# A Signal Adaptation Mechanism for Power Optimization of Wireless Adapters

*Christos Bouras, Computer Technology Institute and Press "Diophantus", Patras, Greece & Computer Engineering and Informatics Department, University of Patras, Patras, Greece*

*Vaggelis Kapoulas, Computer Technology Institute and Press "Diophantus", Patras, Greece & University of Patras, Patras, Greece*

*Georgios Kioumourtzis, Center for Security Studies, Athens, Greece*

*Kostas Stamos, TEI of Western Greece, Patras, Greece*

*Nikos Stahopoulos, Computer Engineering and Informatics Department, University of Patras, Patras, Greece*

*Nikos Tavoularis, Computer Engineering and Informatics Department, University of Patras, Patras, Greece*

## ABSTRACT

*This manuscript introduces, implements and evaluates a feedback-based adaptation mechanism that adjusts the transmission power of a wireless card on commodity mobile devices. Main focus of this work is to minimize the power consumption by adjusting the transmission power of the wireless card, thus extending the battery life, while negative effects on connection quality are avoided. To achieve that, a mechanism that optimizes the power depending on the quality of the connection is presented, which measures the quality of the transmission and adjusts the transmission power, by utilizing an expanded array of metrics, for more accurate estimation. The mechanism has been implemented and tested on actual wireless adapters. In order to evaluate, fine-tune and improve the mechanism, a list of real environment experiments has been performed. The results indicate that power consumption can be significantly reduced for nodes that are either almost stationary or slowly moving, without any significant increase in packet loss.*

*Keywords:* *Green Networking, RSSI, Signal Adaptation Mechanism, SNR, Wireless Power Management*

DOI: 10.4018/IJWNBT.2015070104

## 1. INTRODUCTION

As networks and connected devices become more mobile and thus energy constrained, and as the requirements for lower energy consumption become more demanding, the issue of consumed power by wireless network cards is becoming an intensively researched topic. Furthermore, concerns by the public on electromagnetic fields increase the interest of such research. When using a wireless connection, increasing the strength of a signal may result in better quality, as perceived by the end user application, but it also results to more energy consumption and stronger electromagnetic fields. On the other hand, if the signal strength is reduced too much, there is the risk of reduced performance or even losing connectivity completely.

Development of mechanisms that adjust the power consumption to optimal levels is considered necessary (Bornholt, Mytkowicz, & McKinley, 2012). For example, the authors in (Mayo & Ranganathan, 2003) conclude that, in order for single general-purpose mobile devices that combine multiple functionalities to achieve longer battery life, they should be designed to include requirements-aware energy scale-down techniques.

One efficient method to deal with this problem is to optimize the power consumption of network adapters. Research in devices such as smartphones has shown that WiFi adapters are responsible for a significant percentage of the consumed power, and thus energy savings in this area are very important for devices with limited power sources such as battery operated ones (Agarwal, Schurgers, & Gupta, 2005; Carroll & Heiser, 2010; Friedman, Kogan, & Krivolapov, 2011; Malik, 2012; Pering, Raghunathan, & Want, 2005; Rozner, Navda, Ramjee, & Rayanchu, 2010; Shye, Scholbrock, & Memik, 2009). For example, the author in (Malik, 2012) lists WiFi as the most power-consuming mode of an Android phone's functions. Furthermore, research in (Carroll & Heiser, 2010) shows that under specific benchmarks the WiFi adapter can exceed 700mW in power consumption. Similar results have also been verified by measurements on smartphones (Balasubramanian, Balasubramanian, & Venkataramani, 2009) including measurements by end users taken "in the wild" (Shye, Scholbrock, & Memik, 2009).

The IEEE 802.11 standard deals with this problem by defining two modes; the active mode, where the network adapter is awake and can receive data at any time and power save mode. Where it cannot receive or send any data, so the energy consumption is reduced in that state. In (Zheng & Kravets, 2005), an on-demand power management technique is taking advantage of the above, to achieve 50% less energy consumption. In (Kravets & Krishnan, 2000), a transport layer mechanism enables the interface periodically or when necessary, reducing the energy consumption to 17%. However, the above mechanisms are based on active and inactive periods of the interface, which leads to additional delay at the arrival of the frames and degradation of the connection quality.

Another approach to the issue of optimizing power consumption has been made by focusing on other features of state-of-art standards, such as Multiple Input-Multiple Output (MIMO) operation. A mechanism focusing on radio chain management in order to reduce the power consumption has been proposed in (Yu, Zhong, & Sabharwal, 2009), which improved energy efficiency by 32% in best case scenario, with a high data rate (50Mbps). Another work related to MIMO utilization is in (Jang, Hao, Sheth, & Govindan, 2011), where the mechanism introduced, schedules the wake-up and sleep times of the clients, and on top of that, determines the antennas that are going to transmit in a way that is considered the most efficient.

The rest of the paper is organized as follows. Section 2 provides an overview of related work and the contribution of this paper. Section 3 describes the architecture and the mechanisms (including the algorithms utilized). Section 4 provides an overview of the implementation in real world mobile devices. Section 5 presents the conducted experiments with performance evaluation results in. Finally, section 6 concludes the paper with a summary and section 7 presents thoughts for future work.

## 2. RELATED WORK

This paper deals with the issue of developing and testing in actual environments a mechanism that manages transmission power on wireless network cards in order to guarantee both acceptable connection quality and the lowest possible power consumption and electromagnetic field. Similar solutions have been proposed in the literature with an emphasis on theoretical treatments of the subject. (Bouras, Papapanagiotou, Stamos, & Zaoudis, 2010) proposes a transmission control power algorithm and tests it with the ns-2 (The network simulator 2, 2012) network simulator. (Monks, Bharghavan, & Hwu, 2001) presents a decentralized power control protocol that manages to improve the throughput performance. The proposed protocol is evaluated with the same simulation software. The 802.11h standard (IEEE Standards Association, 2003) includes a transmission power control mechanism (Qiao, Choi, & Shin, 2007). However, the 802.11h standard refers to 5 GHz band networks and its purpose is to eliminate the interference with satellites and radar systems. In (Lopez-Aguilera & Serra, 2006) proposes another power control mechanism that reduces the influence of interference on cellular networks. Power control is also developed for 802.11b wireless networks in (Sheth & Han., 2003). This model operates between two nodes at the transport (TCP) layer and it is not functional in any kind of topologies with more than one node. Finally, radio resource management features are implemented in Cisco products (Cisco Systems, 2010). These features include various transmission control power algorithms.

Another approach to the problem is proposed in (Pering, Agarwal, Gupta, & Want, 2006), where power is saved by enabling a wireless device to automatically switch between multiple radio interfaces, such as WiFi and Bluetooth. It requires however the existence of possible communication over multiple radio interfaces, which may not always be the case. In (Bouras, et al., 2013), a mechanism focused on the adjustment of the transmission power of the wireless card according to the state of the network has achieved to optimize the power consumption of the wireless cards in ad-hoc networks. This mechanism manages the power consumption of both the base station and the connected peers, which might limit the capabilities of the base station, and renders it unable to transmit to its maximum distance. The access points are often connected to a stable power supply and it's usually the connected peers that have the strongest motivation to adjust their energy consumption in order to extend their life span.

The main purpose of this work is to determine the significance of the transmission power to the quality of the network as well as to provide a mechanism to adjust the transmission power in order to guarantee a fair quality and minimize the power consumption.

Our first mechanism adjusts the transmission power by utilizing the Received Signal Strength Indication (RSSI; a measurement of the strength of a received signal). Several prior efforts have taken place in the areas of power optimization and RSSI utilization for link quality estimation, using either RSSI or other metrics. In general, the suitability and limitations of RSSI as a link quality metric are discussed and evaluated in (Vlavianos, Law, Broustis, Krishnamurthy, & Faloutsos, 2008). In (U.S. Patent No. 6,735,448, 2004), the authors propose a power management mechanism that is used for routing packets in ad hoc networks with power efficiency. In (U.S. Patent No. 7,672,246, 2010), the RSSI is one of the metrics used to improve routing efficiency in a wireless network. In (U.S. Patent No. 7,035,677, 2006), information transferred in a multihop path includes power information in order to guide the power management mechanism. The mechanism described in (U.S. Patent No. 6,970,714, 2005) adapts power levels according to information that is available locally. In (Chaltseva & Osipov, 2012), RSSI is used to estimate wireless channel state and feeds an algorithm that optimizes MAC layer parameters. Most of prior research has not focused on the issue of aggregating the power transmission needs of multiple direct receivers of the data stream.

Our purpose is to expand the model described in (Sheth & Han., 2003) and make it more functional for real world implementation. We consider the problem of the existence of a base station with a number of connected wireless nodes. In this situation the base station has to decide the appropriate level of the transmission power in order to minimize the consumption, but it is also important to guarantee the continuous connectivity of the network. In addition, we consider that the rest of the nodes can also change the power levels. At the beginning of the operation the base station keeps the transmission power at a minimum level. When it ascertains that any of the nodes have moved sufficiently away of its range, it has to increase the transmission power in order to ensure the continuous communication. A very important aspect of the operation is the adaptive behavior of the base station; in which it tries to minimize the transmission power whenever it is possible. The nodes around the base station change their transmission power according to the algorithm presented in (Sheth & Han., 2003).

The contribution of the paper lies both in resolving problems and removing assumptions in the actual implementation of the model proposed in (Sheth & Han., 2003), as well as extending the model and the implementation to work in a setting with a base station (access point) and multiple wireless devices connecting to it.

In an actual environment, the base station may be any wireless router which wants to minimize power consumption. This includes mobile and portable devices that use tethering to become local WiFi access points for other devices in their vicinity. Another case is in ad-hoc networks in which the nodes participating in the network act also as routers forwarding packets that are received by other nodes. Especially, the proposed mechanism can find its place in wireless sensor networks in which power consumption is a big issue. Results indicate that the implementation of the extension of the model in (Sheth & Han., 2003), can lead to considerable power savings that might extend the battery life-time of such devices, especially in the case of slowly moving nodes (e.g. walkers).

The second mechanism in this paper extends the first mechanism (Bouras, et al., 2013). Instead of using only the RSSI to measure the efficiency of the mechanism, we also utilize the Signal-To-Noise ratio to improve the power performance of the adapters. Our mechanism adjusts the transmission power by utilizing along the Received Signal Strength Indication (RSSI; a measurement of the strength of a received signal) an additional variety of metrics (Sauter, 2010), and especially Signal-to-Noise Ratio (SNR). In (Zhang, Tan, Zhao, Wu, & Zhang, 2008), the authors verify that SNR is a good prediction tool for channel quality and propose solutions for avoiding poor results due to the dependence of SNR values on hardware characteristics and interference effects. We propose a feedback based Signal Adaptation Mechanism (SAM) which would guarantee fair connection quality with the lowest possible transmission power. SAM is based on the previous mechanism (Bouras, et al., 2013) but the SNR metric has also been used in order to measure the quality of the connection. Moreover, SAM is completely independent of the driver and portable. Finally, we test the efficiency of SAM though various sets of experiments.

# 3. ARCHITECTURES AND THE MECHANISMS

## 3.1. Received Signal Strength

The architecture of the mechanism that will be used is based on the utilization of the Received Signal Strength (measured in dBm). Consequently, the Received Signal Strength can determine the amount of power consumed by the sender of a packet to the receiver.

In order for a network card to send a packet to a peer in the network, it has to transmit the packet with power more than $P_{th}$ where $P_{th}$ is the amount of power needed to transmit a packet safely through the network. Moreover, the signal power is reduced due to path loss, which is caused by environmental factors, such as free-space loss, refraction, reflection, etc.

We first need to define the Equivalent Isotropically Radiated Power (EIRP), which is the amount of power after antenna gain.

$$\mathrm{EIRP} = P_{Tx} - L + G \tag{1}$$

In Equation 1, $P_{Tx}$ represents the transmission power and $G$ is the antenna gain. $L$ is the cable loss that is considered negligible. Supposing that $P_{Rx}$ is the reception signal, we can evaluate the path loss as described below:

$$\mathrm{PathLoss} = \mathrm{EIRP} - P_{Rx}$$

Equivalently:

$$\mathrm{PathLoss} = P_{Tx} + G - P_{Rx} \tag{2}$$

Each peer has to know the Received Signal Strength of the packets they send, so that they become aware of their transmission power, and become able to make the desired adjustments. To achieve this, the receiver of the packet extracts the Received Signal Strength value that is included in the packet, and then it returns it back to the sender of the packet.

## 3.2. RSSI-based Adaptation

Our mechanism adjusts the transmission power by utilizing the Received Signal Strength Indication (RSSI). RSSI is the measurement of the strength of a received signal which can be used as an indication of the distance between the communicating nodes; a low RSSI signifies great distance and the possible need to increase power transmission; a higher RSSI indicates that the communicating nodes are in close proximity and power transmission may be lowered without compromising the quality of the link between them.

If the RSSI is lower than a specific threshold ($P_{thr}$), the decoding of the signal cannot be guaranteed due to low Signal to Noise ratio (SNR).

It is obvious that the power of the received signal must be higher than the threshold. Thus the minimum transmission power can be calculated as follows.

$$P_{Tx_{min}} = \mathrm{PathLoss} + P_{thr} \tag{3}$$

However that value is not tolerant to any fluctuations to RSSI and would cause continuous errors in received packets. To solve that problem we increase the above value by a constant factor ($P_c$) that provides a comfortable buffer zone for RSSI fluctuations.

$$P_{Tx} = \mathrm{PathLoss} + P_{thr} + P_c \tag{4}$$

To calculate the transmission power it is important for the senders to have knowledge of the RSSI of their own packets. Thus the receivers have to send a feedback message to the senders containing the RSSI value.

This value can also change temporarily due to environmental factors that are independent of the movement of the nodes. These factors are not likely to affect the next frames and should therefore not affect heavily the mechanism calculations. For that reason, using the single last RSSI value to calculate the path loss is not a sufficiently robust approach. Instead, we calculate an average value using the Exponential Weighted Moving Average (EWMA) (Chou, 1975).

A moving average is the average value of a fixed size list. Every time that a new value is appended to the list, it is placed at the head and the tail is removed (FIFO). Then the average value is recalculated. To emphasize the more recent values we use different weights for each data value according to its place on the list. The more recent data have greater weights than the older ones.

Using this method to calculate the path loss we remain consistent to the previous values but give more importance to more recent values. Additionally, we have smooth plots and avoid significant changes to the path loss. These changes are more likely to occur due to environmental factors rather than the movement of the nodes.

In order ensure connectivity for all the nodes in a network, it is crucial that the base station sends to each node with the appropriate estimated

If the sender is a base station and multiple nodes are connected, then the reduction of the transmission power is not efficient before we guaranty the connectivity to the rest of the nodes. In order to achieve this, we use a table containing the nodes that are connected to the base station and the path loss for each one of them. The base station sets its power according to the maximum path loss. If we receive an RSSI feedback message we have to update that table. Also if the sender of this message is the node who defines the transmission power we have to recalculate the power.

We present the pseudo code of our mechanism, in Algorithm 1.

Algorithm 1 contains two main functions:

- The message_received function runs when a packet has been received, and then it informs the sender about its RSSI. This method runs at the receiver.
- The get_rssi_information function runs when RSSI information has been received. Then it calculates path loss and the appropriate transmission power. This method therefore runs at the sender of the packets.

Since every node can be both a sender and also a receiver, these two functions run in parallel.

The base station, implements a different get_rssi_information function, in Algorithm 2.

This function updates the table and ensures that the transmission power would be set according to the node that is located further away (the one with the maximum path loss). If the

*Algorithm 1.*

```
message_received(packet) {
rssi=extract_rssi(packet);
rssi_avg=average(rssi,mac)
send the rssi_avg to node with that mac address
previous_rssi=get_previous_rssi(packet.mac)
if(change(rssi_avg,previous_rssi)>MAX_CHANGE)
{
send rssi to node with that mac address
set_previous_rssi(packet.mac,rssi_avg)
}
}
get_rssi_information(rssi) {
Path_loss=calculate_path_loss(rssi).
Ptx=calculate_ptx(path_loss)
set_transmition_power(Ptx)
}
```

*Algorithm 2.*

```
get_rssi_information_for_station() {
rssi=wait_until_get_rssi_packet();
Path_loss=calculate_path_loss(rssi)
PrevMaxPathLoss=getMaxPathLoss(table);
getMaxPathLoss(table)
update_table(packet.mac,Path_loss)
if(PrevMaxPathLoss != getMaxPathLoss(table)) {
Ptx=calculate_ptx(path_loss)
set_transmition_power(Ptx)
}
}
```

maximum path loss has changed, we also recalculate the transmission power. This is possible in two cases: The first case refers to the scenario in which any node moved too far away and we have to increase the power. The second case refers to the scenario in which the node that was located further away has come closer. That means that we can minimize the power according to the path loss of the node with what used to be the second largest distance to the base station. In other words the algorithm sets the power at a level that would be suitable even for the most distant node at any moment.

Every node sends periodically a keep-alive message to the base station. If the base station stops receiving that messages from a node, it may consider that node inactive and it removes it from its node table. It also minimizes its power if necessary, in order to accommodate the next most-distant node.

### 3.3. SNR-based Adaptation

The mechanism used is based on the utilization of Signal-to-Noise Ratio (SNR). By definition, SNR is the power ratio between a signal and the background noise. Noise is a very important factor regarding the integrity of the information transferred through the wireless network.

Since the value of SNR reflects the quality of the signal, we can make some conclusions about the performance of the network and its impacts. For example, BER is directly affected by the value of SNR. If the value of SNR is relatively low, for example 10 dB, it indicates that bit error probability will be high, since noise is proportionally large in comparison with the actual signal. In order to achieve decent connectivity and correct signal transmission, a high signal-to-noise ratio is needed.

From the above, it is very clear that the goal of this adaptation is to approach a high SNR level, while at the same time the transmission power is not at a fixed value, but it varies according to the parameters of the environment. Of course, noise is a quantity that cannot be measured directly or predicted before the transmission, so it is not considered as a parameter that should be taken into account for immediate calculations. Instead, past noise values are used as indicators for subsequent packet transmissions. Also, the distance between two peers is a parameter that has a great effect on the signal transmission, and it can be measured using various parameters, such as AOA (Angle of Arrival), TOA (Time of Arrival), TDOA (Time – Distance of Arrival) and RSSI. In (Savarese, Rabaey, & Beutel, 2001), these methods are proposed for the distance measurement between 2 nodes, but only the exploitation of RSSI is an efficient method. However, (Parameswaran, Husain, & Upadhyaya, 2009) claims that RSSI is an unreliable measure to estimate distance, due to the attenuation caused by physical obstacles and interference and due to its behavior in great distances. So, we can't take advantage of this parameter in this mechanism.

Based on the above, it is concluded that the goal of this mechanism, namely the upkeep of the SNR on satisfactorily high level, is very difficult or unreliable to be implemented using in the calculations, the parameters referenced previously. More specifically, the immediate estimation of the adaptation that a peer must do is not possible. So, the estimation has to be done considering the value of parameters, such as the received noise on the signal, in the immediately preceding time slots.

In order to exploit the full potential bandwidth of a channel, the value of SNR must be at least 25 dB. In this case, the quality level of the link between two nodes is fair and a high bit-rate is achieved. As shown in (Zhang, Tan, Zhao, Wu, & Zhang, 2008), 25 dB is a value that allows for high frame delivery ratio (FDR) for various transmission rates. For the transmission rates used in the experiments, a value as low as 15 dB could have been used. However we opted for a more conservative value in order to guarantee that almost no frames are dropped due to the reduced power. In this paper we do not consider the effect of interference by other transmitting nodes. The effect of the proposed mechanism in such scenarios will be studied in the future. However, it is expected that the effect might be positive as the reduced power reduces (and possibly eliminates) the interference with nodes that are further away.

As referenced earlier, the power of a received signal can be calculated from equation (2) as:

$$P_{Rx} = P_{Tx} + G - \mathrm{PathLoss} \tag{5}$$

Depending on the alterations of the environment, the amount of noise added to the signal varies. SNR can be calculated from the following formula:

$$SNR_{dB} = P_{RxdBm} - N \tag{6}$$

where $P_{Rx}$ is the power of the received signal in decibels and *N* is the noise in decibels. Since we want SNR to be 25 dB, $P_{Rx}$ can be calculated as:

$$P_{Rx_{dBm}} = 25dBm + N \tag{7}$$

In this mechanism, this SNR threshold is set, to ensure that the signal quality is decent.

Nevertheless, after the above adjustment in power, it is impossible to predict the accurate value of noise added to the signal at the next time moment. This fact makes the signal unreliable, since it is not known whether the SNR is above the threshold, and consequently the signal is corrupted. Moreover, we can extract from equation (1) that cable losses can exist. So, a default 5 dB is added to the above expression, in order to have some margin that allows avoiding the undesirable negative performance influence of such factors. Finally, the calculation of transmission power is:

$$P_{Rx_{dBm}} = 30dBm + N \tag{8}$$

Moreover, the received signal is weakened due to path loss, so the received power in equation (6) is expressed as in equation (3):

$$P_{Tx_{dBm}} - PathLoss + G = 30dBm + N$$

Finally, the power that is suitable for successful transmission is:

$$P_{Tx_{dBm}} = 30dBm + N + PathLoss - G$$

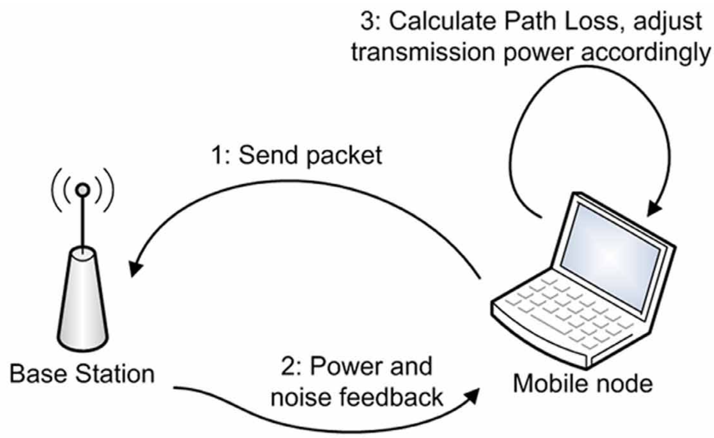
As the peers are moving in the range of the base station, its signal level is changing. Therefore, whenever the base station receives a packet, it gathers information concerning the power of the received signal, as well as the noise of the channel. Then it sends this information back to the peer that sent the packet.

When the peer receives the feedback message containing the power of the signal and the noise level of the channel, it calculates the signal power needed in order to achieve the desired signal to noise ratio. The whole process is depicted in Figure 1.

The procedure is described in Algorithm 3.

In function message_received, which is used by the base station, the feedback message is sent only if the SNR is not between the interval [optimal_snr-snr_threshold, optimal_snr+snr_threshold], where optimal SNR is 25 dB and snr_threshold is a default value (5 dB), which allows the mechanism to be a bit flexible. For example, if the calculated SNR value is 27 dB, it is not that necessary to send a feedback message to the peer to make adjustments, since this value is very close to the ideal one. In this way the traffic in the network caused by the mechanism is reduced

*Figure 1. The main steps in the mechanism*



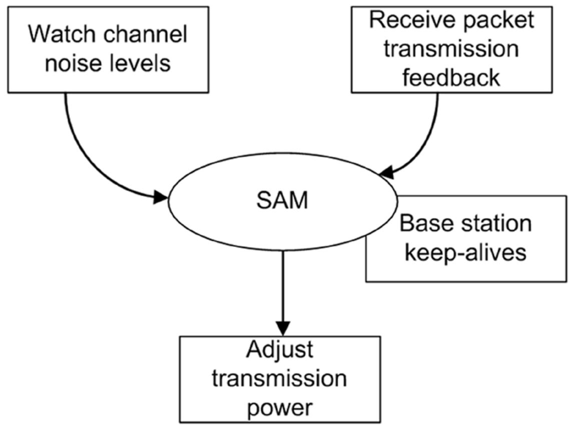

*Algorithm 3.*

```
Base Station:
message_received(packet) {
signal=extract_signal_value();
noise= extract_signal_value();
snr = signal-noise;
if(snr<optimal_snr-snr_threshold |
snr>optimal_snr+snr_threshold) {
if(peer is not informed) {
send(signal,noise) ;
}
}
}
Connected Peer:
get_rssi_information(signal,noise) {
Path_loss=calculate_path_loss(signal);
Ptx=calculate_ptx(path_loss,noise);
set_transmition_power(Ptx);
}
```

to the least amount necessary. Another important optimization is that the station does not send messages if the peer has already been informed about its signal and the noise. It is possible for a peer that it cannot reach the optimal SNR, for example due to high distance from the station. In this situation the base station avoids sending feedback messages repeatedly.

Gathering information at the reception of a packet is not enough for the mechanism to work properly. In order to guarantee the optimal SNR it is important to watch the channel for changes at the noise as well. Consequently, every peer adjusts its power whenever the noise level has changed significantly. Another problem is that a peer can be inactive for a period of time. If that peer is moved further from the base station it is possible to lose connectivity due to the fact that previously it was transmitting at a lower power. To surpass this problem, the base station

*Figure 2. SAM structure*




periodically sends messages to the all the inactive peers waiting for an acknowledgement. The time period until the station assumes a peer is inactive can be configured. A short period allows the peer to move faster but more messages are being sent. The whole SAM structure is depicted in Figure 2.

### 3.4. Network Setup

In this case the network consists of a base station and the peers connected to it. The base station holds its transmission power at the maximum level in order to transmit at the higher distance. In contrast, each peer adjusts its transmission power in order to achieve both a reduction in its energy consumption and the maintenance of the SNR at the optimal level. Therefore the base station sends feedback messages to inform the peers for its revived signal strength and the noise of the channel. Our setup is using a realistic access point as base station and laptops as nodes.

## 4. IMPLEMENTATION

Retrieving the RSSI per packet and setting the transmission power is not supported by all wireless adapters and their drivers. In our work we initially used Cisco Aironet cb21ag cardbus adapters (Cisco Systems Inc., n.d.) and the ath5k driver for Linux (Atheros Linux wireless driver Ath5k, 2012). This driver is open source software which allows us to perform a number of changes.

The hardware supports a variety of transmission power levels. The default transmission power without our mechanism is the maximum value. The ath5k driver can extract the RSSI per packet instead of calculating the average value like most drivers do.

Our mechanism consists of two components. First we change the driver to create a virtual file at the proc filesystem (Killian, 1984). This file contains information about the RSSI and the MAC address of every new packet received. Secondly, at the application level we create a service that reads the information from the virtual file and communicate with the nodes using a known port. This service calculates the exponential moving average for every node and sends a UDP packet whenever the average RSSI has changed significantly. It listens also to that port, revives the packets and changes the transmission power using system commands. As we use UDP packets for feedback messages it is possible that some of them may be lost. For this reason when we receive an RSSI packet we send an acknowledgment message containing the RSSI value that we have received. If the sender of the RSSI message does not receive the acknowledgment or the value on the acknowledgment packet is wrong, it resends the RSSI message.

This implementation divides the very fundamental element on driver level and implements the basic mechanics on an application making it simpler and easily expandable.

To calculate the average value we use the Linux implementation of EWMA. For retrieving the SNR the mechanism uses some available network utilities and libraries of linux and works on a linux environment. The base station sniffs the network for any kind of packets thought the *pcap* library. When a packet has been received, the signal level of the packet is gathered from the *iw* utility. Moreover the *iw* contains information about the noise of the channel. A function periodically checks for changes at the noise of the channel and informs the peers. All the feedback messages between the station and the peers set using the User Datagram Protocol (UDP) in order to avoid the complexity of Transmission Control Protocol (TCP).

The pcap and the iw command are supported from the majority of the wireless adapters currently in market. Thus the mechanism does not depend on the driver. However a lot of drivers are incapable of setting the transmission power or extracting the noise of the channel.

Our implementation of the proposed mechanism is open source code which can be downloaded, tested and modified freely The source code implementing the mechanism is available from the web site of Research Unit 6 / Computer Technology Institute and Press “Diophantus”, at the address: http://ru6.cti.gr/ru6/cross_layer.php#pman (Cross-layer Design and Mechanisms, Feedback-based Adaptation for Improved Power Consumption).

## 5. EXPERIMENTS AND RESULTS

### 5.1. RSSI-based Adaptation

To measure the quality of the network we use the MTR (My traceroute) utility, which is a computer application that combines the functionality of the traceroute and ping programs in a single network diagnostic tool. It uses ICMP or UDP protocol to take statistics from the network, such as the average latency, the worst latency, the packet loss, etc in a given amount of tries. The performance evaluation of the implemented mechanism is measured by the aforementioned metrics. We are particularly interested in the levels of power consumption and the packet losses as they indicate the level of potential trade-off that the mechanism may achieve. Packet loss provides an indication of the way throughput will be affected under a given situation with and without the operation of the proposed mechanism. Increased packet loss causes retransmissions, more bandwidth usage and increased delay, leading to an overall reduction of Quality of Service (QoS).

For the first experiment we use only two nodes simulated by two laptops. The first laptop (which serves as the base station) maintains a static position and we move the second inside the range of the first one. We take statistics of the quality of the network on predefined locations using the MTR utility as described above. We choose these locations to represent a variety of situations (w.r.t. to the distance between the nodes, and obstacles in the line of sight) so that the laptops would have different transmission power in every case. We repeat each experiment twice; the first time by using our adaptation mechanism and the second time without using any radio resource management mechanism. The purpose of this experiment is to determine how efficient our mechanism is compared to the default transmission method. The experiment is conducted in an open space; this is the most common use case with moving nodes (i.e. outdoors). It also reduces the possibility of interference of walls and other factors.

Table 1 shows the experimental results from several experiments with different random movements, repeated both with and without the adaptation mechanism. Other parameters that are also measured such as latency indicate no variation with or without the adaptation mechanism, as the transmission distance always remained at 1 hop.

According to the results there is no important variation on packet loss, which means that the adaptation mechanism does not affect connection quality. However, the average transmission power has been reduced significantly, which demonstrates that the mechanism is capable of achieving significantly lower energy consumption. The energy savings can range from 2% to 75% depending on the distance of the transmitting and receiving nodes.

The behavior of the adaptation mechanism in these experiments satisfies our design goals. The power savings level is higher when the distance between the base station and the moving node is small. At the same time the packet loss ratio values are negligible. Obviously, the mechanism is very suitable for smaller distances. For moving nodes in larger distances from the base station the power savings may be smaller or even negligible (near the outskirt of the coverage area).

Figure 4 presents the results from a similar experiment conducted while the node was slowly moving (at walking speed) at a straight direction away from the base station (as shown in Figure 3), in order to evaluate the adaptation mechanism's response to a deteriorating environment.

Figure 4 depicts the dependence between the average power transmission levels and the distance between the base station and the moving node. We can observe how the power level increases as the distance increases, until it peaks just before the node is about to lose connectivity with the base station. The difference in the power used by the base station and the moving node reflects the different estimation done based on the (slightly) different feedback they get. Still both follow a similar pattern of adapting the transmission power as their distance increases.

Figure 5 shows how packet loss is simultaneously affected. It can be seen that until the 50m distance (where communication was lost), packet loss increases very slowly, as a result of both nodes increasing the transmission power accordingly (i.e. adapting to the changing distance between the nodes). After the moving node reaches the limit of the coverage area of the base station, connection is lost (as even with maximum transmission power it could not be maintained).

In our next experiment, we use two nodes connecting to a base station (Figure 6). We are moving the nodes in order to measure the quality of the network connection as well as the average transmission power of each node at the new positions. We consider the case that one node moves while the other remains stationary.

Figure 7 and Figure 8 present the results split in two periods. During the first period, Node 1 stays 10m away from the base station, while Node 2 slowly moves away from the base station. Then Node 1 moves to 30m away from the base station, and Node 2 repeats the above described movement sequence.

*Table 1. Comparison of experimental results*

| **No adaptation** | | **Using adaptation** | |
|---|---|---|---|
| ***Tx power (avg)*** | ***Packet loss*** | ***Tx power (avg)*** | ***Packet loss*** |
| 20 | 1.6% | 19.5 | 2.6% |
| 20 | 0.2% | 13.5 | 3.6% |
| 20 | 0.0% | 5 | 0.1% |
| 20 | 0.0% | 5 | 0.0% |

*Figure 3. Experiment with a single receiver*

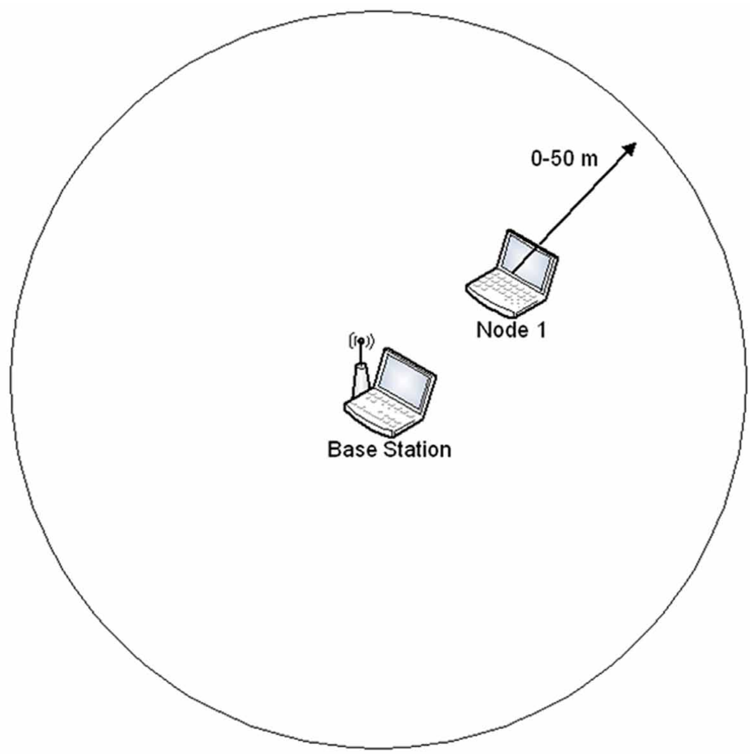



*Figure 4. Average power level for a single receiver slowly moving away*

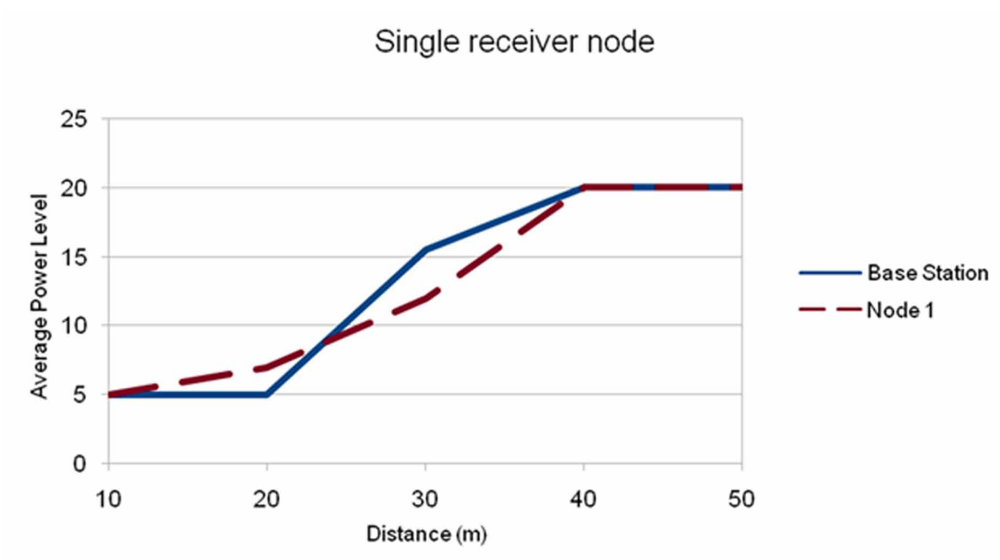


*Figure 5. Packet loss for a single receiver slowly moving away*

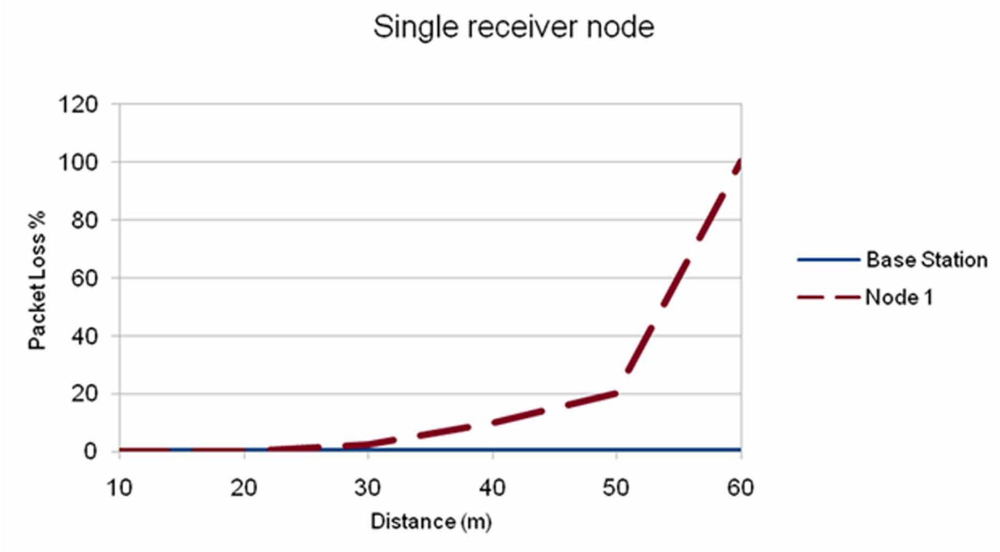
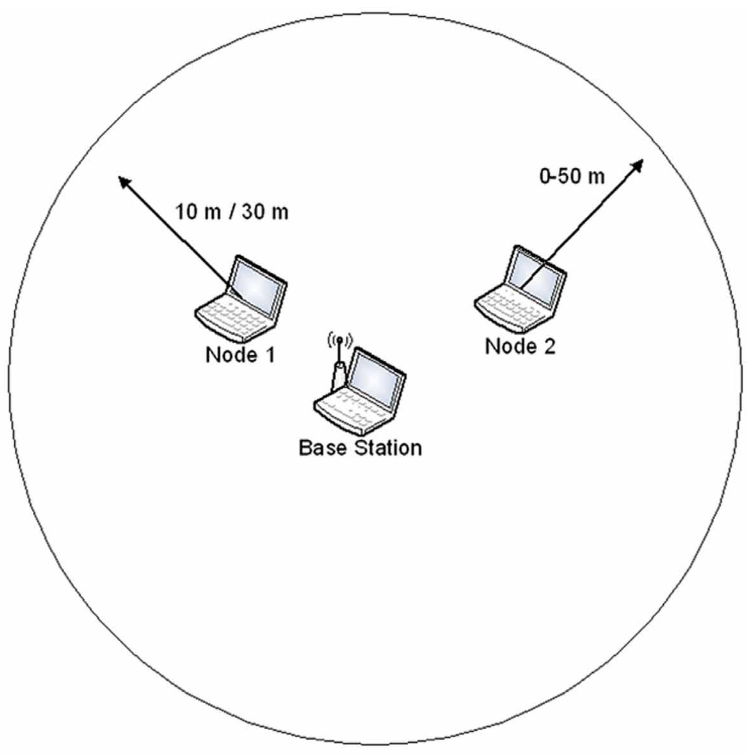



*Figure 6. Experiment with multiple receivers*



As can be seen in Figure 7, the power level for the moving Node 2 gradually increases while it distanced itself, whereas Node 1 power level always remained at a comfortable low level. Obviously, the power level for the base station changes like the one for Node 2, so that connection can be maintained with the node farthest away.

When Node 1 also moves further away from the base station, its power level increases, initially to a high value, but afterwards settles to lower values that still guaranteed connection quality. This can be verified by Figure 9 and Figure 10, which show that packet losses for neither node increased to a level above 5%, except when Node 2 was about to exit the connection range of the base station at about 50 meters distance from it.

The only exception is a brief period just after Node 1 moved to 30m distance from the base station, due to the amount of time that the algorithm needed to adjust power levels. That means that the transmission power adaptation mechanism is more suitable for slowly moving nodes (e.g. walkers) rather than quickly nodes (e.g. cars). Quickly moving targets may be accommodated, with less packet loss, by being conservative and using more transmission power than required. i.e., for quickly moving nodes we can trade-off less packet loss for more transmission power. It may also be possible to tune the mechanism to adapt more aggressively, again at the cost of using more transmission power that necessary in other cases.

## 5.2. SNR based Adaptation

For the evaluation of the mechanism, we conducted some experiments that indicate the way the mechanism functions, as well as the effect it has on the network connection. From the description of the mechanism, it is obvious that each peer connected to the base station is not affected by the actions of the rest of the peers. Each peer depends on the base station. So, it is not necessary to conduct an experiment whose the setup consists of multiple peers. One peer is enough to prove the functionality of the mechanism.

The first set of experiments tests the efficiency of the mechanisms and the connection quality. Therefore a node has been connected to the base station and the quality of the connection has

*Figure 7. Average power level for two receivers, one staying near the base station and the other slowly moving away*

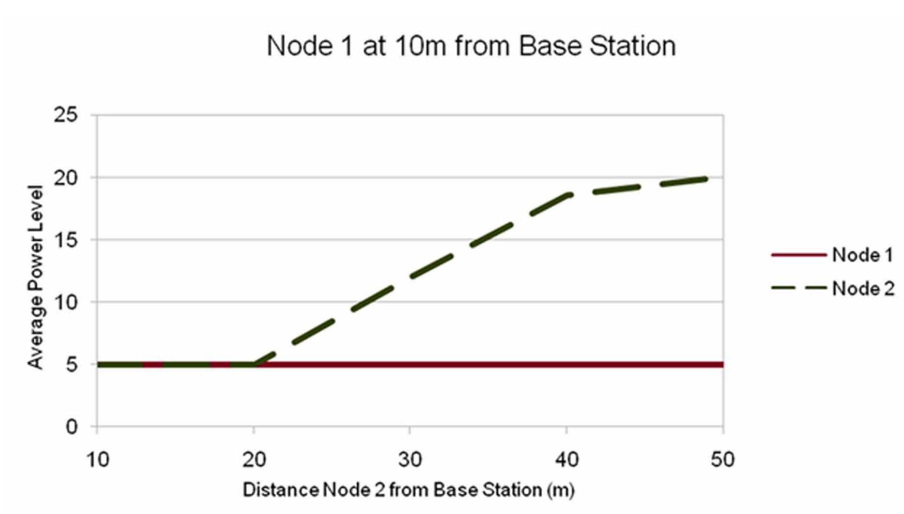


*Figure 8. Average power level for two receivers, one staying away from the base station and the other slowly moving away*

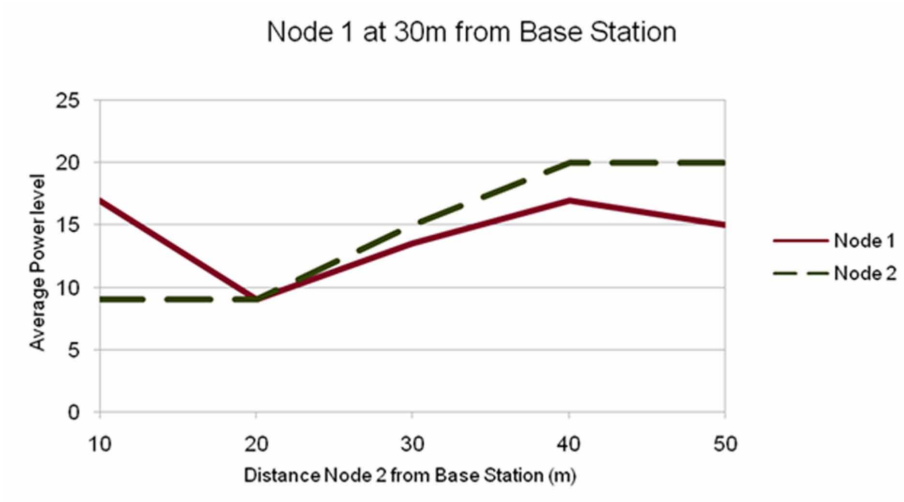
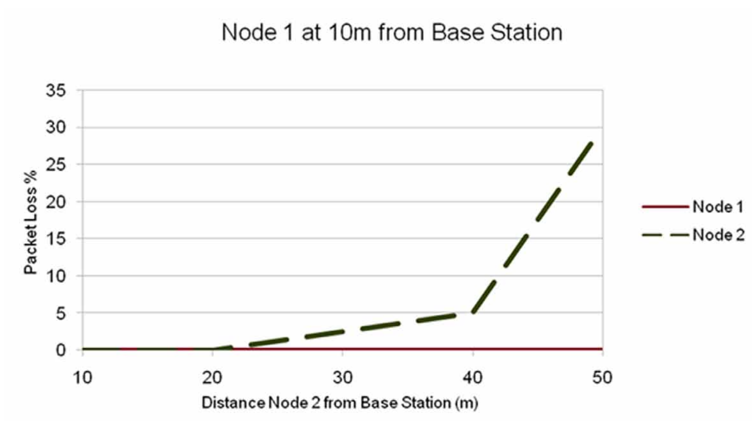



*Figure 9. Packet loss for two receivers, one staying near the base station and the other slowly moving away*




been measured at different positions. The node has been placed at various positions, each one even further from the base station. The transmission power and the average SNR are measured in this experiment with and without the mechanism (Table 2 and Table 3). Figure 11 and Figure 12 show the results of this experiment.

Considering that Position 1 is the closest to the base station, while Position 3 is the furthest, the node transmits with the minimum possible power to the maximum one. Generally the transmission power is increasing respectively to distance from the base station. In Table 2, we can see that the average SNR is closer to the preferred value of 30 dBm when using the mechanism.

*Figure 10. Packet loss for two receivers, one staying away from the base station and the other slowly moving away*

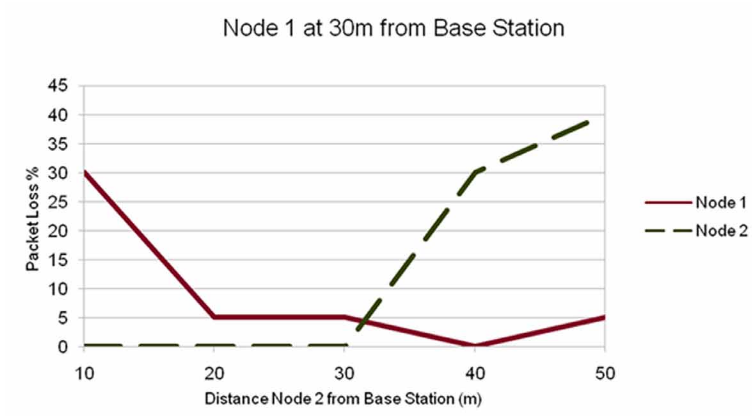



*Table 2. SNR of the testing node with the use of SAM and without*

| SNR | SAM | Without SAM |
|---|---|---|
| Position 1 | 33.61 | 42.72 |
| Position 2 | 29.45 | 36.20 |
| Position 3 | 29.64 | 36.20 |

*Table 3. Transmission power of the node with the use of SAM and without*

| Tx Power | SAM | Without SAM |
|---|---|---|
| Position 1 | 5.00 | 20.00 |
| Position 2 | 12.30 | 20.00 |
| Position 3 | 16.86 | 20.00 |

*Figure 11. Results of the first set of experiments (SNR)*

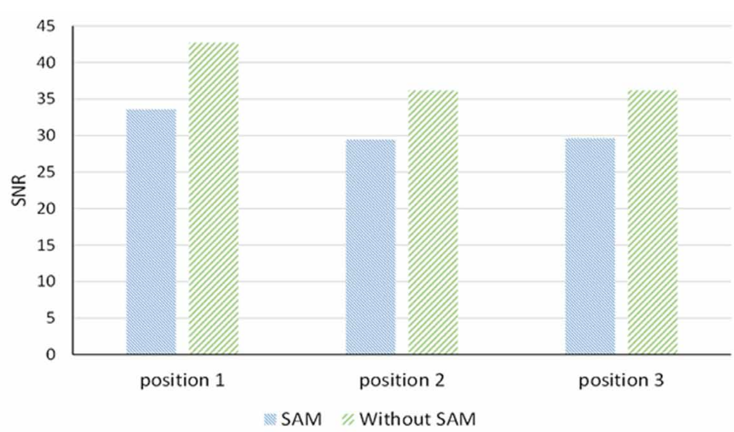
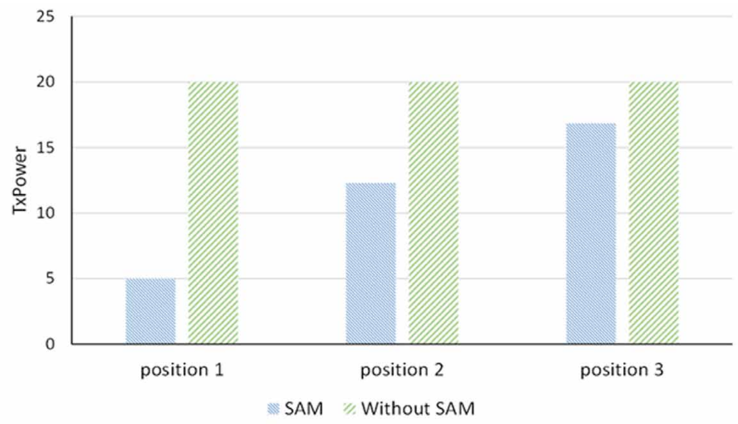


Figure 12. Results of the first set of experiments (Tx power)




On the other hand, the average SNR value without the use of the mechanism is higher at the cost of high power consumption.

During the experiment, it was noticed that the bitrate was not affected by the variation of the transmission power, so no results concerning the bitrate are presented. This nevertheless verifies our initial assumption that a target SNR of 30 dBm is sufficient for achieving the desired connection quality. Moreover, the mechanism managed to minimize the transmission power at levels where the connection quality was fair and, as expected, there was no packet loss.

The second set of experiments tests the behavior of the mechanism on a continuously moving peer. In the beginning, the peer is right next to the base station, as it starts moving away from the latter. When the peer reaches the maximum distance possible, it moves back to the base station. It should be noted that the speed of the node was stable. Figure 13, shows the results of the experiment versus time.

The peer is moving away from the base station for 150 seconds and it is turning back to the station for the rest of the time. The yellow area in the graph indicates the desired range of the SNR. We observe a similarity between the SNR with the use of the mechanism and the SNR without using it. Moreover, when the SNR is failing outside of the desired range the mechanism adjusts the transmission in order to maintain the SNR in range (e.g. at 45 seconds). This figure demonstrates how SAM continuously monitors the connection parameters and intervenes when SNR is falling to dangerously low levels by increasing the transmission power, or when SNR is high by efficiently managing and saving power.

The average transmission power with the mechanism is 13.02dBm while, without the mechanism the power is steady at 20dBm. By doing the standard conversions in mW we can calculate that the mechanism achieves an average power consumption reduction of about 80% (from 100mW to 20mW). Since power consumption by WiFi during intense network usage has been shown in the literature to be one of the main drains of power in a battery-powered device, the consumption decrease achieved can be considered highly beneficial.

In the final experiment our purpose was to test a movement pattern that contained multiple increases and decreases of the distance between the base station and the peer node. In this case the peer is moving along a triangle, while the station is located at one its edges.

The node moves along the arrows drawn in the figure. The results of the experiment are shown in the graph, in Figure 14 below.

*Figure 13. Results of the second experiment*

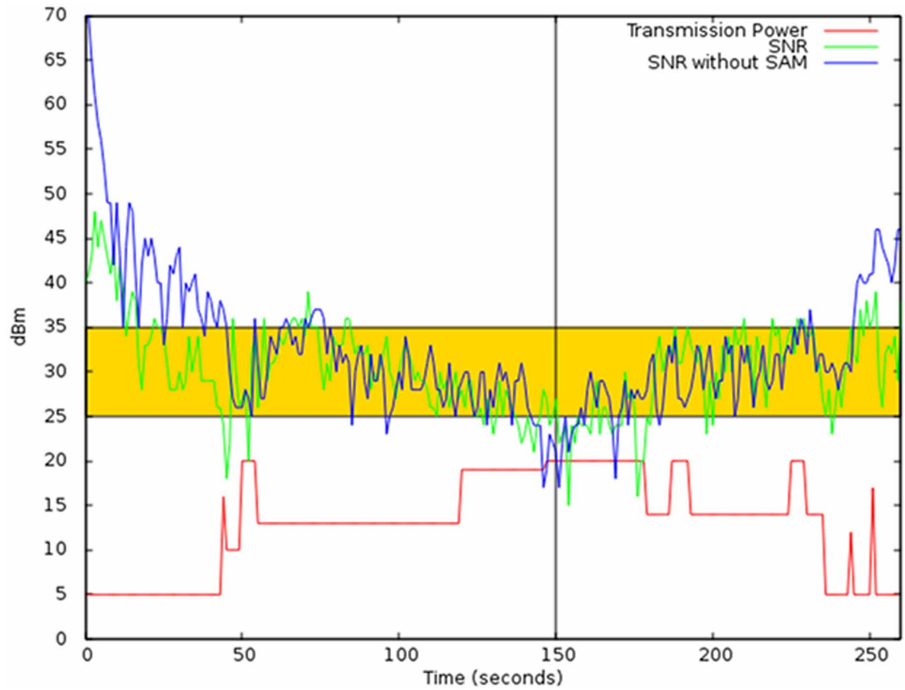
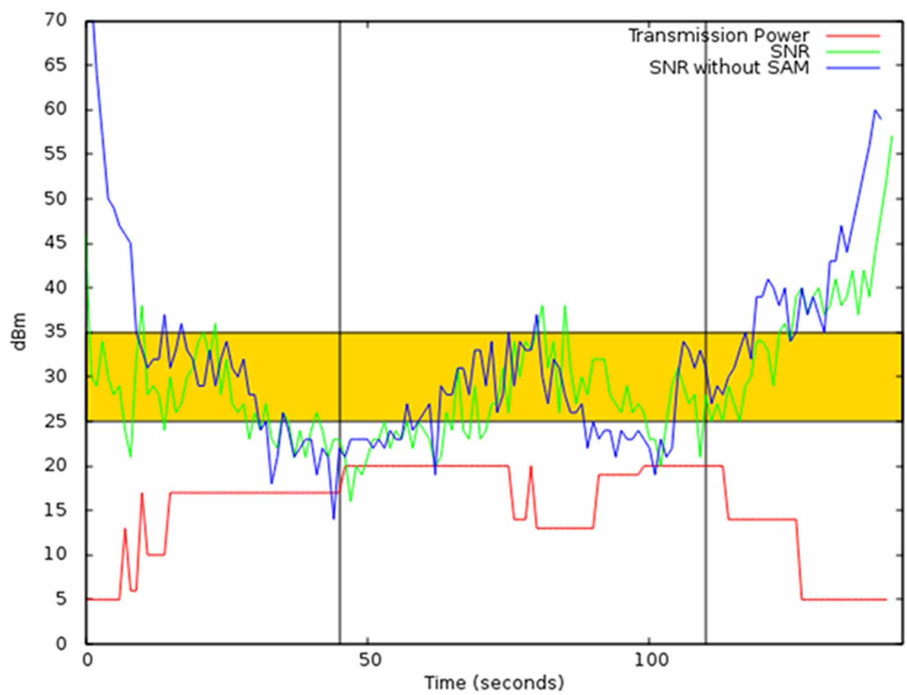



*Figure 14. Results of the third experiment*



At 45 seconds, the peer reaches the first edge of the triangle, and at 110 seconds the second. Then it returns to the station again. As in the previous experiments, the yellow colored area indicates the desired range of the SNR. As with the previous experiment, the SNR values decrease as the distance becomes larger and gradually increases when the distance becomes smaller. The mechanism manages to keep the SNR close to its corresponding values when running the experiment without the mechanism, and thus both SNR lines appear very similar, The average power consumption when the mechanism is used is about 32.5 mW, while without using the mechanism the average power consumption is 100mW. So, the average consumption reduction in this case is 67.5%.

The overhead induced by the extra frames transmitted to exchange the information that drives the proposed mechanism, depends heavily in the motion and the nodes and the changes in their location. Therefore, it is not easy to estimate them as a percentage of the payload data. However, for the experiments conducted the mechanism data were well below 1%. Therefore, the power required to transmit them is negligible related to the reduction achieved.

## 6. CONCLUSION

In this paper we have demonstrated how a power management mechanism that utilizes RSSI, as well as SNR, as feedback, may be implemented in a real-world operating system and be evaluated in realistic settings.

The actual implementation revealed several issues that were not easily identifiable through simulations and allowed accurate performance measurements. The experiments showed that for slowly moving nodes, the RSSI-based adaptation mechanism achieved an important reduction of the transmission power. That reduction can significantly minimize the power consumption, leading to obvious environmental and economic advantages. Also minimizing the signal strength is important for the human health, especially on people with electromagnetic hypersensitivity, although that sector needs more research before we can safely reach conclusions. We expect the implementation of such mechanisms to increase in the near future as mobile computing becomes more wide spread and environmental, economical and health concerns attract a lot of attention.

From the experiments conducted for the SNR-based adaptation, it is shown that in relatively close distances, which occur in most scenarios, the mechanism can minimize power consumption drastically. There is a trade-off between SNR and power consumption. High signal strength means high power consumption and high SNR. This mechanism represents a way to hold the SNR at fair values and minimize the power consumption. However, it is not measured how the transmission power effects actual electric consumption. The main fallback of the mechanism is that it requires feedback messages to operate. Moreover, the execution of the mechanism at the CPU causes some additional energy consumption which is difficult to measure precisely.

The implementation of such a mechanism in self-powered sensor networks provides also the potential to increase the life–time of the network. This is a very important application area of this and other similar power adaptation mechanisms.

## 7. FUTURE WORK

In our future work we intend to extend the experimentation to a larger variety of devices, where power consumption benefits may be more directly measured in terms of battery life. This approach also has the welcome characteristic that any side-effect from the mechanism implementation, such as potentially increased CPU power consumption, will also be taken into account.

Also, we intend to investigate the mechanism under faster movement scenarios, in order to investigate ways for reducing its delay in adapting power levels.

Finally, we plan to extend our proposed mechanism to adapt in case of interference by other communicating nodes in the vicinity. We consider using a method, such as the one in (Zhang, Tan, Zhao, Wu, & Zhang, 2008), to identify the presence of interference, and adapt the transmission power (rather that the rate in (Zhang, Tan, Zhao, Wu, & Zhang, 2008)), accordingly.

## REFERENCES


Agarwal, Y., Schurgers, C., & Gupta, R. (2005). Dynamic Power Management using On Demand Paging for Networked Embedded Systems.*Proceedings of Asia-South Pacific Design Automation Conference (ASPDAC)*. doi:10.1109/ASPDAC.2005.1466450

*Atheros Linux wireless driver Ath5k*. (2012, September). Retrieved from http://wireless.kernel.org/en/users/Drivers/ath5k

Balasubramanian, N., Balasubramanian, A., & Venkataramani, A. (2009). Energy consumption in mobile phones: a measurement study and implications for network applications.*Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference (IMC '09)* (pp. 280-293). New York, NY, USA: ACM. doi:10.1145/1644893.1644927

Bornholt, J., Mytkowicz, T., & McKinley, K. S. (2012). The Model Is Not Enough: Understanding Energy Consumption in Mobile Devices. *Hot Chips: A Symposium on High Performance Chips,* San Jose, CA, USA

Bouras, C., Kapoulas, V., Stamos, K., Tavoularis, N., Kioumourtzis, G., & Stathopoulos, N. (2013). Feedback-based Adaptation for Improved Power Consumption. *Proceedings of the27th IEEE International Conference on Advanced Information Networking and Applications (AINA - 2013)* (pp. 562 - 568). Barcelona, Spain. doi:10.1109/AINA.2013.32

Bouras, C., Papapanagiotou, V., Stamos, K., & Zaoudis, G. (2010). Efficient Power Management Adaptation for Video Transmission over TFRC. Proceedings of the AICT '10, Barcelona, Spain.

Carroll, A., & Heiser, G. (2010). An analysis of power consumption in a smart-phone.*Proceedings of the 2010 USENIX conference on USENIX annual technical conference.*

Chaltseva, A., & Osipov, E. (2012). On passive characterization of aggregated traffic in wireless networks. *Proceedings of the 10th international conference on Wired/Wireless Internet Communication WWIC'12,* Santorini (pp. 282-289).

Chou, Y.-L. (1975). *Statistical Analysis*. Holt International.

Cisco Systems. (2010). *Radio Resource Management under Unified Wireless Networks*.

Cisco Systems Inc. (n. d.). *Cisco Aironet 802.11A/B/G Wireless CardBus Adapter*. Retrieved from http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-802-11a-b-g-cardbus-wireless-lan-client-adapter-cb21ag/product_data_sheet09186a00801ebc29.html

D'Souza, R. M., Ramanathan, S., & Lang, D. T. (2005, November 29). *U.S. Patent No. 6,970,714*.

Friedman, R., Kogan, A., & Krivolapov, Y. (2011). On power and throughput tradeoffs of WiFi and Bluetooth in smartphones. *Proceedings - IEEE INFOCOM* (pp. 900–908).

IEEE Standards Association. (2003). *IEEE Std 802.11h-2003, Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 5: Spectrum and transmit power management extensions in the 5 GHz band in Europe*. IEEE.

Jang, K.-Y., Hao, S., Sheth, A., & Govindan, R. (2011). Snooze: Energy Management in 802.11n WLANs. *Proceedings of the Seventh Conference on emerging Networking EXperiments and Technologies CoNEXT '11,* Tokyo.

Killian, T. (1984). Processes as Files. Proceedings of the USENIX Summer Conf., Salt Lake City.

Kravets, R., & Krishnan, P. (2000). Application-driven power management for mobile communication. *Wireless Networks*, *6*(4), 263–277. doi:10.1023/A:1019149900672

Krishnamurthy, S., ElBatt, T., & Connors, D. (2004, May 11). *U.S. Patent No. 6,735,448*.

Lopez-Aguilera, E., & Serra, J. C. (2006). A transmit power control proposal for IEEE 802.11 cellular networks. *Proceedings of the6th International Workshop on on Applications and Services in Wireless Networks*, New York (pp. 235-242).

Malik, M.Y. (2012). Power Consumption Analysis of a Modern Smartphone.

Mayo, R. N., & Ranganathan, P. (2003). *Energy Consumption in Mobile Devices: Why Future Systems Need Requirements-Aware Energy Scale-Down*. Internet Systems and Storage Laboratory, HP Laboratories Palo Alto.

Monks, J. P., Bharghavan, V., & Hwu, W.-m. (2001). *A Power Controlled Multiple Access Protocol for Wireless Packet Networks, April, 2001* (pp. 219–228). Alaska: IEEE INFOCOM.

Orlik, P., Sahinoglu, Z., & Zhang, J. (2006, April 25). *U.S. Patent No. 7,035,677.*

Parameswaran, A. T., Husain, M. I., & Upadhyaya, S. (2009). *Is RSSI a Reliable Parameter in Sensor Localization Algorithms – An Experimental Study.*

Pering, T., Agarwal, Y., Gupta, R., & Want, R. (2006). CoolSpots: reducing the power consumption of wireless mobile devices with multiple radio interfaces.*Proceedings of the 4th international conference on Mobile systems, applications and services (MobiSys '06)*, (pp. 220-232). New York, NY, USA. doi:10.1145/1134680.1134704

Pering, T., Raghunathan, V., & Want, R. (2005). Exploiting radio hierarchies for power-efficient wireless device discovery and connection setup.*Proceedings of the IEEE International Conference on VLSI Design*. doi:10.1109/ICVD.2005.97

Qiao, D., Choi, S., & Shin, K. G. (2007). Interference analysis and transmit power control in IEEE 802.11a/h wireless LANs. *IEEE/ACM Transactions on Networking*, *15*(5), 1007–1020. doi:10.1109/TNET.2007.900381

Rozner, E., Navda, V., Ramjee, R., & Rayanchu, S. (2010). NAPman: Network-Assisted Power Management for WiFi Devices. *Proceedings of theInternational Conference on Mobile Systems, Applications and Services (MobiSys)*. San Francisco, CA, USA. doi:10.1145/1814433.1814445

Sauter, M. (2010). Mobility Management in the Cell-DCH State. In *From GSM to LTE: An Introduction to Mobile Networks and Mobile Broadband* (p. 160). John Wiley & Sons. doi:10.1002/9780470978238

Savarese, C., Rabaey, J. M., & Beutel, J. (2001). Locationing in distributed ad-hoc wireless sensor networks. *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP '01)*.

Sheth, A., & Han, R. (2003). Adaptive Power Control and Selective Radio Activation For Low-Power Infrastructure-Mode 802.11 LANs. *Proceedings of the23rd International Conference on Distributed Computing Systems Workshops* (pp. 812 - 818). Providence, Rhode Island, USA: IEEE. doi:10.1109/ICDCSW.2003.1203652

Shye, A., Scholbrock, B., & Memik, G. (2009). Into the wild: studying real user activity patterns to guide power optimizations for mobile architectures.*Proceedings of the 42nd Annual IEEE/ACM International Symposium on Microarchitecture, MICRO 42* (pp. 168–178). doi:10.1145/1669112.1669135

*The network simulator 2*. (2012, December). Retrieved from http://www.isi.edu/nsnam/ns/

Vann Hasty, W. J., & Stanforth, P. J. (2010, March 2). *U.S. Patent No. 7,672,246.*

Vlavianos, A., Law, L. K., Broustis, I., Krishnamurthy, S. V., & Faloutsos, M. (2008). Assessing link quality in IEEE 802.11 Wireless Networks: Which is the right metric? Personal, Indoor and Mobile Radio Communications PIMRC '08, Cannes.

Yu, H., Zhong, L., & Sabharwal, A. (2009). Adaptive RF chain management for energy-efficient spatial-multiplexing MIMO transmission. *Proc. ACM/IEEE Int. Symp. Low Power Electronics and Design,* San Francisco. doi:10.1145/1594233.1594336

Zhang, J., Tan, K., Zhao, J., Wu, H., & Zhang, Y. (2008). A practical SNR-Guided Rate Adaptation. *Proceedings of the IEEE INFOCOM '08.*

Zheng, R., & Kravets, R. (2005). On-demand power management for ad hoc networks. *Ad Hoc Networks*, *3*(1), 51–68. doi:10.1016/j.adhoc.2003.09.008

*Christos Bouras is Professor in the University of Patras, Department of Computer Engineering and Informatics. Also, he is a scientific advisor of Research Unit 6 in Computer Technology Institute and Press - Diophantus, Patras, Greece. His research interests include Analysis of Performance of Networking and Computer Systems, Computer Networks and Protocols, Mobile and Wireless Communications, Telematics and New Services, QoS and Pricing for Networks and Services, e-learning, Networked Virtual Environments and WWW Issues. He has extended professional experience in Design and Analysis of Networks, Protocols, Telematics and New Services. He has published more than 450 papers in various well-known refereed books, conferences and journals. He is a co-author of 9 books in Greek and editor of 2 in English. He has been member of editorial board for international journals and PC member and referee in various international journals and conferences. He has participated in numerous R&D projects.*

*Vaggelis Kapoulas obtained his Computer Engineering diploma from the Computer Science and Engineering Department, School of Engineering, University of Patras, Greece. He obtained his PhD from the same department. He is currently an R&D engineer, and Head of Research Unit 6: Networks Telematics and New Services, Computer Technology Institute and Press - Diophantus (CTI), Greece. His research interests include Networks, Telematics and Algorithms for Distributed Systems. He has extended professional experience in the Analysis and Design of Networks, Applications of Networks and Advanced Network Services, Telematic Applications, Open & Distance Learning and Tele-working. He has participated in numerous (more than 50) R&D projects in several national and EU (co)funded programmes. He has published more than 10 articles in scientific journals and more than 50 research papers in various well-known refereed conferences.*

*Georgios Kioumourtzis obtained his Diploma from the Hellenic Army Military Academy and graduated as Signal Officer in 1986. In 1996 he extended his studies in the Telecommunications School for Signal Officers. He also received two Master Degrees, one in Computer Science and the second in Systems Engineering from the Naval Postgraduate School CA, USA in 2005. In 2010 he received his PhD from the Computer Engineering and Informatics Department of Patras University (Greece). His research interests include Computer Networks, Simulations, Multimedia transmission, Wireless Ad Hoc Networks and Cross Layer Design. He has published more than 30 research papers and journals in well-known refereed conferences. He is also the author of a book for multimedia data transmission over best-effort networks. Since 2012 he is a research associate at the Center for Security Studies - KEMEA of the Hellenic Ministry of Citizen Protection.*

*Kostas Stamos received his Diploma, Master Degree and PhD from the Computer Engineering and Informatics Department at the University of Patras. His diploma thesis was on the subject of multicast video transmission supporting adaptive QoS, while his research subject for the PhD was the automated brokering of network resources and especially in conjunction with the IPv6 protocol. Since 1999 he works as a R&D Computer Engineer with Research Unit 6 of CTI, where he has participated in several R&D projects on IPv6, application streaming, QoS, automated circuit provisioning among others. He has taught at the Computer Engineering and Informatics Department at the University of Patras, at the Technological Educational Institute of Western Greece and at the Hellenic Open University. He has published 11 articles in Journals and 41 papers in well-known refereed conferences. He is also co-author of 2 technical books, several encyclopaedia articles and of a Global Grid Forum (GGF) standard document.*

*Nikolaos Stathopoulos entered the Computer Engineering and Informatics Department in 2008 and joined RU6 in 2013. He has obtained the Certificate of Proficiency in English of University of Michigan. He graduated from Computer Engineering and Informatics Department in 2014. Currently he is a postgraduate student in Computer Engineering and Informatics Department of University of Patras. Since 2014 he has been working as R&D Computer Engineer with Research Unit 6 of CTI, where he has participated in projects such as GN3plus and EduSAFE. His main interests are network programming, VPN technologies, android development, power management in wireless networks and web development.*

*Nick Tavoularis entered Computer Engineering and Informatics Department in 2007 and later joined ru6. He is interested in network programming, open source development, and qt programming.*