2015 IEEE International Conference on Computer and Information Technology; Ubiquitous Computing and Communications;
Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing

Power Management and Rate Control Mechanism for Wi-Fi Infrastructure Networks

C. Bouras, V. Kapoulas, K. Stamos
Computer Technology Institute and Press "Diophantus",
Patras, Greece, and
Computer Engineering and Informatics Dept.
University of Patras, Greece
{bouras, kapoulas, stamos}@cti.gr

N. Stathopoulos, N. Tavoularis
Computer Engineering and Informatics Dept.
University of Patras, Greece
{stathopou, tavoularis}@ceid.upatras.gr

***Abstract*—The advances in wireless networks have encouraged the use of mobile devices in everyday life. However, one of the main problems of these devices is the limited amount of energy they have available to use in order to function and the extended energy consumption of wireless adapters. A lot of research has been done to reduce the amount of energy spent on wireless communications. On the other hand, the extended use of wireless networks causes interference problems in communications, which affect the overall performance of each network. The purpose of this work is to provide a mechanism, which can reduce the power consumption on the station side and increase the mobile devices' operation time, and in combination with a rate adaptation mechanism on the access point side, improve the overall performance of the network.**

Keywords*—*power management; wireless; SNR; RSSI; PDR; interference

I. INTRODUCTION

Wireless communication is the most common way for electronic devices to communicate with their surroundings, and most importantly the rest of the world. However, their density leads to degradation of the communication channel due to interference. It is very important that new mechanisms that are able to minimize the effects of interference, to the benefit of better network performance, are designed.

Moreover, the energy requirements for wireless devices are increasing steadily, since most of the components, tend to waste more energy in order to achieve higher performance. Wireless devices depend on batteries in order to operate, so the expansion of battery life of such devices is a great challenge. Research has shown that the wireless connection highly decreases battery life and the use of a power management mechanism is necessary [1].

Power management in wireless networks has been approached in various ways. In [2], a power-efficient scheme is proposed, which takes advantage of the sleep and up state of the wireless adapter and uses a probabilistic model in order to achieve its goal. The work in [3] provides a Transmit Power Control and Rate Adaptation algorithm where communication between Basic Service Sets (BSSs) determines the power consumption, in order to improve the throughput in each one of them. [4] creates a self-optimizing network, where the power transmission is adjusted by utilizing algorithms based on various TCP protocols.

In [5], a mechanism that minimizes the power consumption has been proposed. That mechanism adjusts the transmission power according to Signal-to-Noise Ratio (SNR). This mechanism has been tested on channels that have a stable bitrate and the mechanism was not able to deal with possible interference that occurred in the network. Jiansong Zhang et al. [6] have conducted experiments that show that the transition range of SNR differs according to the bit rate. However, the effects of interference between the peers have not been studied yet.

In this work we combine the mechanism in [5] with a rate adaptation mechanism, in order to optimize the overall performance of the wireless network. We study the issue of interference and how this affects the network performance.

The rest of the paper is organized as follows: section II discusses the effects of interference, section III proposes a new Transmit Power Control and Rate Adaptation mechanism, section IV describes the experiments and discusses their results, and section V concludes the paper.

II. EFFECTS OF INTERFERENCE

The main problem that is caused by the overpopulation of devices is communication interference. Other networks can cause co-channel and adjacent channel interference. Channel overlapping or sharing, reduces the capacity of the channel that each network can use and leads to transmission failures, which reduces Packet Delivery Ratio (PDR).

Choosing one of non-overlapping channels for the operation of the network in order to avoid interference is a common practice. Fuxjäger et al. in [7], proved that even these channels are not independent from each other and interference free. It was shown that in higher bitrates the frame loss ratio was increasing dramatically.

In [8], it is claimed that the Request To Send / Clear To

978-1-5090-0154-5/15 $31.00 © 2015 IEEE
DOI 10.1109/CIT/IUCC/DASC/PICOM.2015.107

Send (RTS/CTS) handshake is not effective enough in interference detection, and a new Medium Access Control (MAC) layer mechanism is proposed, in which a station can reply with CTS packet only if the reception power of the RTS packet is larger than a certain threshold. The experiments proved that the scheme in [8] reduced Packet Error Rate greatly, but the connectivity of the network was decreased as well.

The mechanism we introduce in this paper, aims at mitigating the effects of interference caused by other Wi-Fi networks that coexist in the same space, while it adjusts the transmission power and rate in order to save energy.

III. ARCHITECTURE

The mechanism proposed in this paper focuses in the optimization of the overall performance in the network, by introducing two separate modules. The first module aims at reduction of power consumption at the station (STA) side, while the other manages to improve the STA's reception rate by adjusting the Access Point's (AP's) transmission rate.

A. *Transmission power*

The transmission power of a device defines the amount of energy that is consumed in order to deliver a packet. However, no matter how strong the signal is, propagation effects always reduce the strength of the signal while it travels in space. These effects are described as path loss. Path loss is the reduction of signal power during a wireless transmission. It depends on a variety of factors such as the distance between the peers, refraction, reflection etc.

However, in many cases path loss is not significant enough to degrade signal quality. At the same time, power consumption of the STAs is always on the maximum level available. So, considering the fact that the peers are still able to communicate even if their power levels are lower, there is a waste of valuable energy.

In [5], the mechanism that is proposed applies a power control algorithm based on SNR. Specifically, it is considered that for a certain bit rate, if SNR has the value of 25dB, the Packet Delivery Ratio is high. So, as long as SNR is about 25dB, the peers can lower their transmission power accordingly.

The previous mechanism in [5] estimates the power needed to achieve the desired SNR value using equation (1)

$$P_{Rx_{dB}} = 30dB + N + PathLoss - G \qquad (1)$$

where N is the noise of the channel, G the gain of the antenna and $PathLoss$ the path loss of the signal till it reaches its destination.

The experiments that were conducted showed that the above mechanism can achieve power saving up to 80% in normal case scenarios. However it is assumed that the value of 25 dB is the optimal in terms of link quality and power saving. In [6] though, it was shown that for different bit rates, the optimal SNR value varies.

B. *Rate Adaptation*

Rate adaptation can be applied to limit the error probability that occurs due to interference. In [9], a rate adaptation method is proposed which uses a prediction technique to predict channel state by utilizing the Received Signal Strength Indication (RSSI) and then it adjusts the bit rate based on that prediction. However, it is stated in [10] that RSSI is not reliable enough, because it is not able to detect the interference in a link. Measurements in [6], [11] showed that for lower bit rate, lower SNR threshold is required.

The main advantage in [6] is that the SNR threshold values for each bit rate are calculated for each wireless adapter individually, which means that the hardware specifications is not a factor that needs to be considered in the search of the optimal SNR value. On the other hand, the need for rate adaptation even for one peer, leads to bit rate reduction for the other peers as well, even if they are not affected at all.

C. *Improved Signal Adaptation Mechanism*

In this section we introduce the improved version of the mechanism in [5], which aims at both power management and rate adaptation. The mechanism consists of 2 phases: Calibration and Adaptation Mechanism.

a. Calibration: The first phase of the mechanism is about finding the best Signal to Noise Ratio for each data rate. During this phase, the STA is transmitting to the AP in all the available data rates, so that the optimal value for the SNR where Packet delivery ratio is above 90% is detected. The measurements produced by the calibration are to be used in the next phase of the mechanism by the STA, during power adjustment.

b. Adaptation Mechanism: In order to clarify the effects of interference in an 802.11n network, we conducted some experiments to detect the circumstances under which packets are dropped, and try to create a mechanism that can adapt to these circumstances, by using only metrics that can be produced by fundamental metrics, such as signal and noise levels, and SNR.

The STA moves in a random pattern, which gives us the ability to observe various situations inside the environment.

At the first experiment the channel was free of interference. The SNR varies smoothly identically to the top line of Fig. 1 (the actual figure due to space restrictions). At the beginning the station was moving closer to the access point causing increase of SNR. After 20 seconds the station started drifting away and the SNR was decreasing.

At the second experiment a nearby ad-hoc network was transmitting (intermittently) with the data rate of 8 Mbps causing interference. Fig. 1 denotes the fluctuation of the SNR value and the large drops when the ad-hoc network was transmitting. Please note that the ad-hoc network is transmitting (and thus interfering) intermittently. This is done to display the effect of interference.

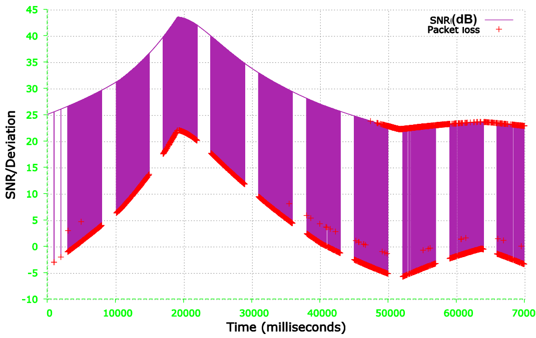

Fig. 1. Measurement of SNR and packet loss from the packets sent from the Access point with interference

Finally, we calculated the standard deviation of SNR in a window of 10 packets (Fig. 2). We noticed that interference leads to high standard deviation in the value of SNR. Also when the deviation exceeds 0.5 it is likely that the packet would be dropped. As a result we can make the assumption that if the standard deviation of the SNR is above the threshold of 0.5, the STA is susceptible to interference. However, not all the packet loss at this is due to interference, as SNR lower than 24dB also causes packet loss. In this work we take advantage of the high SNR standard deviation to predict interference and drop the data rate accordingly.

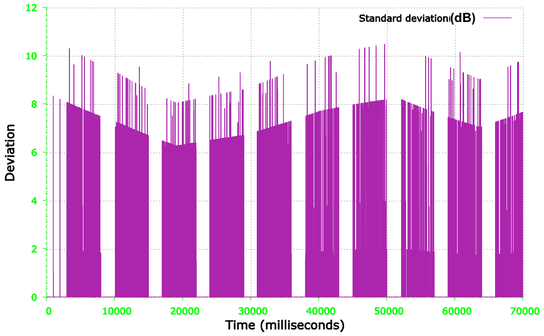

Fig. 2. Standard deviation of SNR

Our mechanism consists of two modules. The first module is applied to the access point and has a passive role, since it does not make decisions, but it only sends information regarding the status of the received packet and executes the instructions sent by the peers.

The second module is applied to the peers, and has the active role of the mechanism. It adjusts transmission power of each STA separately, depending on the information sent by the access point and since we need to mitigate the interference on the STA, it has to implement a method to achieve that. In conclusion, the mechanism focuses on utilizing power control on the STA side, and rate control on the AP side.

Assume there is a wireless network, consisting of an AP and STAs connected to it. Whenever the AP receives a packet coming from a STA, it sends back to the STA the signal level, noise level and SNR during the reception of the packet. When the STA receives the information, it checks whether the SNR of the AP is close to SNR_{perf} , which is the SNR threshold for a certain data rate, above which transmission is considered to be successful and error-free. If the above condition is not fulfilled, the STA calculates its new transmission power based on formula (2) below:

$$P_{Tx_{dBm}} = SNR_{perf} + N + PathLoss - G \tag{2}$$

where N is the noise of the channel, G the gain of the antenna and $PathLoss$ the path loss of the signal at its destination

However, the swift changes in the environment do not allow the new value to achieve its goal by its own. Sudden and steep changes in the transmission power might cause a very high SNR at the reception of the AP, which in turn will send back to the STA information that will possibly reduce the transmission too much, and so on.

As mentioned, the STAs are responsible for interference detection and rate adaptation decisions. When the STA receives a packet from the AP, it recalculates the deviation based on the new SNR reading, using (2) and (3). If deviation is above 0.5, it infers that interference from other networks are degrading the channel, so it notifies the AP to drop its data rate to next lower one.

On the other hand, if interference is absent, but rate control has taken place in the moments before, it is acceptable to increase the data rate again. Since it is not possible to predict the state of the channel in the future, we take precautious steps. For each consecutive successful reception, the STA increments a counter. If at a certain time the STA has received more than 1000 packets in a row successfully and the deviation is below 0.5, it notifies the AP to begin transmitting using the next higher rate from the current one.

In the case of multiple STAs connected to the AP, the AP's module is designed so that the data rate is decreased by requests sent by any STA, and increased only if the increment request was sent by the last STA that sent a data rate reduction request. In this way, it is guaranteed that the worst case scenario in the network is covered, and also, it prevents the other STAs to be affected by the interference in the future.

In this design, considering that the power is sufficient enough to send packets successfully, data rate has to be adjusted, in order to maintain a low transmission power and successful delivery of the packets. At the same time, if the SNR of the AP is higher than the required value of the current data rate of the STAs, power management takes place in order to save energy, valuable to the mobile STAs.

The mechanism does not simply manage to reduce power consumption under normal circumstances, but tries to deal with the interference that a STA might have, which is possibly coming from external sources. The interference-inflicted station will have reduced packet loss at the cost of throughput, but the network's performance will increase, since there will be less retransmissions.

The pseudocode of the mechanism is provided below:

Access Point Side

```
packet_received(packet) {
  if(message == ‘lower_bitrate’){
    new_bitrate = getBitrateFromPacket();
    setBitrate(new_bitrate);
    updateMostRecentlyAffectedNode();
  } else
    if(isMostRecentlyAffectedNode()== true){
      new_bitrate = getBitrateFromPacket();
      setBitrate(new_bitrate);
    }
  }
}
```

Station Side

```
Packet_received(packet){
  packetsReceived++;
  signal = readSignalFromPacket();
  noise = readNoiseFromPacket();
  snr = readSNRFromPacket();
  tx_power = getTxPower();
  if(snr > maxSnrForCurrentBitrate + offset
        || snr < maxSnrForCurrentBitrate - offset){
    tx_power = adjustTransmissionPower();
    setTxPower(tx_power);
  }
  if(SNRdeviation > 0.5){
    notifyAPtoLowerRate();
    packetsReceived = 0;
  }
  else if(packetsReceived>1000
           && SNRdeviation<0.5){
      notifyAPtoIncreaseRate();
  }
}
```

IV. EXPERIMENTS AND RESULTS

The experiments use the network simulator ns-3. The code that implements the mechanism is available at [12].

A. Network Setup

The mechanism makes the STAs independent from each other, so the setup of the network consists of a stationary base and a peer connected to it. The peer is moving freely inside the range of the station. The transmission power of the station remains at the higher possible level, since it is connected to a power source. On the other hand, the peer alters its transmission power according to the introduced power control scheme in order to achieve the desired SNR and it prompts the AP to apply rate adaptation if it detects interference.

Each node reads the signal and level noise at the reception to calculate the SNR level. Comparing the result with the calibrated SNR values, the node decides whether it should adjust the transmission power or the data rate.

The parameters of the experiments are: Moving Speed between 0.8-1.2 m/s, Maximum Distance at ≈ 30 m, Duration 70 sec, packet size 1500 bytes, and Packet Interval 0.01 sec. The distance of the STA from the AP during its trip inside the network is displayed in Fig. 3.

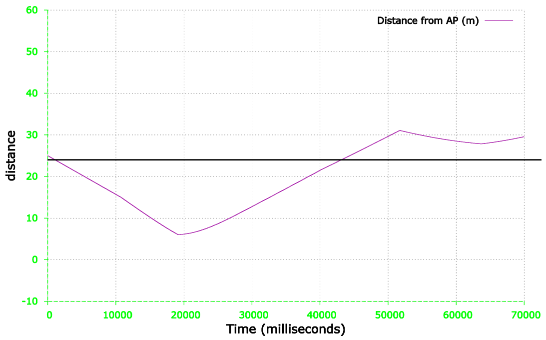

Fig. 3. Distance AP-STA vs execution time

B. Calibration phase

For the calibration phase, we run a script in ns3 simulator which makes use of the `nist-error-model`. We run the model for the rates that are supported by the 802.11n standard, using 20 MHz channel bandwidth and guard interval equal to 800 nanoseconds. Based on [13], we can rely on the results of the selected model, since it is very close to real time experiments and measurements. Moreover, the values recorded in this experiment are values that occur in a channel that lacks of external interference, which is something we do not need at this phase of the mechanism.

In Fig. 4, we see that frame delivery ratio escalates quickly from 0 to 1 after a certain value for each data rate. Moreover, it can be noticed that there is a relatively large gap in SNR after 39 Mbps, due to change of modulation. This results in higher energy per bit, which means that higher SNR is needed in order to send the frames successfully. In order to make our mechanism more flexible, we decided to select as SNR threshold the values where FDR is 0.9. Thus, we expect that even more power is conserved by using the mechanism, while the transmission success is high.

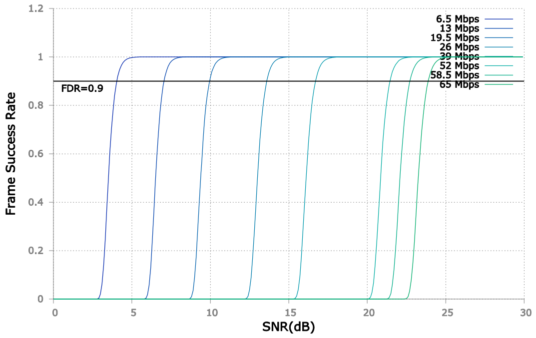

Fig. 4. Frame Delivery Ratio vs SNR per data rate. The horizontal line on 0.9 defines the SNR threshold that we want per data rate.

Table 1 shows the SNR values that give 0.9 as frame delivery ratio, in order to use them later in the actual mechanism. Usually it is preferred to use non floating point numbers for SNR, so we round values (upwards to avoid further frame loss, due to the steepness of the curve).

TABLE I. RESULTS OF CALIBRATION PHASE

Data Rate	$SNR_{FDR=0.9}$	Rounded
6.5	4.1	5
13	7.1	8
19.5	10	10
26	13.6	14
39	16.8	17
52	21.5	22
58.5	22.8	23
65	23.9	24

C. *Adaptation Mechanism Phase*

In our experiment, 20 nodes are connected to an access point. This will help in the comparison of the mechanism with the default configuration of a network in our final results. The connected nodes are moving randomly, since we used the RandomWalk2DMobilityModel that ns3 provides. We send the mechanism messages that are required using packet tags.

In order to evaluate the mechanism, we measured the SNR values of the AP, the AP's data rate, the transmission power of the STA and . Fig. 5 and Fig. 6 display the change in the transmission power using the mechanism. Fig. 7 and Fig. 8 display rate adaptation and packet loss.

In Fig. 5, we display the transmission power for one of the network nodes. The mechanism manages to save wasted energy most of the time, by reducing the STA's transmission power based on the algorithm introduces in III. It is noticeable that the station does not transmit when the channel is not clear due to carrier sense. Hence the STA can freely change its transmission power to conserve energy. When the STA is close to the access point, it transmits at the minimum level of 5 dB while the SNR remains above the threshold of 24 dB almost during the whole experiment.

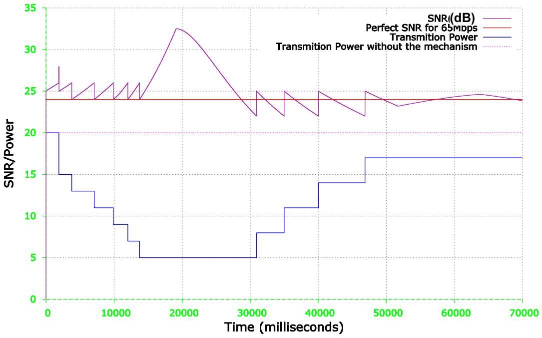

Fig. 5. STA Transmission Power and SNR in the experiment

In Fig. 6, the average transmission power of the nodes is displayed. Most of the simulation time, power tends to be lower than the maximum value allowed, leading to energy saving.

Fig. 7 displays the data rate change of the access point towards the node that was taken into account in Fig. 5. When interference is noticed, the bit rate drops. The new bitrate is the immediate lower from the bit rate with the closer SNR threshold to the current SNR. If the AP receives 1000 packets with no error then it gradually increases the bitrate again.

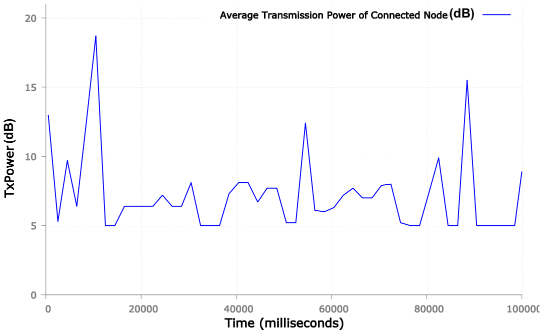

Fig. 6. Average transmission power of STA nodes in the experiment

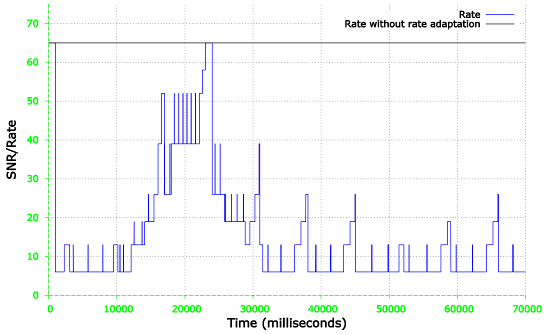

Fig. 7. Rate Control results of the proposed mechanism

Fig. 8 displays the packet loss with the use of the mechanism. The proactive behavior that utilize the SNR deviation, leads to less packet loss, especially when the STA is far from the AP. Slight increment of the deviation can predict the imminent effects of interference, and the STA notifies the AP as soon as possible to take the corresponding measures.

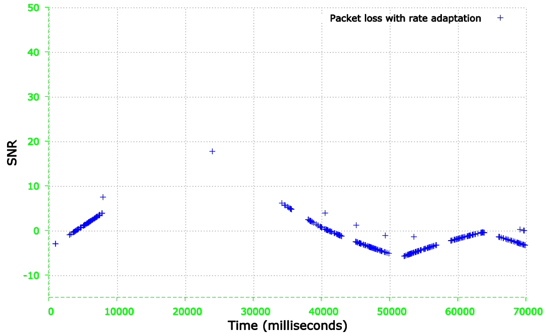

Fig. 8. Packet Loss with the proposed mechanism.

Table 2 summarizes the average packet loss ratios for both directions of communication. Please note that in the STA→AP direction the results are for the case without interference and demonstrate that the power management (i.e., the reduce power usage) does not result in a noticeable increase of packet loss. In the other hand in the AP STA direction the results are for the case with interference and demonstrate that the rate adaptation manages to reduce packet loss significantly.

TABLE II. PACKET LOSS COMPARISON

Packet Loss	AP→STA	STA→AP
Without Mechanism	18.77%	1.99%
With Mechanism	14.30%	2.21%

V. CONCLUSIONS AND FUTURE WORK

In this paper, we introduced a mechanism for the improvement of Wi-Fi networks, by implementing two mechanisms, one for power control on the station side and one for rate control on the access point side. The mechanism uses feedback messages in order to make use of the parameters that are taken account into the calculations. The results showed that the rate control algorithm that is proposed, managed to decrease packet loss, while the rate is kept as high as possible in interference case. On the other hand, the power control mechanism managed to maintain the power levels of the station as low as possible, at the cost of a minor packet loss for the access point.

In conclusion the problem of interference is the major problem of wireless communication without a direct solution. It is impossible to thoroughly eliminate interference and it is certain that the existence of it will degrade the connection. This mechanism succeeds to minimize the negative impact of interference and also to reduce the power consumption. This can reduce the effect of the hidden terminal problem significantly and increase the FDR from the packets sent from the access point. However if the station is the one who accepts interference then it will increase its transmission power causing more interference to the other network. Another disadvantage is the fact that the mechanism has not been tested in real environment in contrast with the mechanism in [5]. Conducting real life experiments in the future will show as the actual efficiency of the mechanism.

REFERENCES

[1] J. Bornholt, T. Mytkowicz and K. S. McKinley, "The Model Is Not Enough: Understanding Energy Consumption in Mobile Devices," in *Hot Chips: A Symposium on High Performance Chips*, San Jose, CA, USA, August 27-29, 2012.

[2] Y. Zhu, S. Luan, V. Leung and K. Chi, "Enhancing Timer-based Power Management to Support Delay-Intolerant Uplink Traffic in Infrastructure IEEE 802.11 WLANs," *IEEE Transactions on Vehicular Technology,* vol. PP, no. 99, p. 1, 23 April 2014.

[3] S. Tang, H. Yomo, A. Hasegawa, T. Shibata and M. Ohashi, "Joint Transmit Power Control and Rate Adaptation for Wireless LANs," *Wireless Personal Communications,* vol. 74, no. 2, pp. 469-486, 2014.

[4] A. Saha, "A Distributed Power Management Algorithm for a Self-optimizing WiFi Network," in *The Ninth Advanced International Conference on Telecommunications (AICT)*, Rome, Italy, June 23-28, 2013.

[5] C. Bouras, V. Kapoulas, K. Stamos, N. Stathopoulos and N. Tavoularis, "Power management for wireless adapters using multiple feedback metrics," in *10th International Wireless Communications and Mobile Computing Conference (IWCMC)*, Nicosia, August 4-8, 2014.

[6] J. Zhang, K. Tan, J. Zhao, H. Wu and Y. Zhang, "A Practical SNR-Guided Rate Adaptation," in *The 27th Conference on Computer Communications (INFOCOM)*, Phoenix, AZ, April 13-18, 2008.

[7] P. Fuxjäger, D. Valerio and F. Ricciato, "The Myth of Non-Overlapping Channels: Interference Measurements in IEEE 802.11," in *Fourth Annual Conference on Wireless on Demand Network Systems and Services. WONS '07.*, Oberguyrgl, January 24-26, 2007.

[8] K. Xu, M. Gerla and S. Bae, "How Effective is the IEEE 802.11 RTS/CTS Handshake in Ad Hoc Networks?," in *Global Telecommunications Conference. GLOBECOM '02. IEEE*, November 17-21, 2002.

[9] M. Vuukuru, H. Balakrishnan and K. Jamieson, "Cross-layer wireless bit rate adaptation," in *SIGCOMM '09*, New York, NY, USA, August 17-21, 2009.

[10] A. Vlavianos, L. K. Law, I. Broustis, S. V. Krishnamurthy and M. Faloutsos, "Assessing link quality in IEEE 802.11 Wireless Networks: Which is the right metric?," in *IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Cannes, September 15-18, 2008.

[11] M. Hossein, M. Lacage, C. Hoffmann and T. Turletti, "On Selecting the Best Transmission Mode For WiFi Devices," *Wireless Communications & Mobile Computing,* vol. 9, no. 7, pp. 959-975, July 2009.

[12] "Research Unit 6 - CTI "Diophantus"," [Online]. Available: http://ru6.cti.gr/ru6/research-areas/network-simulations

[13] P. Guangyu and H. Thomas R, "Validation of OFDM error rate model in ns-3," The Boeing Company, 2010.