indication Map (TIM)

For the needs of the new mechanism, we add an extra field in order to accommodate the information of *APUtil* on these frames. The traffic information will be included with a specific coding in which we use 4 bits for the specific traffic indicator. As a result, 16 different levels (ranging from 0 to 15) will be supported. The calculation of the coded throughput utilization parameter is going to be described below. The APUtil will be calculated by the

$$APUtil = int\left(16 * \frac{average\_Throughput\_in\_last\_2\min}{Maximum\_Throughput\_of\_network}\right) \ (3),$$

where the throughput is in kbps

For example if we have an $average\_Throughput\_in\_last\_2\min$ of 2500 kbps and the $Maximum\_Throughput\_of\_network$ is 5500 kbps (a typical valu for a IEEE 802.11b network) then the code value is 0111 or 7. If we have 100% utilization of the network the coded value is going to be 1111 or 15.

III. Evaluation through Simulation and Alternative Approach

A. Simulation Results

By utilizing the radio-planning tool WINPROP for indoor WLAN environment [8], we simulate the radio coverage and the most specific the best server areas of an infrastructure IEEE 802.11b network with 4 APs .

In *Figure 1*, we use different colors in order to depict the dominance areas of each AP. The black dots represent 5 randomly created users.

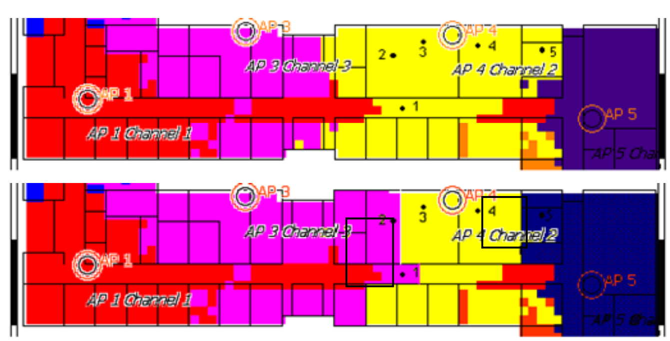

Figure 1: Best server simulation between 4 APs

According to the new AP reselection mechanism, we calculate the Q parameters for every Wlan user and for the adjacent APs 3 and 5. We can see that the AP 4 has 5 users. Also, we suggest that this each MS utilizing an IP traffic with Average_throughput of 1000 kbps.

With the help of WINPROP and multi-wall-and-floor model for indoor radio propagation [11], we know the RX level that receives each user from the corresponding dominant AP,

Thus, we calculate $Q_{user,AP} = RXLevel(dBm) + APUtil$

Within the blue frame we indicate the new dominant AP for each of the 5 users.

For the new AP reselection mechanism, we have:

Q_{WLAN}(new AP) > Q_{WLAN} (old AP) + APRH

Finally, we have two users to the APs 3 and 4 and 1 user to AP5, which is a much better distribution instead of 5 users on AP4.

B. An alternative approach

In this subsection, we present an alternative method through which we can address the problem of load balancing, but without the utilization of a NMS at the AP side in order to retrieve statistical information and enhanced the beacon frame [3]. Here, the calculation of the *APUtil* is being performed from the side of the MS. The new technique is also presented as an enhancement of the AP reselection mechanism. As, we refer each AP transmits periodically some beacon frames, in order to broadcast to MSs administrative information. This management frames act as a synchronization signal to the network, in order the distributed users to have synchronized clocks with the AP. These frames are being broadcasted when the AP has no data for transmission. In *Figure 2*, we could observe the frame and the relevant time periods [12].

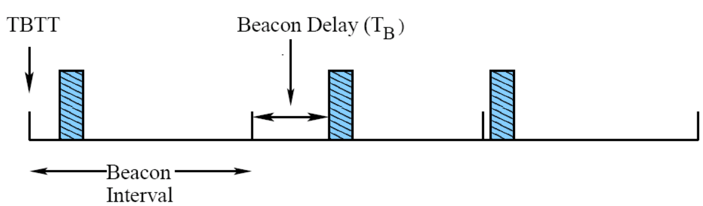

Figure 2: Beacon frames and time delays that transmitted from an AP

The time point TBTT (Target Beacon Transmission Time) is the zero point of the synchronization of the network. The time T_B is the competition time, which needs a frame in order to be transmitted from the AP. Now from the expletive delay that a beacon frame has from the other, corresponds to the utilization of the RF media by the AP in order to transmit data. Thus from the delay between one programmable beacon frame transmission, we could indirectly calculate the carried throughput of the AP. For the accurate calculation of the throughput, we consider two different occasions. The first one is when we have an infrastructure network, which not implements the transmittance of (Ready To Send and Clear To Send) RTS/CTS flags. The second one is the case of a network that utilizing the RTS/CTS flags in order to avoid the "hidden node" problem. In *Table 1,* we present analytically the values used to calculate the downstream bandwidth for each instance.

TABLE I
DOWNSTREAM BANDWIDTH CALCULATION

PARAMETER	VALUE
T	Total delay incurred by a data frame from an AP
T_D	Delay incurred between the instant when a data frame is scheduled for transmission to the instant when the frame is received at the receiver
T_A	Delay of the ACK frame from the receiver to the sender
T_B	Total contention delay experienced by a data frame from the AP
Data RTS, CTS	Size of the data, RTS, CTS frame respectively
R	Data rate at which the sender transmits the data frame
R_b	Basic rate at which control frames are transmitted (default 1 Mbps)
B	Potential bandwidth from the AP to the end-host

1) Network without RTS/CTS

Considering that we have not transmission of RTS and CTS frames on the air interface, the total time delay of data frame transmission is being calculated by the time of contention and the delay of and acknowledgment (ACK) frame.

$$T = T_D + T_{ACK}$$

The T_D is being calculated by the formula $T_D = T_B + \frac{DATA}{R}$

The T_{ACK} is given by the function $T_{ACK} =$ SIFS+$\frac{ACK}{R_b}$,

where SIFS (Single Inter Frame Space)

Like this the estimated throughput is being calculated by:

$$B = \frac{DATA}{T} = \frac{DATA}{T_B + \frac{DATA}{R} + SIFS + \frac{ACK}{R_b}}$$

2) Network with RTS/CTS

In a network with handshaking of RTS/CTS flags, the total data frame delay is being calculated by:

$$T = T_{RTS} + T_{CTS} + T_D + T_{ACK}$$

$T_{RTS} = T_B + \frac{RTS}{R_b}$ and $T_{CTS} = SISF + \frac{CTS}{R_b}$

And the total time delay is $T_D = SIFS + \frac{DATA}{R}$.

Thus we have:

$$B=\frac{DATA}{T}=\frac{DATA}{T_B+\frac{RTS}{R_b}+SIFS+\frac{CTS}{R_b}+SIFS+\frac{DATA}{R}+SIFS+\frac{ACK}{R_b}}=$$

$$\frac{DATA}{T_B+3\cdot SIFS+\frac{RTS+CTS+ACK}{R_b}+\frac{DATA}{R}}$$

(4)

3) New modified AP Reselection

Similarly with the previous method we have the new reselection method.

$Q = RXLevel(dBm) - f \cdot \mathrm{B}$ (5), where f bandwidth factor with values from 0 – 5.

With the bandwidth factor the user could select the weight of the desirable throughput, in relevance with the RX level from the AP.
The new reselection mechanism is given by, Q(new AP) > Q(old AP) + Access_Point_Reselect_Hysteresis

From the above functions we can calculate the theoretical overhead that the RTS/CTS mechanism introduces to the throughput of a WLAN network, when we have not “hidden node” conditions.

$$T_{overhead}=\frac{T_B+\frac{DATA}{R}+SIFS+\frac{ACK}{R_b}}{T_B+\frac{RTS}{R_b}+SIFS+\frac{CTS}{R_b}+SIFS+\frac{DATA}{R}+SIFS+\frac{ACK}{R_b}}\cdot 100$$

(7)

IV. Conclusion

In this paper we presented two new MAC mechanisms that could be implemented and integrated on modern Wireless LANs. On the infrastructure WLAN, which we had developed on the campus of National Technical University of Athens (NTUA), we notice a network improvement of around 120 % on the overall carried throughput when we applied these techniques. More specific, the technique that is based on dynamic modification of RF power of each AP and the mechanism that use the MAC filter feature, require the use of an external NMS platform in order to retrieve statistical information from each AP and calculate the KPIs, like throughput, packet loss, delay and jitter. Also, this NMS has to decide which technique is suitable to implement and with the appropriate values. The congestion avoidance MAC mechanism with the use of the enhance beacon frame, also needs the use of NMS for the retrieval of statistical information and supply of this information to the new two fields of beacon packet. On the other hand the last form of the congestion avoidance requires only a slight modification to the client side. This modification could be a new firmware or a new modified driver of the card in order to recognize the new beacon frames.

Currently, there is no effective mechanism to prioritize traffic within a 802.11 domain. As a result, the 802.11e task group is currently refining the 802.11 MAC (Medium Access Layer) to improve QoS for better support of audio and video applications. The 802.11e group could include these mechanisms in order to be standardized. Also, 802.11e falls within the MAC Layer, which is common to all 802.11 PHYs, and be backward compatible with existing 802.11 wireless LANs. As a result, the utilization of the above mechanism, doesn't impact to the decision on which PHY to utilize. In addition, it is possible by upgrade on existing 802.11 access points to comply with 802.11e through relatively simple firmware upgrades.

References

[1] Yan Chen, Toni Farley and Nong Ye. QoS Requirements of Network Applications on the Internet – IOS Press

[2] Zagar D., Rimac-Drlje S. Applications classification and QoS requirements, Information Technology Interfaces, 2002. ITI 2002.

[3] IEEE, ”Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications”, ANSI/IEEE Std 802.11, 2005 Edition

[4] G. Judd and P. Steenkiste, Fixing 801.11-access point selection. Proceedings of ACM Mobicom, Pittsburgh, Aug 2002.

[5] N.Papaoulakis, G. Karetsos, D. Kanellopoulou, G. Elefsiniotis, "Radio Resource Management Techniques for 4G Mobile Telecommunication Platforms", IST Mobile & Wireless Summit, 27-30 Jun. 2004, Lyon, France

[6] Mohammad Haidar, Robert Akl, Hussein Al-Rizzo, Yupo Chan, Rami Adada, Optimal Load Distribution in Large Scale WLAN Networks Utilizing a Power Management Algorithm, *Proceedings of IEEE Sarnoff Symposium*, May 2007, 5 pgs.

[7] Jyh-Cheng Chen, Tuan-Che Chen, Tao Zhang, and Eric van den Berg, Effective AP Selection and Load Balancing in IEEE 802.11 Wireless

[8] A Novel Idle Mode Operation in IEEE 802.11 WLANs, Sunggeun Jin, Kwanghun Han and Sunghyun Choi, International Conference on Mobile Computing and Networking Proceedings of the 4th international workshop on Wireless mobile applications and services on WLAN hotspots, Los Angeles, USA, 2006, page 71-80

[9] A. Mishra, M. Shin, and W. A. Arbaugh, “Context Caching using Neighbor Graphs for Fast Handoffs in a Wireless Network,” in Proc. IEEE - INFOCOM’04, 2004.

[10] AWE-Communications, http://www.awe-communications.com

[11] M. Lott, I. Forkel , A multi-wall-and-floor model for indoor radio propagation, 53rd IEEE Vehicular Technology Conference, 2001, VTC 2001 Spring,

[12] S. Vasudevan, K. Papagiannaki, C. Diot, J. Kurose and D. Towsley, Facilitating Access Point Selection in IEEE 802.11Wireless Networks, IMC '05, 2005 Internet Measurement Conference