Power management for wireless adapters using multiple feedback metrics

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***Abstract*— The main focus of this work is the effort to minimize the power consumption on mobile devices such as notebooks, netbooks, tablets, tablets, smartphones, etc. by adjusting the transmission power of the wireless card, thus extending the battery life. In order to achieve that, we provide a mechanism (which we call Signal Adaptation Mechanism – SAM) that optimizes the power depending on the quality of the connection. This mechanism measures the quality of the transmission and adjusts the transmission power accordingly, by utilizing an expanded array of metrics along the Received Signal Strength Indicator (RSSI), for more accurate estimation. It also aims at easy implementation on various wireless adapters. In order to evaluate, fine-tune and improve the mechanism, a list of experiments has been performed. These experiments were conducted on a real (as opposed to simulated) ad-hoc network, where the nodes of the networks followed varying moving patterns.**

Keywords*— Signal Adaptation Mechanism; cross layer; power management; wireless; SNR; RSSI

I. INTRODUCTION

As internet access via mobile devices is becoming more and more popular, the energy consumed by using networking applications is increasing drastically. So, the development of mechanisms that adjust the power consumption to optimal levels is considered necessary [1]. For example the authors in [2] 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 [3] [4] [5] [6] [7] [8] [9]. For example, the author in [4] lists WiFi as the most power-consuming mode of an Android phone's modes. Furthermore, research in [3] shows that under specific benchmarks the WiFi adapter can exceed 700mW in power consumption. Similar results have also been verified by measurements on smartphones [10] including measurements by end users taken "in the wild" [7].

The IEEE 802.11 standard deals with this problem by defining two modes, active mode and power save mode. While in active mode, the network adapter is awake and can receive data at any time. Whenever the interface is idle, it switches to a low-power state. While in power save mode, the adapter cannot receive or send any data, so the energy consumption is reduced in that state. In [24], an on-demand power management technique is taking advantage of the above, to achieve 50% less energy consumption. In [23], 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.

The 802.11n standard has the same policy regarding power management. Additionally, it supports Multiple Input-Multiple Output (MIMO) technology, by using multiple radio chains. A mechanism focusing on radio chain management in order to reduce the power consumption has been proposed in [25], which improved energy efficiency by 32% in best case scenario, with a high data rate (50Mbps). However, MIMO is not supported by 802.11b/g networks, which are the most widespread standards, so we do not study the power consumption over 802.11n.

The main purpose of this paper 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. The work in this paper extends previous work in [11]. In the current work, 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.

Another approach to the problem is proposed in [12], 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 [11], 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.

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 [13]. 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 [14]. In [15], the authors propose a power management mechanism that is used for routing packets in ad hoc networks with power efficiency. In [16], the RSSI is one of the metrics used to improve routing efficiency in a wireless network. In [17], information transferred in a multi-hop path includes power information in order to guide the power management mechanism. The mechanism described in [18] adapts power levels according to information that is available locally. In [19], RSSI is used to estimate wireless channel state and feeds an algorithm that optimizes MAC layer parameters.

In [22], the authors verify that SNR is a good prediction tool for channel quality and propose solutions for avoiding poor results due to dependence of SNR values on hardware characteristics and interference effects. Their SNR-Guided Rate Adaptation (SGRA) scheme is also tested in a real environment.

In this paper, 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 [11] 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.

The rest of the paper is organized as follows. Section 2 presents the proposed architecture and section 3 provides the algorithmic details. Section 4 discusses the implementation on a real Linux system, and section 5 presents the experimentation and results obtained from this implementation. Finally section 6 concludes the paper and suggests future work.

II. ARCHITECTURE

A. 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.

$$EIRP = P_{tx} - L + G \quad (1)$$

In the above equation, 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:

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

Equivalently:

$$PathLoss = P_{tx} + G - P_{Rx} \quad (2)$$

Each peer has to know the Received Signal Strength of the packets it sends, so that it becomes aware of its 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.

B. 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, bit error rate (BER) is directly affected by the value of SNR. If the value of SNR is relatively low, for example 10dB, 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 [20], these methods are proposed for the distance measurement between 2 nodes, but only the exploitation of RSSI is an efficient method. However, [21] 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 25dB. In this case, the quality level of the link between two nodes is fair and a high bit-rate is achieved. As shown in [22] 25dB is a value that allows for high frame delivery ration (FDR) for various transmission rates. For the transmission rates used in the experiments a value as low as 15dB 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 (2) as:

$$P_{Rx} = P_{tx} + G - PathLoss \quad (3)$$

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

$$\mathrm{SNR_{dB}} = \mathrm{P_{Rx_{dBm}}} - \mathrm{N} \quad (4)$$

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:

$$\mathrm{P_{Rx_{dBm}}} = 25\mathrm{dBm} + \mathrm{N} \quad (5)$$

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 if the SNR is above the threshold, and consequently the signal is corrupted. Moreover, we can extract from (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. This is in line with [22] where 30dB are enough for any transmission speed. Finally, the calculation of transmission power is:

$$P_{Rx_{dBm}} = 30dBm + N \quad (6)$$

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

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

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

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

C. *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.

III. THE MECHANISM

In this section, we present the algorithm that describes the mechanism that is discussed above.

The whole process is depicted in Fig. 1.

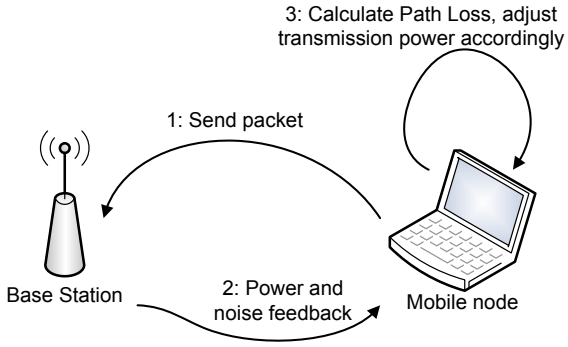

Fig. 1. The main steps in the mechanism

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.

Below, the algorithm is presented in form of pseudocode:

```
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);
   }
```

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 25dB 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 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 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 Fig. 2.

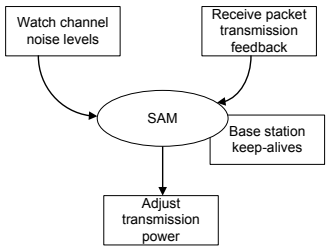

Fig. 2. SAM structure

IV. Implementation

This 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.

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).

V. Experiments and Results

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 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. Fig. 3 and Fig. 4 below, show the results of this experiment.

SNR	SAM	Without SAM
position 1	33.61	42.72
position 2	29.45	36.20
position 3	29.64	28.58

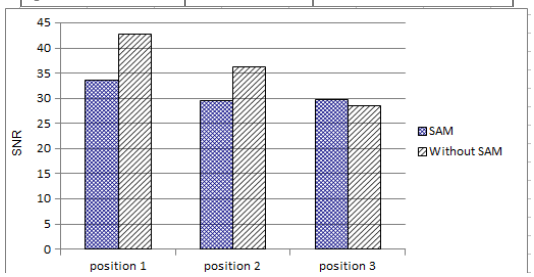

Fig. 3. Results of the first set of experiments (SNR)

Tx Power	SAM	Without SAM
position 1	5.00	20.00
position 2	12.30	20.00
position 3	16.86	20.00

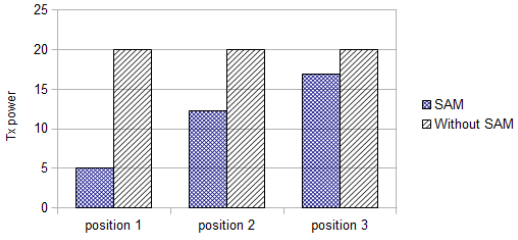

Fig. 4. Results of the first set of experiments (Tx power)

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 the table, we can see that the average SNR is closer to the preferred value of 30 dBm when using the mechanism. 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. The graph Fig. 5 below shows the results of the experiment versus time.

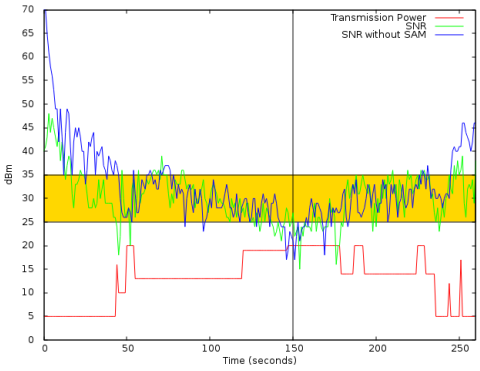

Fig. 5. Results of the second experiment

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. Fig. 6 below shows this pattern.

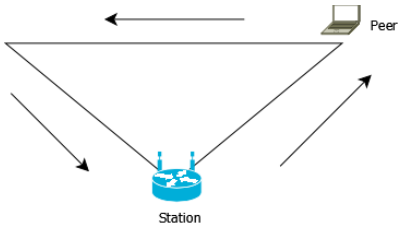

Fig. 6. Setup of the third experiment

The node moves along the arrows drawn in the figure. The results of the experiment are shown in Fig. 7, below.

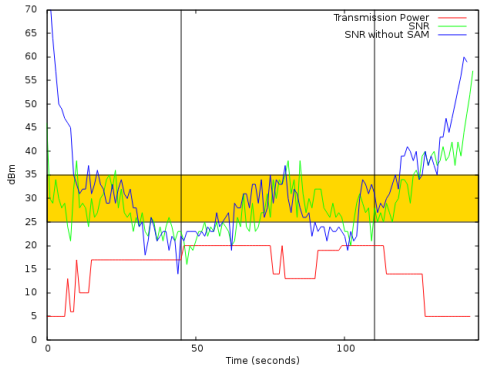

Fig. 7. Results of the third experiment

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 on 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 in relation to the reduction achieved.

VI. Conclusions and Future Work

From the experiments conducted, 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.

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.

We also 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 [22], to identify the presence of interference, and adapt the transmission power (rather that the rate in [22]), accordingly.

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