New Channel Allocation Techniques for Power Efficient WiFi Networks

V. Miliotis†, A. Apostolaras†, T. Korakis†, Z. Tao⋆ and L. Tassiulas†
†Computer & Communications Engineering Dept. University of Thessaly
Centre for Research & Technology Hellas
Volos, Greece
⋆Mitsubishi Electric Laboratories Research, Principle Technical Staff
Cambrdige, Massachusetts, USA
Email: †{vmiliotis, apaposto, korakis, leandros}@inf.uth.gr, ⋆tao@merl.com

***Abstract*—Energy efficiency becomes ever*green* than ever before. Over the last few years a significant research in wireless communications, aiming to enhance communications efficiency subject to constraint of power consumption, has given rise to optimization techniques of power control and management in wireless networks. Although the initial target was the utilization of resources in order to exploit communications services, the benefits of this effort, underlying the green perspective, are now opening eyes out to research community for a more green matter of conscience in use of communication equipment and devices. Towards this direction and affected by a green sensitivity in terms of wasting useful resources, we propose a system model for infrastructure WiFi networks aiming to reduce the consumed power, by introducing a scheme for channel allocation to Wireless LANs under energy conserving criteria.**

I. Introduction

Green Technologies brings the promise of providing significant improvements on reducing global energy consumption. On communications area, green technologies are mainly keen on reducing power consumption on portable devices, since a critical issue for almost all kinds of such devices is power saving.

Because of the battery-dependence, portable devices will become useless if there is an unrestrained power consumption. Battery power is a limited resource, and it is expected that battery technology is not likely to progress as fast as computing and communication technologies do. Hence, efficient ways of lengthening batteries lifetime is an important issue, on optimizing communications.

Power Control techniques aim to reduce energy consumption in a way that a sender transmits information and consumes only the required power for each transmission, that depends on the length (buffer backlog length) of the transmitted information or the channel quality. In cases of backlog driven power control, on each time-slot unit a calculation for the transmitted power is being performed. On the long term, a significant power consumption reduce is achieved since transmissions are being emitted, proportional to the information length energy amount and the recalculation for the power settings is frequently evaluated. Moreover, by adopting techniques for reasonable power transmissions would affect the communications quality environment, since the noise realized by the nearby Access Points and Stations would be mitigated. The increased number of networks in contemporary urban environments and the utilization of the limited frequency spectrum causes many networks to operate on shared channels. If all Stations and Access Points reduce their power transmission level to a minimum quality threshold that does not adversely affect the link quality communication among them, that would improve immediately communication quality on nearby networks in terms of diminished neighborhood interference.

While 802.11h [1] amendment provides for a DFS mechanism in WLANs, its purpose was initially to avoid cochannel operation with radar systems and to insure uniform utilization of available channels in the 5GHz band. This amendment was mainly introduced for European Countries, where radio regulations prohibit the utilization of 5 GHz band in locations where there exist radar operation. The Transmit Power Control (TPC) mechanism described in the same amendment was introduced, in order for WLANs to operate complying with the European regulatory maximum transmit power for each allowed channel and to reduce interference with satellite services.

However, in most cases of wireless technologies it is required to achieve throughput improvement while also reducing energy consumption due to limited power resources that also bring high cost. In a wireless network, throughput is directly dependent on the channel quality. In particular, more often than not, there may be a mismatch in the quality of the link from the AP (Access Point) and its STAs (stations) due to unrestrained external interference. This mismatch leads us to adopt more efficient ways on channel selection: (a) for achieving higher throughput and (b) for reducing power consumption since packet congestion implies augmented amount of retransmissions.

In this paper, we propose a Dynamic Frequency Selection (DFS) algorithm, that takes into account the network's traffic and the contention free period of time, perceived by all STAs and the AP of a WLAN and switches to the channel that will provoke less frame retransmissions.

Continued on the paper below, a related work analysis is reported on Section II, on Section III our system model is presented, on section IV the experimentation platform that we used is described, on Section V experimentation results on real case scenarios are presented and on section V we finalize with conclusions.

II. Related Work

In the last years, there has been a wide spread in the usage of wireless LANs. Due to this degree of dissemination of WiFi technology, large research effort has been devoted to the improvement of medium access control protocols aiming to minimize the transmission delay and to maximize throughput. Power consumption has only later become an issue of research interest. The initial perspective was to extend the battery life of mobile devices in order to keep the network alive for longer duration [2], [3], [4]. Now, the aspect of green wireless technology has become a hot topic and through sustainable development it aims to preserve the environmental resources by minimization of power consumption. Towards this concept, the research activity regarding power efficiency in 802.11 wireless networks is divided in two main fields. The first refers to ad-hoc wireless networks and the second to infrastructure wireless LANs.

In ad-hoc 802.11 networks, the power management is based on traffic indication messages. The stations of an independent network use announcement traffic indication messages (ATIMs), to preempt other stations from sleeping. All stations in an Independent Basic Service Set (IBSS) listen for ATIM frames during specified periods after Beacon transmissions. Stations that do not receive ATIM frames are free to conserve power entering power saving mode. According to the standard [5], no stations are permitted to power down their wireless interfaces during the ATIM window. To monitor the entire ATIM window, stations wake up before the target Beacon transmission. There are four possible situations. The station may have transmitted an ATIM, received an ATIM, neither transmitted nor received and both transmitted and received an ATIM. A station is permitted to sleep only if it neither transmitted nor received ATIM frames. A scheme in which a station can vary the duration of awake-state to adapt the traffic to the network is proposed in [6]. Oppose to the fixed value of ATIM Window and Beacon Interval mentioned in the standard, the proposed scheme splits the ATIM Window into two parts, the Earlier Time Slot (ETS) and the Later Time Slot (LTS). If the transmitter issuing a Beacon has data packets to send in its buffer, it tries to transmit the Beacon in the ETS, otherwise it tries to delay it till the LTS. If no Beacon transmission takes place during ETS, all nodes assume that no buffered data exist and change their state to sleep mode right after receiving a Beacon in the LTS. The optimal ETS and LTS duration is also explored. The proposed protocol in [7] addresses the problem of power consumption by trying to minimize overhearing, over transmission and packet collisions by using a 2-hop receiver centric message passing mechanism. This mechanism mitigates the hidden terminal and the exposed terminal in multi-hop environments. In order to achieve this goal, during the ATIM window, the sender node transfers an ATIM Request packet to the receiver node, which includes the time duration for the data transmission. The receiver node transfers an ATIM ACK packet to the sender node, including again the time duration of the transmission. This control packet is transferred to all nodes having logical 2-hop distance from the receiver node. By mitigating the hidden and the exposed terminal problems, less retransmission is provoked and consequently power consumption is reduced.

In infrastructure 802.11 networks, according to the standard, power conservation is achieved by means of buffering traffic at the AP. As all traffic must go through the AP and simultaneously assuming that it has access to continuous power, it makes an ideal location for buffering traffic and plays a key role in power management on infrastructure networks. The power management described in the standard consists of two elements, the Traffic Indication Map (TIM) and the Power Saving Poll (PS-Poll). The AP periodically assembles TIM, which is used to inform stations for which frames are buffered. TIM is transmitted in Beacon frames and refers to unicast frames. Buffered broadcast and multicast frames are announced in Delivery Traffic Indication Map (DTIM). At a fixed number of Beacon intervals DTIM is transmitted in Beacon frames instead of TIM. A mobile STA wakes up, following the Listen Interval parameter agreed during the association procedure, to receive the TIM. If the AP has buffered traffic on its behalf, it transmits a PS-Poll frame to retrieve buffered frames. Once buffered traffic is delivered, the STA can resume sleeping. There is several reported work in literature on power efficiency for infrastructure 802.11 networks. In [8], power efficiency is expressed as the transmitted traffic per unit of energy. The proposed power optimization scheme is based on a cross layer selection of appropriate power level and modulation. An analogous scheme, that combines Transmit Power Control (TPC) with PHY rate selection, is presented in [9] for the point coordination function (PCF) operation of 802.11 wireless LANs. Based on the fact that low rate STAs, when transmitting, oblige high rate STAs, willing to transmit, to consume considerable amount of energy listening the channel, a cooperative scheme is proposed in [10]. In this scheme, low rate STAs are alloted, unequal to other STAs, with less channel access time for data communication with the compensation of communicating with the AP through a high rate path. This way high rate STAs function as relays between the AP and the low rate STAs, establishing this high rate path.

In our work, we propose channel allocation techniques for infrastructure 802.11 wireless networks, aiming to mitigate the energy consumption of the wireless LAN. The 802.11h amendment, where Dynamic Frequency Selection (DFS) for 802.11 networks was defined, mainly for avoidance of cochannel operation with Radars and uniform utilization of available channels, boosted the research activity on this area. Both distributed [11], [12] and centralized [13], [14] algorithms for dynamic channel allocation have been proposed, but less attention has been given on channel allocation with energy conserving criteria. With our work we give a new perspective in this field, introducing new channel allocation techniques for power efficiency in WiFi networks.

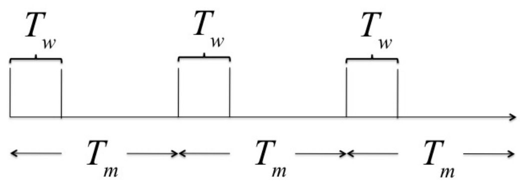


Fig. 1. Monitoring Window Intervals.

III. System Model

We consider an IEEE 802.11 based WLAN, which consists of one access point (AP) and mobile stations (STAs) and it is placed among other WLANs. This scenario is frequently met in dense urban environments, where in every home and enterprise there is a wireless AP, creating an overused wireless environment. In our model we introduce a periodical monitoring window, during which, all STAs and the AP that comprise the WLAN, monitor their operating channels for equal duration. We define as T_m the period between the beginning of every monitoring window and T_w the duration of this time window, which is a silent period for the WLAN. During T_w every STA and the AP monitor their operating frequencies for equal period of time t_c. During t_c, the received power level at the wireless Network Interface Card (NIC) is measured and the time that the sensed power is below a prespecified threshold is captured. We define this captured time a_i^c as contention free time factor of the channel c, $c \in \{1, 2, \ldots, 11\}$ detected by STA$_i$, $i \in \{1, 2, \ldots, N\}$.

$$a_i^c = \frac{t_{free}}{t_c} \tag{1}$$

The contention free time detected by the AP is symbolized as a_0^c. In the end of the monitoring window T_w, every STA sends its measurements of contention free time factors to the AP. During T_m, the AP keeps track of the mean downlink traffic for every STA$_i$, equal to $\bar{\lambda}_i$, and for the total incoming uplink traffic from all stations of the WLAN, equal to $\bar{\lambda}_0$. Consequently, in order to select the channel that will lead the WLAN to meet less contention for the downlink case, we need to find the channel c, that maximizes the following quantity:

$$\max_c \left(\sum_{i=1}^{N} \bar{\lambda}_i a_i^c \right) \tag{2}$$

For the uplink case, aiming again to face less contention with the neighboring WLANs, we want to maximize the following quantity:

$$\max_c \left(\bar{\lambda}_0 a_0^c \right) \tag{3}$$

In order to choose the best channel for the joint downlink and uplink case we assign weights to quantities (2) and (3), proportional to the downlink and uplink traffic ratio to the total traffic of the WLAN. In this way, we formulate our utility function as follows:

$$\max_c \left[\frac{\sum_{i=1}^{N} \bar{\lambda}_i}{\bar{\lambda}_0 + \sum_{i=1}^{N} \bar{\lambda}_i} \left(\sum_{i=1}^{N} \bar{\lambda}_i a_i^c \right) + \frac{\bar{\lambda}_0}{\bar{\lambda}_0 + \sum_{i=1}^{N} \bar{\lambda}_i} \left(\bar{\lambda}_0 a_0^c \right) \right] \tag{4}$$

For every period T_m we symbolize the downlink and the uplink mean traffic ratio as d_r and u_r respectively. Namely:

$$d_r = \frac{\sum_{i=1}^{N} \bar{\lambda}_i}{\bar{\lambda}_0 + \sum_{i=1}^{N} \bar{\lambda}_i} \tag{5}$$

and

$$u_r = \frac{\bar{\lambda}_0}{\bar{\lambda}_0 + \sum_{i=1}^{N} \bar{\lambda}_i} \tag{6}$$

Combining equations (5) and (6) with the quantity (4) we can rewrite our utility function as follows:

$$\max_c \left[d_r \left(\sum_{i=1}^{N} \bar{\lambda}_i a_i^c \right) + u_r \left(\bar{\lambda}_0 a_0^c \right) \right] \tag{7}$$

In our implementation we compare our proposed model with a static weighted model where $d_r = \frac{1}{2N}$ and $u_r = \frac{1}{2}$ that chooses the channel of operation, without considering the traffic ratios, according to the following utility function:

$$\max_c \left[\frac{1}{2N} \left(\sum_{i=1}^{N} a_i^c \right) + \frac{1}{2} a_0^c \right] \tag{8}$$

as well as with the case where only the APs measurements are considered. In this case the utility function is:

$$\max_c \left(a_0^c \right) \tag{9}$$

Through experimentation on NITOS testbed [16], we prove the superiority of our proposed scheme compared to (8) and (9).

IV. NITOS Wireless Testbed

In order to evaluate the performance and study the behavior of the DFS scheme that we have designed, we used a large scale programmable wireless testbed of heterogeneous wireless nodes. Moving one step further than analysis/simulation, implementation of algorithm in a real wireless platform, would provide results from real world settings. Hence, evaluation and justification of the DFS algorithm proposed was tested on NITOS wireless testbed.

NITOS (Network Implementation Testbed for using Open Source platforms) is a wireless testbed that is designed to achieve reproducibility of experimentation, while also supporting evaluation of protocols and applications in real world settings. NITOS consists of nodes based on commercial WiFi cards and Linux based open source platforms. It is *remotely* accessible and supports 15 wireless nodes outdoor located in a non-RF-isolated environment. Users can perform their experiments by reserving slices (nodes, frequency spectrum)

Algorithm 1 DFS

Require: TIME $:= K * T_m$, $K \in \mathbb{N}$
Ensure: FREQUENCY SELECTION

while TIME $< K * T_m + T_w$ **do**
  for $c \in \{1, \ldots, 11\}$ **do**
    for $i = \{0, \ldots, N\}$ **do**
      CALCULATE a_i^c
    end for
  end for
  for $i = \{1, \ldots, N\}$ **do**
    SEND a_i^c TO ACCESS POINT *// This code block refers to (7) and (8) only.*
  end for
  ACCESS POINT SELECTS $\arg c$ CHANNEL THAT MAXIMIZES (7), (8) OR (9)
  WLAN SWITCHES ON NEW CHANNEL
end while

of the testbed through NITOS scheduler, that together with OMF[17] management framework supports ease of use for experimentation and code development.

V. Implementation Details

In order to evaluate our proposed model, we implemented it, together with the static weighted model and the model in which the decisions are made, based only on the APs measurements, using the MadWifi open source driver [19]. For the implementation of our algorithm, we modified the driver adding a periodical monitoring window. During this monitoring window, every STA and the AP take measurements of the contention free time factor of every channel, for equal duration. We also added the generation of 802.11 unicast frame transmission, so as to give to STAs the functionality of transmitting their measurements to the AP at the end of the monitoring window. As soon as the measurements are gathered at the AP, a function that calculates the best channel according to (7) is invoked and the WLAN changes its operating channel to the new one. In order to compare our algorithm with other schemes, we also implemented their functionality on MadWifi according to (8) and (9) as we have already described on previous section.

The evaluation of the performance of our modified MadWifi driver was executed on the NITOS wireless testbed [15]. We used one wireless node of the testbed as AP, and two as STAs. As NITOS testbed is a non-isolated wireless testbed we were able to confront a rich interference wireless environment for the implementation of our algorithm. More particularly, during the experimentation process we observed the existence of more than 9 interfering APs operating randomly on different channels. This fact gave us a prolific setting to prove that our Dynamic Frequency Selection algorithm is more energy efficient than the two others we mentioned above. Hence, our proposed model presents a *greener* WiFi operation.

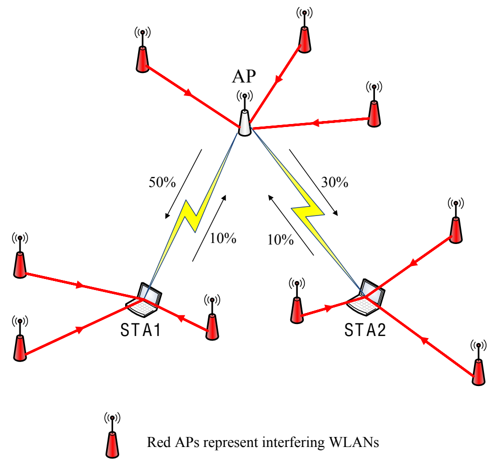


Fig. 2. Experiment Traffic Setup.

A. Algorithm

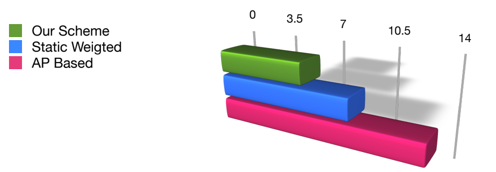
Here, we give a brief pseudocode description of the implemented algorithm, that leads the WLAN to switch to the best channel according to metrics acquired by the evaluation of (7), (8), (9). We denote $K \in \mathbb{N}$ the discrete monitoring time intervals.

VI. Experimentation Evaluation

The performance of our proposed model and the comparison with the other two stated models was evaluated with experiments in NITOS wireless testbed, on the 11 available channels of 802.11g. We evaluated the energy consumption of every one of these models, for a WLAN operating in a real environment, regarding the interference that it suffered from. The total traffic between the AP and the two associated stations was 550 Mbytes and the transmission rate at 24 Mbps. We generated typical traffic in our WLAN transmitting 30% of the total traffic from the AP to STA1, 50% of the total traffic from the AP to STA2 and 20% to the uplink, equally generated from each station to the AP as depicted in Fig. 2. We used *iperf* [20], in order to create UDP traffic and MadWifi *athstats* to take measurements of the retransmitted frames. UDP traffic does not provide Transport Layer retransmission like TCP and thus we were able to measure clean MAC Layer frame retransmissions, provoked by PHY Layer collisions.

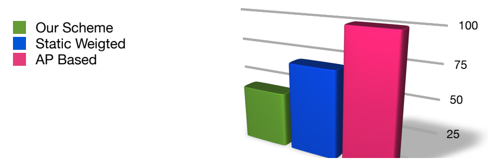
The energy efficiency of our Dynamic Frequency Selection model is justified compared to the Static Weighted and the AP measurement based model by means of retransmission percentage of the total UDP traffic generated frames. In our model only 5.6% of the total traffic was retransmitted, while in the second and the third model the retransmission percentage was 8.9% and 13.2% respectively. Hence, our DFS model proves its superiority regarding the green aspect of WiFi infrastructure networks, as presented in Fig. 3.a

Our Scheme	Static Weighted	AP Based
5.9	8.9	13.2



(a) Frame Retransmission Percentage.

Our Scheme	Static Weighted	AP Based
43	68.4	100



(b) Power Consumption Percentage.

Fig. 3. Experimental Results (Comparisons are made to the worst case).

Taking into account an AP based measurements decision model and power consumption of the Atheros [21] chipset AR5212, with which NITOS wireless testbed nodes are equipped, we calculated the amount of energy consumption that retransmissions provoked in our WLAN. For this reason, we measured the average transmission rate in our experiments, that is 24 Mbps approximately. The per bit energy on 802.11g operating at 24 Mbps rate is 20.4 nJoule for transmission and 6.4 nJoule for reception. Consequently the percentage of energy saved comparing the AP measurement based model with the static weighted and our DFS model is derived by accounting both energy saved on the transmitter and on the receiver side of the communication. As depicted in Fig. 3.b the static weighted model consumed 31.6% less power than the AP measurement based model and *our DFS model achieved* 57% *less power consumption* compared again to the AP measurement based model. Therefore, we show the significant power savings that we achieve by using our proposed scheme (7) in comparison with two other considered schemes (8), (9).

VII. Conclusion And Future Work

In this work we presented a green DFS model for infrastructure WLAN, which presents a noticeable energy efficiency compared to a static weighted model and an AP measurements decision model. As many manufacturers have not included in their APs functionality the smart choice of operating channel, we tested our adaptive model in a static environment regarding the ability of switching to better operating frequencies.

In our future work, we aim to investigate the stability of our model, when a WLAN that uses our DFS model, operates among other WLANs that use the same model on choosing their operating channel. In order to explore how this stability can be achieved, we are going to formulate our model using a game theoretic model and investigate if equilibrium exists.

References

[1] *"IEEE standard 802.11h supplement",* Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. Spectrum and Transmit Power Management Extensions in the 5GHz band in Europe, 2003

[2] Y. Xu, J. Lui and D-M. Chiu, *"Improving energy efficiency via probabilistic rate combination in 802.11 multi-rate wireless networks"*, Elsevier, 2009

[3] J-C. Chen, K. Sivalingam and P. Agrawal, *"Performance comparison of battery power consumption in wireless multiple access protocols"*, IEEE INFOCOM 1998, San Francisco, CA, USA

[4] J-H. Chang and L. Tassiulas, *"Energy Conserving Routing in Wireless Ad-hoc Networks"*, IEEE INFOCOM 2000, Tel Aviv, Israel

[5] IEEE Standard 802.11 - 1999, *"Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications"* Nov. 1999

[6] J-M. Choi, Y-B. Ko and J-H. Kim, *"Enhanced Power Saving Scheme for IEEE 802.11 DCF Based Wireless Networks"*, Springer, Personal Wireless Communications, vol. 2775/2003, Sep, 2003

[7] M-A. Malik and D. Shin, *"Collision Free and Energy Efficient MAC protocol for Wireless Networks"*, IJCSNS, vol. 7 No.9, Sep. 2007

[8] J. Zhao, Z. Guo and W. Zhu, *"Power Efficiency in IEEE 802.11a WLAN with Cross-Layer Adaptation"*, in Proc. IEEE ICC, Anchorage, Alaska, May 2003, pp. 2030–2034.

[9] D. Qiao, S. Choi, A. Soomro and K. Shin, *"Energy Efficient PCF operation of IEEE 802.11a WLANs via transmit power control"*, Comput. Netw. 42, 1 May. 2003, pp. 39–54

[10] L. Guo, X. Ding, H. Wang, Q. Li, S. Chen and X. Zhang, *"Exploiting Idle Communication Power to Improve Wireless Network Performance and Energy Efficiency"*, in Proc. of IEEE INFOCOM 2006. Barcelona, Spain, April 2006

[11] G. Athanasiou, I. Broustis, T. Korakis and L. Tassiulas, *"Routing-Aware Channel Selection in Multi-Radio Mesh Networks"*, International Conference on Communications (ICC 2009)

[12] B-J. Ko, V. Misra, J. Padhye and D. Rubenstein, *"Distributed Channel Assignment in Multi-Radio 802.11 Mesh Networks"*, WCNC 2007, Hong Kong March, 2007

[13] A. Raniwala, K. Gopalan and T. Chiueh, *"Centralized Channel Assignment and Routing Algorithms for Multi-Channel Wireless Mesh Networks"*, ACM Mobile Computing and Communications Review 2004, vol. 8, pp. 50–65

[14] R. Akl and A. Arepally, *"Dynamic Channel Assignment in IEEE 802.11 networks"*, in Proc. IEEE Portable 2007: International Conference on Portable Information Devices, Orlando USA, March 2007

[15] *"Network Implementation Testbed Laboratory"*, http://nitlab.inf.uth.gr/

[16] *"Network Implementation Testbed for using Open Source platforms"*, http://nitlab.inf.uth.gr/NITlab/index.php/testbed

[17] *"OMF, cOntrol & Management Framework"*, http://omf.mytestbed.net/

[18] *"CERTH, The Centre for Research & Technology Hellas"*, http://www.certh.gr/

[19] *"MadWifi open source driver"*, http://madwifi-project.org/

[20] *"Iperf"*, http://dast.nlanr.net/Projects/Iperf/

[21] *"Atheros"*, http://www.atheros.com/