2007－ＡＶＭ－57（13）
2007／7／20

Wireless Interface Monitoring and Link Status Detection in Cognitive Radio Networks

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Abstract Cognitive Radio Networks are being developed to provide high speed and spectrum efficient wireless access for mobile users. These networks integrate multi hop access in combination with concurrent use of multiple wireless access interfaces. For efficient use of radio resources, route decisions in Cognitive Radio Networks are based on wireless interface and link status information which need to be monitored at each single wireless interface separately. We have designed and implemented a Wireless Monitor which monitors multiple wireless interfaces simultaneously. The Wireless Monitor measures 7 wireless parameters which are combined for link status detection inside an interface status monitor. In this paper we report wireless monitor results which have been obtained when multiple Wi-Fi interfaces are bonded, showing the effectiveness of the monitored parameters for interface and link status detection in Cognitive Radio Networks.

Keywords Wireless Monitor, Wireless Link Parameter, Link Status, Multiple Interfaces, Wi-Fi

1. Introduction

Cognitive Radio Networks use cognitive monitoring functions to provide high speed and an efficient use of wireless resources. Cognition includes receiving information, acting, and learning functions. These cognitive functions are expected to be useful in future heterogeneous wireless systems, which will consist of different types of wireless systems, infrastructure based, multi hop ad hoc and multiple interfaces, sharing same spectrum [1].

Cognitive Radio Networks need to identify the surrounding wireless environment and wireless resource usage for decision making. Route, path and interface selection on each mobile terminal and access points have to be decided based on multiple wireless characteristics which change in time [2]. In order to determine the status of interface and wireless link, it is necessary to design a wireless monitor system which can do frequent monitoring of all wireless interfaces which are involved in the communication.

We have designed and implemented a prototype of a Wireless Monitor which provides the monitoring of multiple wireless interfaces simultaneously. The Wireless Monitor can monitor 7 wireless parameters which can be used to identify the wireless characteristic of each interface or link which is involved in communications. The Wireless Monitor also includes a decision module which uses the current values of the wireless parameters to decide the interface status. Links which have good quality (classified as good link) can be aggregated into a logical link to improve the throughput. Links which shows bad quality (classified as bad link) can be identified by a high number of retries or low signal strength.

In this paper we will show results from simultaneous monitoring of multiple wireless parameters on two Wi-Fi interfaces during the transmission of TCP data via two bonded interfaces [3].

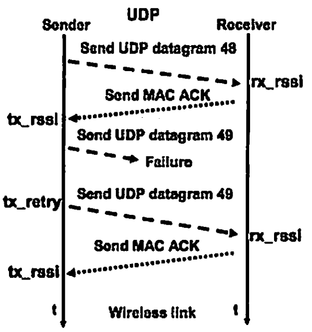

Figure 1: UDP transmission and wireless monitoring

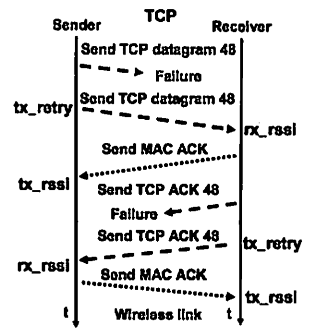

Figure 2: TCP transmission and wireless monitoring

2. Wireless Monitor

We developed a Wireless Monitor which is a kernel space Linux implementation (kernel 2.6.9) and passively monitors 7 different wireless parameters, namely tx_rssi, rx_rssi, tx_rate, rx_rate, tx_retry, tx_success, and tx_failure. Tx_rssi and rx_rssi are both values of the received signal strength (RSSI). Tx_rate and rx_rate are the sending rates at the Wi-Fi interfaces. Tx_success and Tx_failure are values which show the number of packets which were transmitted successfully or counted as failures due to transmission errors. The Wireless Monitor in this paper gets the parameter directly from the Madwifi [4] driver (version 0.9.2), which has been extended to output parameters for each interface and each wireless neighbor. Parameters can be monitored in different intervals started from 10ms. All three wireless modes, master, managed, ad hoc are supported and multiple nodes can be monitored separately, including a targeting function.

The Wireless Monitor includes a decision module to decide the up/down status of each Wi-Fi interface based on the wireless parameters, such as RSSI, using a decision function. Hysteresis in the decision criteria is included to avoid too frequent changes of decisions whether a link is good or bad. The hysteresis can be easily implemented into the decision module and different thresholds can be tested.

In this paper we are going to show the monitoring of rx_rssi, tx_rssi, and tx_retry parameter. We will also show how these values perform in a real test setup while moving in-door over a distance of 100m.

3. Wireless Monitoring of UDP and TCP Streams

The RSSI (received signal strength indicator) is widely used as an indicator of link quality. The RSSI can decrease due to increased distance or due to increased fading. Since the correspondence between RSSI and packet loss or delay is not clear in some situations, status decision is difficult based just on the signal strength. However, the RSSI is one important indicator of link quality.

In free-space, received signal power P_{rx} is a function of the signal power at the sender P_{tx}, the distance d and the wave length λ (Frii's space model) [5]:

$$P_{rx}(d) = p_{tx} \cdot \left(\frac{\lambda}{4\pi d} \right)^2 \quad (1)$$

However in practice, multipath interference, absorbtion and other factures affect the radio transmission in a practical wireless environment. As a simple model to match the measured RSSI in our tests we used the log-normal-shadowing model [5] as follows:

$$RSSI(d) = \left(P_{tx} - P_l(d_o) - 10\eta \log_{10} \cdot \frac{d}{d_o} + X_\sigma \right) \quad (2)$$

P_{tx} was measured as the max measured signal power at 1m distance between sender and receiver. The path loss factor P_l was set to 10dB in correspondence to the measured reference distance d_O. We set the path loss exponent η to 2 for line-of-sight (LOS) in in-door environments and the Gaussian random variable X_σ to 1.

The Wireless Monitor directly measures the Madwifi parameters rx_rssi and tx_rssi which are related to the received signal strength (RSSI). The parameter rx_rssi is the received signal power of incoming data packets from neighbors.

The parameter tx_rssi shows the RSSI from neighbors same as the rx_rssi parameter, but the difference is that tx_rssi is only related to receive MAC acknowledgements (named as MAC ACKs). Based on the IEEE 802.11b standard each uni-cast packet which successfully received by the receiver has to be acknowledged by the receiver sending one acknowledge packet to the sender (positive acknowledgement). MAC ACKs are sent as acknowledge on the MAC level to inform the sender of successful transmission. However received MAC ACKs do not show whether data are corrupted or out-of-order identified by higher layer transport protocols such as TCP.

Fig. 1 and Fig. 2 show the sequence chart of rx_rssi and tx_rssi in detail for two different data streams, UDP and TCP. In Fig. 1 the sequence chart shows an UDP transmission between sender and receiver. The UDP traffic starts at the sender sending UDP datagram 48. When this datagram is received the rx_rssi can be measured at the receiver for incoming UDP datagram 48. The receiver sends a MAC ACK to the sender indicating that the MAC transmission was successful. The sender receives the MAC ACK and tx_rssi can be measured.

After successful transmission of the UDP datagram 48 in Fig. 1 the sender transmits the next UDP datagram 49. Due to a failure (wireless link disruption, etc.) the transmission was not successful. No MAC ACK is send (or cannot received at the sender) which indicates at the sender (timeout) that the packet needs to be retransmitted. Retransmissions of datagram can be monitored at the sender and the tx_retry parameter shows the number of retransmissions. After successful retransmission of datagram 49 the receiver monitors the new rx_rssi related to the new datagram 49 and sends the MAC ACK to the sender. The new MAC ACK is received and a new tx_rssi value is monitored at the sender.

The result of this UDP transmission example is that the UDP sender monitors tx_rssi and tx_retry only. The UDP receiver monitors rx_rssi only. This is valid for a single UDP transmission in one direction between sender and receiver. In the case of an error free transmission no tx_retry occurs at the sender.

Fig. 2 shows an example of a TCP transmission between sender and receiver. Both, sender and receiver are able to monitor rx_rssi, tx_rssi and tx_retry. This is due to the fact that TCP is a reliable transmission which identifies out-of-order packets or corrupted transmission. TCP sends cumulative acknowledgements to inform the sender whether the transmission was successful or not.

Fig. 2 shows the TCP communication between sender and receiver in detail. The sender starts with the TCP datagram transmission number 48. Due to a failure (wireless link disruption, etc.) the packet was not received at the receiver side. After timeout the sender starts to retransmit datagram 48. The retransmission on the MAC level is monitored by tx_retry at the sender. The receiver sends the MAC ACK to the sender after it received the datagram. The sender receives the MAC ACK and monitors the tx_rssi of the MAC ACK.

To acknowledge successful TCP transmission the receiver starts to transmit the TCP acknowledge (named as TCP ACK) to the sender. Due to a failure the TCP ACK cannot be received at the sender side. The receiver starts to retransmit the TCP ACK until the MAC ACK was received. If the sender received the TCP ACK it monitors the rx_rssi of the TCP ACK 48. A successful transmission will be indicated by the MAC ACK received at the receiver which monitors the tx_rssi.

The result of this TCP transmission is that TCP sender and TCP receiver monitor rx_rssi, tx_rssi and tx_retry. In the case of an error free transmission no tx_retry occurs.

The result of an application based wireless monitoring is that different applications, such as UDP and TCP lead into different combination of wireless parameters.

4. Link Status Detection

A wireless link can be classified as a good link when there are few errors or small delay in transmission at maximum transmission rate. In single user situations transmission errors can be due to fading or link disruption while moving. Fading and link disruption may need to be handled differently, because fading may not show decreased throughput whereas link disruption it definitely does. Decreased RSSI and increased retries may identify a bad link performance. In this paper we report the use of monitoring of RSSI to detect bad links were RSSI value goes below a given threshold and redirect transmissions from the bad links to the good links.

5. Test Scenario

We tested the performance of the Wireless Monitor during the transmission of a UDP or TCP stream over two bonded interfaces. The test system is setup for ad hoc communication between two PCs which are setup on trolleys. Fig. 3 shows the setup of two wireless links in ad hoc mode between PC1 and PC2 using ath0

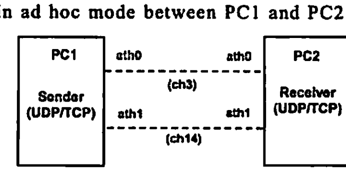

Figure 3: Wireless setup

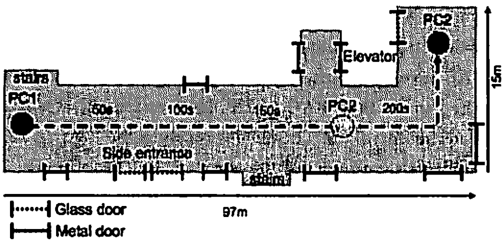

Figure 4: Measurement track layout

and ath1 as one virtual bonded interface [3]. We used widely separated channels, Wi-Fi channel 3 and 14 (IEEE 802.11b) for the measurement.

We used the ground floor in the ATR building to test performance in a real environment. The layout of the test track is shown in Fig. 4. The figure shows the distance which was measured between PC1 (left hand side) and PC2 (right hand side). Numerous structural features affected the radio transmission such as metal doors or stairs, resulting in non-simple interference features, as can be seen in the following results.

6. Measurement Results

6.1. UDP Traffic Scenario

During the UDP session we conducted measurements for rx_rssi at the receiver and tx_rssi and tx_retry at the sender. Other wireless parameters cannot be monitored at the sender and receiver as described in section 3.

Due to page limitations we do not discuss the results for UDP in detail. Instead, we note that the results for UDP measurement are consistent with the results for TCP, given the difference in monitor parameters mentioned in section 3.

6.2. TCP Traffic Scenario

For the TCP session we setup a TCP sender on PC1 (stationary) and a TCP receiver on PC2 (mobile). We moved with PC2 over the distance described in Fig. 4 while the Iperf TCP flow was sending via two bonded interfaces, ath0 and ath1.

In the near distance we can observe max throughput at 10 Mbps while the RSSI shows the highest value. In Fig. 5 top graph the RSSI is shown for min, max, and average value of rx_rssi at ath0. Due to the movement of PC 2 (increased distance) up to 100 m within 200s, the rx_rssi shows expected reduction. Note the characteristic shape of the log-normal shadowing curve in the following RSSI graphs. We can observe the same characteristic at ath1 in the RSSI graph below (Fig. 5). In this case, the rx_rssi (max) threshold for a bad-link is set at 0, so that we were able to monitor over the entire distance until the interfaces shut down due to loss of connectivity at around 100m.

Fig. 5 also shows the tx_retry values for both interfaces. It can be clearly observed that regions of strong fading exists which show significant increase of retries. The region around 50m shows the highest fading. This is where the side entrance of the building is located with glass doors. Beyond 100m the measured value remains with a low constant value due to the link disruption after moving the trolley behind the corner. Without link connection no traffic occurs and no values can be measured. In this situation, the Wireless Monitor repeatedly outputs the last recorded values with a constant system time (jiffies).

Fig. 6 shows the tx_rssi for ath0 and ath1. We can observe that both graphs show similar radio characteristic as rx_rssi. We can observe a drop in the received signal strength at 50m. Fig. 6 also shows the tx_count value showing the number of failures for each interface. In the region with the highest number of retries at 60m (Fig.5), and at the end of the measurement range at 100m, we can observe increased failures (Fig. 6, failure counter).

The bottom graph in Fig. 6 shows the throughput of the two bonded interfaces starting at 10 Mbps and significant drops in fading areas and at the end of the measurement range. High fluctuations in throughput performance are due to the retries which increase the transmission time and forces TCP to reduce the sending rate.

In Fig. 7 we can observe the behavior of the receiver station (PC2). The figure shows the correlation of ath0 and ath1 at both PCs. The graphs show the correlation for rx_rssi, tx_rssi, tx_retry, and tx_failure. It shows that there is a significant correlation between the interfaces. This result can be expected since both interfaces are located close together and oriented in the same way.

The result of the comparison of the interface correlation at PC1 and PC2 shows that both PCs are monitoring a similar radio condition (symmetric channel). At the end of the transmission at 90m the correlation decreases due to the different status of the interfaces.

Fig. 8 shows the link-up status during the movement of PC2 using different rx_rssi (max) thresholds 0, 10, 20, 30, 40 and 50. The graph shows decreased link-up distance due to the RSSI threshold being reached earlier. For rx_rssi(max)=30 the graph in Fig. 8 shows a difference between the interfaces on each PC which can be explained through the difference in fading properties in the region

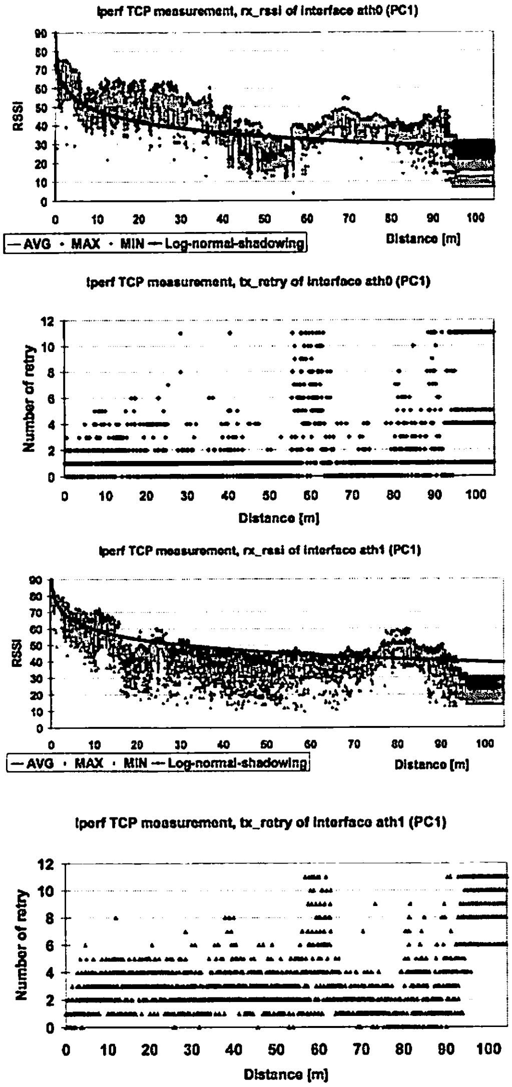

Figure 5: Wireless monitor result for TCP session. Graph shows rx_rssi at ath0 and ath1 and number of retries (tx_retry) at PC1 (sender).

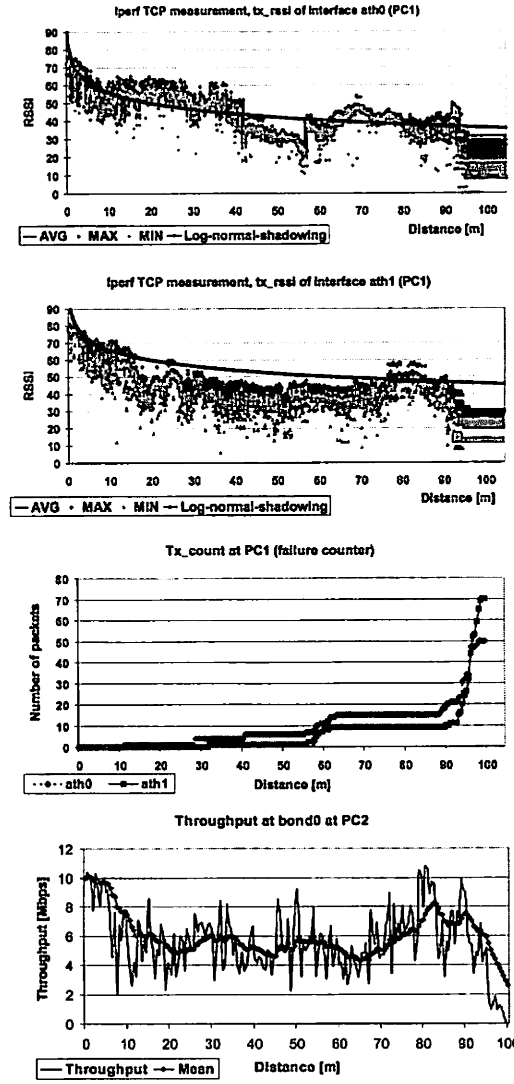

Figure 6: Wireless monitor result for TCP session. Graph shows tx_rssi at ath0 and ath1, tx_count value (failure) and the throughput performance of the bonded interfaces ath0 and ath1 at PC1 (sender).

between 40m and 50m. The difference is also evident in the reduced correlation of rx_rssi in Fig. 7.

The correlation between the data is mainly due to the same physical direction of the two wireless cards. The distance between the cards is around 3cm, while external antennas were used. The distance between the antennas was around 50cm. If both wireless channels show the same characteristic we can expect a strong correlation.

7. Conclusion

Cognitive Radio Networks need to identify the surrounding wireless environment for efficient path decisions which make maximum efficient use of the available wireless resources. We presented a Wireless Monitor which simultaneously measures 7 wireless parameters at multiple wireless interfaces. We discussed the monitoring results obtained when a single TCP stream

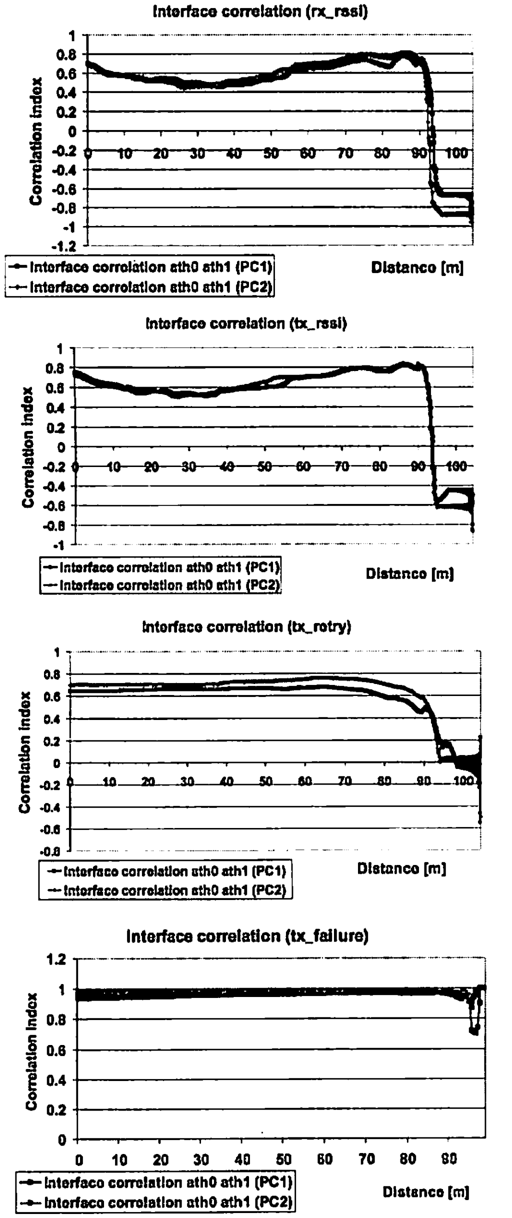

Figure 7: Wireless monitor result for TCP session. Graph shows correlation for rx_rssi, tx_rssi, tx_retry, and tx_failure at ath0 and ath1 at PC1 and PC2.

was split over two aggregated wireless links using interface bonding. It was shown that a significant correlation between the monitored information exists when Wi-Fi interfaces and antennas are close on both

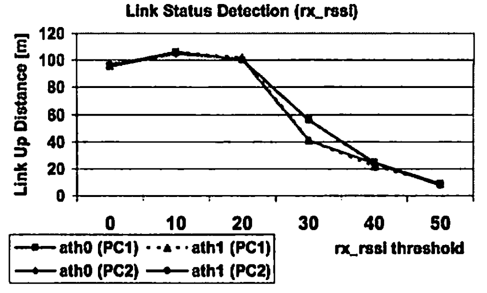

Figure 8: Link up distance during a movement over 100m and increased rx_rssi threshold.

sender and receiver terminals. An automatic link-status detection function was also introduced, with an example using RSSI threshold.

8. Future Work

Future work will be based on the evaluation of the link status decision function using a combination of multiple wireless parameters, such as tx_rssi and tx_retry, and the integration of the wireless interface monitoring link status detection in our experimental Cognitive Radio Network system.

9. Acknowledgment

This research was performed under contract for the Ministry of Internal Affairs and Communications.

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