2008-06-01

Practical Issues of Power Control in IEEE 802.11 Wireless Devices

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Recommended Citation

Kowalik, K. Bykowski, M., Keegan, B. & Davis, M. (2008) Practical issues of power control in IEEE 802.11 wireless devices. *IEEE International Conference on Telecommunications* (ICT 2008), St. Petersburg, June, 2008.

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Practical Issues of Power Control in IEEE 802.11 Wireless Devices

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***Abstract*— Power control techniques for IEEE 802.11 wireless networks have already gained much attention. Such techniques are particularly attractive because they can improve various aspects of wireless network operation such as interference mitigation, spatial reuse in dense wireless deployments, topology control, and link quality enhancement. However, until recently implementing such advanced power control using off-the-shelf wireless devices was not considered possible. For example, Abdesslem et al. [1] stated that "many novel power control solutions cannot be efficiently implemented over existing IEEE 802.11 cards". However, in this paper we demonstrate that power control is now feasible and can be implemented in current IEEE 802.11 cards with per-packet granularity and low power switching latency.**

I. INTRODUCTION

Interference has been identified as a key cause of performance degradation in Wireless Mesh Networks (WMNs) [2], [3]. WMNs are a type of radio-based network system which require minimal configuration and infrastructure and which allow for a quick and inexpensive deployment of wireless local area networks (WLANs) [4]. Transmit power control is one of the methods which allows for interference mitigation and spatial reuse through per-link power control.

Per-link power control allows a network node to transmit packets to its neighbours at different power levels. Data transfers to close neighbours may be performed at low transmission power, thereby minimising the interference with remote nodes. While the communication with remote neighbours may be improved by using a higher transmission power, i.e. by providing a stronger signal at the receiver, it has been shown by Muqattash et al [5] that a power controlled MAC (POWMAC) protocol can significantly improve network throughput.

However, increasing the transmission power for weak links also has a negative effect of producing increased interference. There are other factors which can adversely impact on the benefit of employing transmit power control. For example, Broustis et al. [6] have observed that when power control is combined with virtual carrier sensing (RTS/CTS messages) the performance often degrades.

Transmit Power Control (TPC) mechanisms when implemented in WMNs can be used to:

- minimise interference with other nodes (and thus increasing spatial reuse) as implemented in POWMAC [5] or in [7];
- improve the quality of wireless links (as implemented in [8]);
- reduce the energy consumption [9];
- control the network topology [10];
- reduce interference with satellites and radar operating in the 5 GHz frequency band (as required by the IEEE 802.11h Standard [11]);
- ensure good coverage (as implemented by some access point manufacturers).

Some of these objectives can be realised by modifying only a single layer, such as the POWMAC [5]. However, in general power control needs to be aware of the operation at multiple layers and is more accurately a cross-layer optimisation problem. Moreover, the majority of the power control techniques proposed require power control with per-packet level granularity and with low latency.

Therefore, in this paper we evaluate a number of WLAN cards based upon Atheros chipsets to establish if they allow for such a fine power control. The combination of Atheros chipsets with the MadWifi (Multiband Atheros Driver for Wi-Fi) drivers is currently the most popular experimental test bed setup used by the wireless research community. Moreover, the current version (ver 0.9.3) of the MadWifi driver supports a "TPC" (Transmit Power Control) parameter that enables per-packet transmit power control. In this paper we investigate if the "TPC" feature allows for high-granularity and low-latency power control.

II. RELATED WORK

Recently Abdesslem et al. [1] expressed an opinion that was sceptical about the power control features of the existing WLAN cards. They stated that "many novel power control solutions cannot be efficiently implemented over existing IEEE 802.11 cards". The reasons being that the "number of existing wireless devices does not fulfil the requirements for power control" and that the power level cannot be easily implemented on a per-packet basis.

Earlier Kawadia and Kumar [12] observed another problem that the process of changing the power level incurs a significant latency. They stated that "experimental performance evaluations were anyway not possible for any of the protocols due to hardware limitations, which are essentially designed for changing power levels at start-up.” [12]. They have observed the power switching latency to be around 100ms.

However, more recently Navda et al. [7] have reported on a simple experiment which demonstrates that per-client power control has become feasible. In this paper we conduct a detailed evaluation of the feasibility of power control in current IEEE 802.11 devices.

III. CROSS-LAYER POWER CONTROL

Power control can be used to enhance the performance at multiple layers of the network stack. For example, TPC can be combined with routing to control network topology, or it can be combined with the MAC to minimise interference. Kawadia and Kumar present an comprehensive discussion about principles of such a cross layer design of power control in [12] .

Here, we present a simple and straight forward means to achieve cross-layer control of transmission power on a per-packet basis. This method has been implemented by Kohler in the Click Modular Router Software [13], and here we describe how it can be used for cross-layer power control.

In Click there is a limited amount of status information in the form of “packet annotations” associated with each packet. These annotations are sent with each packet between the modules are responsible for performing functions of separate communication layers. Thus, if the transmission power is used as one of such annotations, then power control can become available across multiple network layers. Moreover, when a packet is ready to be sent the information about transmission power can be encapsulated into radiotap or Atheros descriptors headers (i.e. encapsulation and decapsulation modules are all provided by Click [13]) and injected into the MadWifi drivers operating in the monitor mode. The wireless card then transmits the frame with the output power as specified in radiotap/Atheros descriptors headers.

Such an architecture allows for convenient access to power information at multiple layers. The transmission power is specified on per-packet basis, and thus allows for high-granularity control. Moreover, the use of radiotap/Atheros descriptors headers not only allows for control of the output power but also of the sending rate, antenna, number of retries after failure, etc.

IV. MEASUREMENT TOOLS

To investigate the feasibility of power control we have developed a number of new Click [13] modules which allow us to broadcast custom made packets which include information about transmission power. The format of these packets is shown in Figure 1 and is intended to allow the receiver to discover the power level that the packet was send with and also if any of the packets were lost. Moreover, we have developed other modules which are used to parse and log the RSSI/power information to a file. The module which generates the packets can produce various transmission power patterns, such as a constant power level, square wave (which corresponds to switching power between two power levels), or it can slowly increase transmission power in steps of 0.5dBm to generate saw-tooth like pattern.

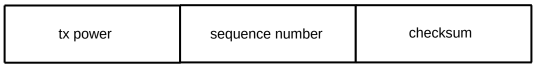

Fig. 1. Custom packet format for transmission power testing

To perform the experimental tests we used three WLAN nodes located about 2 meters away from each other. The nodes were based around the Soekris net4521 platform. Later, we repeated all the tests using three standard PCs. The experiments were performed indoors in a single room, unfortunately we could not completely isolate the tested network from external sources of interference. All three nodes were running Linux operating systems (the Pebble distribution in the case of the net4521 based nodes and Fedora Core 6 in the case of the PCs) and were operating in the monitor mode to allow for packet injection, and Click [13] to generate 802.11 frames and also to log information about the transmitted power and received RSSI values.

In order to enable the TPC feature of MadWifi drivers one needs to compile it with `COPTS+= -DATH_CAP_TPC=1` and pass the `tpc=1` parameter to `insmod ath_pci`.

By setting the MadWifi drivers to operate in the monitor mode and to return packets with atheros descriptors (or radiotap) headers we were able to obtain RSSI values for individual frames. Thus the RSSI values were not averaged using EWMA (Exponentially Weighted Moving Average) filters which are normally applied to the measurements provided by the `iwconfig` or `iwlist` commands.

Moreover, the transmission rate was fixed for all the experiments at 11Mbps and the antenna diversity was also switched off. All the experiments were repeated several times and with different node locations and orientations.

We have performed our tests for three cardbus wireless cards with Atheros 5212 chipset, namely the Cisco Aironet CB21AG, 3Com Wireless 3CRPAG175, Netgear WAG511. We also tested one PCI card with the Atheros AR5002G chipset (which incorporates 5212) namely the Netgear WG311T.

V. GRANULARITY OF POWER CONTROL

The MadWifi drivers allows one to specify the transmission power in half dBm units. The MadWifi drivers provides the function `ath_hal_getmaxtxpow` which can be used to obtain the maximum value of the transmit power provided by the device. We queried all the wireless cards used in the test setup and found that that they all used a value of 36 which corresponds to a maximum transmission power of 18dBm. Thus the transmission power could be specified in the range 0 dBm to 18 dBm in steps of 0.5 dBm.

To investigate the feasibility of per-packet power control for each of the four WLAN cards we conducted the following experiment. One node was configured to act as a transmitter of broadcast frames, while the other two nodes were used to capture the broadcasts and to log the RSSI values with the corresponding transmission power values. The transmitter was broadcasting the custom packets described earlier and used an inter-packet interval of 10ms. The transmission power was increased by 0.5dBm for every packet until the maximum value was reached. After reaching the maximum transmission power level of 18dBm the procedure was repeated starting from 0dBm. In this way we generated a saw-tooth like power pattern. In Figure 2 we present the average values of the received power calculated over a thousand periods of the power wave.

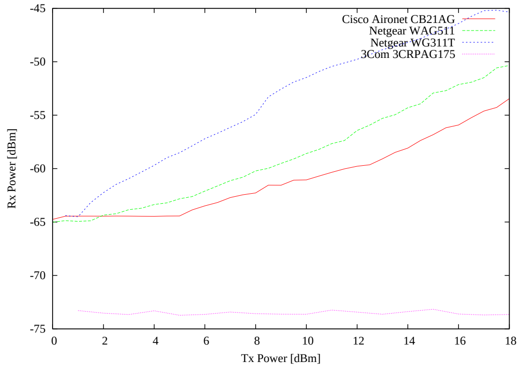

Fig. 2. Average received RSSI values expressed in dBm computed for four different wireless cards

It can be observed here that all three cards, namely Cisco Aironet CB21AG, Netgear WAG511, and Netgear WG311T were able to control the transmission power on a per-packet level. All three of them exhibited a gradual increase in the output power in steps of 0.5 dBm. The Cisco Aironet however did not show any power increase until the specified output power was above 5dBm. Only one card the 3Com Wireless 3CRPAG175 was not able to control the power on per-packet basis even though it was based on the same Atheros chipset as the other cards.

VI. Latency of power switching

The other important factor which influences the performance of per-packet power control techniques is latency in switching the output power. Kawadia and Kumar [12] have measured the power switching latency in an experiment and it was found to be as high as 100ms. Here, we wanted to investigate if the combination of the current Atheros chipsets and MadWifi drivers would allow for any reduction in this latency.

To determine the switching latency of the three cards (Cisco Aironet CB21AG, Netgear WAG511, and Netgear WG311T) which allow for power control, we conducted the following experiment. We configured one node to act as a transmitter of broadcast frames, while the other two nodes were capturing the broadcasts and logging the RSSI values with the corresponding transmission power values. The transmitter was broadcasting custom made packets with an inter-packet interval time of 1ms. The duration of a 802.11 frame (which included the custom packet and a transmission rate of 11Mbps) was about 800µs. Thus, broadcasting these custom packets every 1ms was the fastest test which could be run. The transmitter was configured to send the first 100 packets with 0dBm output power, and then the next 100 packets with 18dBm output power. This resulted in a square wave power pattern, as shown in Figure 3 with the period of 200 packets. We also tested different periods values, as long as 2000 packets and as short as 2 packets. However, the results remained the same.

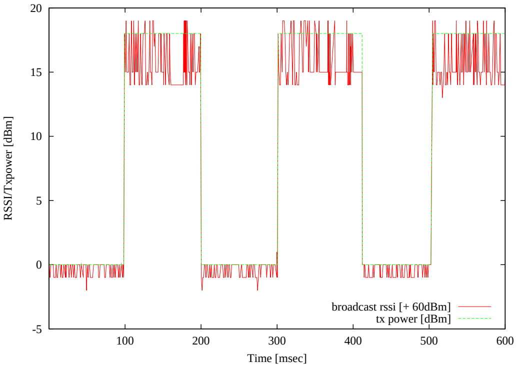

Fig. 3. Square power wave of the requested transmitted power and the received RSSI values expressed in dBm

Figure 4 presents the received signal strength values averaged over a thousand periods of the square wave power pattern. The received signal strength clearly shows a sharp step change between the power levels which would indicate that the latency associated with changing the transmission power is negligible.

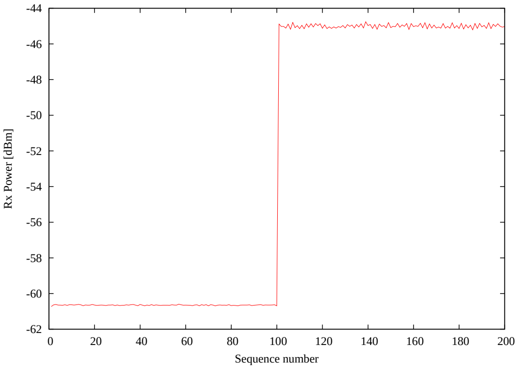

Fig. 4. Average received RSSI values expressed in dBm computed for power square wave over 1000 periods

Similar results were also observed (but not presented here) when the transmission power was altered more frequently, i.e. at every packet. Also, all three WLAN exhibited the same performance. This suggests that the transmission power can be changed with minimal latency.

VII. Anomalous Power Control Observed

The experimental results presented so far, support out claim that power control can be implemented with current IEEE 802.11 cards with per-packet granularity and low latency.

However, the transmission power can also be altered by other wireless link adaptation mechanisms. Thus to achieve complete control over the transmission power such mechanisms must be disabled. For example Giustiniano et al. [14] has observed that the the received power can often differ from the expected value or can even fluctuate. They have found that the antenna diversity mechanism (i.e. that results in switching between the two antennas and is a common feature in most off-the-shelf WLAN devices) to be the cause. Giustiniano et al. [14] have reported the following:

- the received power of broadcast transmissions can oscillate because of the antenna diversity mechanism;
- Atheros based cards (with antenna diversity enabled) perform antenna switching upon loss of two successive packets;
- Intel based cards (with antenna diversity enabled) perform antenna switching when the received power of a beacon frame changes significantly from its previous value;
- Atheros based cards change tx antenna for data retransmission attempts.

Therefore, in our experiments the antenna diversity was always switched off. The rate selection algorithms were also disabled as well as the virtual carrier sensing (RTS/CTS) mechanism. Thus, we sought to disable all the diversity/adaptation mechanisms which could alter the transmitted power. However, we have observed that periodically, and only for a single frame, the received signal strength drops by about 12dB compared to the signal strength of other frames. Figure 5 demonstrates that the drops of the transmission power for data frames occur every second. These drops occur just for a single packet, and other packets before and after this packet were not affected. Then after a few minutes following the start of the experiment the power drops started to occur every 30 seconds.

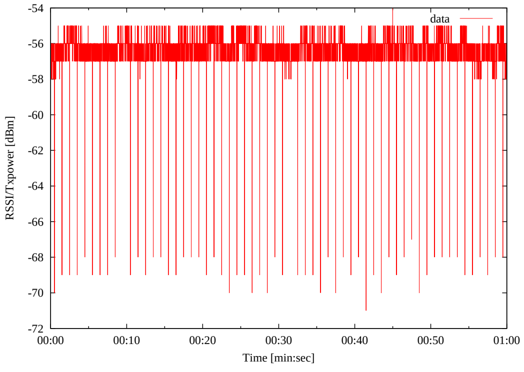

Fig. 5. Drops of the transmission power caused by calibration

Similar power drops were also observed by Glenn Judd and Peter Steenkiste [15], however they suggested that these were “bogus RSSI values” reported by the receivers. However, we have observed these anomalous power drops are observed simultaneously on two or three independent receivers and thus cannot be explained as bogus values.

After detailed analysis of the MadWifi source code we have established that these power drops were caused by the calibration procedure which was invoking a peak-to-average power detection (PAPD) mechanism. PAPD causes the wireless card to transmit the next packet with the lowest possible power, while monitoring the transmission power in order to compute gain. Consequently the next packet which was sent just after the calibration procedure is essentially a “probe” packet. Consequently, any receiver would observe it with a much smaller power compared to the other packets in a stream.

We have already proposed a patch to the MadWifi community to correct this issue in the next release of the MadWifi driver. Thus we hope that in future, as a result of our contribution, other researchers will experience less difficulties in implementing efficient power control mechanisms.

VIII. VENDOR INFORMATION

We have also made a number of interesting observations when studying the technical specifications of 802.11 wireless cards supplied by the vendors. We have realised that most vendors specify that the transmission power of their wireless cards is fixed on some predefined value. We have even checked the available vendor information of all the cards with Atheros chipsets listed on `http://atheros.rapla.net/`. From this study we have found that only Cisco claims that it manufacturers 802.11 wireless cards which allow for multiple transmission power levels. For other vendors the most common practise is to specify that the transmit output power is fixed at a value around 16 dBm, or that it features two output power levels, one for 802.11a mode and the other for 802.11b/g mode.

From our experiments we have discovered that some of these cards allow for power control even though their manufacturers state that the output power is fixed. Therefore, if one wishes to implement power control mechanism, one needs to test for oneself if the card allows for power control, as such information may be not provided by the equipment vendor.

IX. CONCLUSIONS

In this paper we have investigated the feasibility of the transmission power control mechanism provided by the combination of Atheros chipsets with the MadWifi (Multiband Atheros Driver for Wi-Fi) drivers. We have established that per-packet power control can be implemented with high granularity of 0.5dBm and with low switching latency (less than 1 msec). Thus, our evaluation shows that even sophisticated power control techniques can be implemented with such a hardware/driver combination.

However, we have also demonstrated that even though the cards allow for per-packet power control they may also exhibit some anomalous fluctuations in the transmitted power. These could be caused by some adaptation/diversity/calibration mechanisms. Moreover, it may be difficult to be disable them, sometimes requiring researchers to modify the sources of wireless divers. Because such mechanisms are often undocumented, each card need to be carefully examined for similar phenomenon before implementing power control mechanisms. Also, we have presented a simple mechanism which allows for cross-layer power control which can be implemented in Click Modular Router Software.

ACKNOWLEDGEMENT

The authors acknowledge the support of Enterprise Ireland (under the Commercialisation Fund 2007) and Science Foundation Ireland (under the grant 03/IN3/I396). We would also like to thank Michael Taylor for his patience and most valuable help with implementing the MadWifi patch. Moreover, we would like to thank Domenico Giustiniano for a most valuable discussion around our results.

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