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An Investigation of the Correlation between Passive Monitoring and Active Probing Techniques Used in WLAN Mesh Networks

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Abstract

In recent years, Wireless Mesh Networks (WMNs) have emerged as a promising solution to provide low cost access networks that extend Internet access and other networking services. Mesh routers form the backbone connectivity through cooperative routing in an often unstable wireless medium. Therefore, the techniques used to monitor and manage the performance of the wireless network are expected to play a significant role in providing the necessary performance metrics to help optimize the link performance in WMNs. This paper presents an assessment of the correlation between passive monitoring and active probing techniques used for link performance measurement in WMNs. The study reveals that by combining multiple performance metrics obtained by using passive monitoring, a good correlation with active probing can be achieved. We then analyze the reaction of the passive monitoring and active probing techniques to variations in the network load. This study shows that these two performance measurement techniques can be used interchangeably.

Keywords: Wireless mesh networks, performance measurement, active probing, passive monitoring.

1 Introduction

The increasing deployment of wireless mesh technologies and infrastructure is leading to an increased usage of applications such as IP telephony, video streaming, public surveillance etc., and in turn these applications often demand a good link performance of the network. These performance requirements necessitate that both the application and the network be able to adapt to the highly variable nature of wireless channels. Therefore, the measurements and analysis of the link performance is becoming increasingly crucial in order to improve network and application characteristics.

In order to optimize the link performance in WMNs, it is necessary to make use of performance metrics that take account of jitter, packet delivery rate, delay, capacity, bandwidth, etc. In general there are two techniques that can be employed to obtain these performance metrics: active probing and passive monitoring. Active probing involves accessing the wireless network and broadcasting probe packets. It has the disadvantage that it generates a transmission overhead. On the other hand, passive monitoring is a technique whereby all network transmissions are passively intercepted and subsequent processing produces the performance metrics. It has the advantage that it does not generate an overhead.

Traditionally, the majority of the WMN research efforts to date have been concerned with a study the performance of the two techniques used separately or in some combined technique [1]. However, to date little attention has been paid to the correlation between passive monitoring and active probing techniques and the possibility of using these techniques interchangeably. Also, much of the research has been conducted using computer simulations which offer an efficient and flexible means to evaluate a network. However, in these simulations, background traffic and random noise are normally not taken into account and often unrealistic traffic traces are employed. Consequently, performance evaluations obtained through computer simulations may not reflect the actual performance obtained in real networks [2].

In this paper, we present an experimental study of the correlation between passive monitoring and active probing techniques. We combined multiple performance metrics obtained through passive monitoring and evaluated its correlation with performance metrics obtained by using active probing. We also investigated the reaction of the passive monitoring and active probing techniques to variations in the network load. The results from this study show that there is a high degree of correlation between the two techniques and that they can be used interchangeably. We believe our study is beneficial in both wireless network capacity planning and routing protocol design.

The rest of the paper is organized as follows. Section 2 briefly introduces the experimental test bed and the set of tools used in the experiments. Section 3 describes the experimental approach and evaluation metrics. Section 4 presents the experiment results and performance analysis. Finally Section 5 discusses our observations and concludes the paper.

2 System Description

All experiments have been carried out using the CNRI wireless mesh test bed [2]. This is a multi-purpose networking experimental platform which consists of 17 IEEE 802.11b/g based mesh routers, located around the DIT Focas building. Various statistical information about the CNRI mesh test bed can be obtained from http://mesh.cnri.dit.ie. As a base platform we have used Soekris net4521 boards [4] running the Pebble Linux distribution.

To facilitate repeatable experiments and accurate data analysis, we have utilized several different tools for network monitoring and diagnosis, as follows:

WLAN Resource Monitor (WRM): The WRM is a tool developed by the CNRI that is capable of measuring both the availability and utilization of network bandwidth in real time and on a per node basis [5]. It operates non-intrusively by passively monitoring the wireless transmissions on the medium and therefore does not in any way interfere with the normal flow of traffic on the network. Moreover, it does not require WEP/WPA security keys to operate and therefore does not pose any security risks when deployed on encrypted networks. The WRM differs from other WLAN Analyzer tools in that it specifically addresses operation at the L2/MAC layer which is where the network bandwidth is shared out between the competing nodes. Consequently, this application can provide the type of critical network bandwidth measurements required for effective radio resource management.

Packet delivery rate calculation tool: Packet delivery rate is an important way of actively measuring the network performance. In our performance analysis we have developed a packet delivery rate calculation tool based on Pcap Library Engine [6]. It works by applying filters to the packets sent from one node to another and recording the number of packets transmitted and received over a given time interval. This allows the packet delivery rate to be calculated.

Time synchronization tool: Since we are measuring one-way delivery rate between mesh nodes, i.e. there are no ACKs allowed, and due to the fact that asymmetric links frequently occur in wireless networks, time synchronization is critical for mesh experiments. We have employed the Network Time Protocol (NTP) [7] to eliminate the clock skew. NTP's accuracy is of the order of tens of milliseconds which we considered to be sufficient for our experiments here.

3 Experimental Setup

In this section we describe the network setup and configuration, as well as the set of experiments that were performed and the evaluation metrics used.

3.1 Network setup and configurations

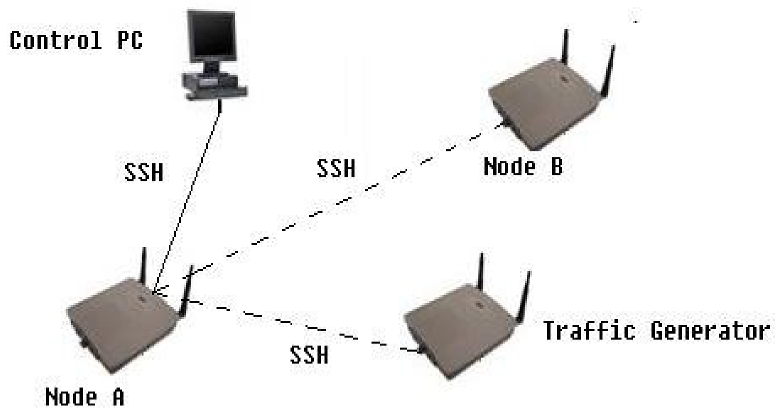

Figure 1: Experimental test bed and a photo of Soekris net 4521 board used in this experiment.

The experimental test bed consists of 3 Soekris net 4521 boards (with a single radio) as shown in Figure 1. Two of the net 4521 boards were configured to operate in the Ad-Hoc mode, while the third node was used to generate bursty traffic on the network. This is intended to introduce variations in the network load. Finally, a control PC is used to control the operations of all 3 nodes using the SSH protocol. All tests were performed with the cards operating with automatic rate selection enabled.

3.2 Experimental approach and evaluation metrics

The experimental approach involves gathering the performance metrics using both active and passive probing techniques, and calculating and plotting the correlation between the measurements Initially, experiments were carried out to study the correlation between the individual RSSI and idle bandwidth (BWidle) measurements (passive), and the packet delivery rate measurements (active). Next, the correlation between the combined metric involving the RSSI and BWidle measurements and the packet delivery rate was studied. A

total of 70 experiments were conducted. Each test case is carried out with the nodes in different locations and the typical duration of each test is between 17 to 24 hours.
During the experiment, packet delivery rate is obtained by using active probing. This is done by sending ICMP broadcast packets from Node A to Node B, and the delivery rate is calculated on the receiving node with the packet delivery rate calculation tool. The passive monitoring uses the CNRI's WRM tool where the BWidle and RSSI values were obtained.

To calculate the correlation between the two data sets, the Pearson correlation coefficient is used which is a dimensionless index that ranges from -1.0 to 1.0 inclusive and reflects the extent of the degree of correlation between the two data sets. The closer the coefficient is to -1.0 or 1.0, the higher the correlation is between the two data sets [8]. Mathematically, the Pearson correlation coefficient is given by:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \qquad \text{Pearson correlation coefficient} \quad \textbf{(1)}$$

4 Results and analysis

4.1 Correlation between the packet delivery rate and the RSSI value of the node.

Initially the correlation of RSSI value of the nodes (i.e. from passive monitoring technique) and packet delivery rate (i.e. from active probing technique) was investigated through 20 test cases.

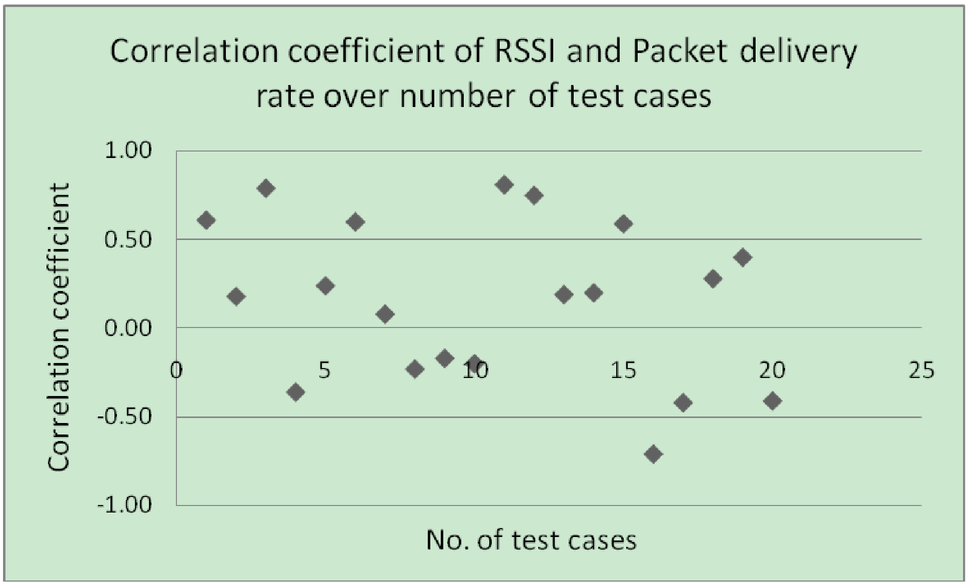

Figure 2: Correlation coefficient of RSSI and packet delivery rate over all test cases.

From Figure 2 it can be observed that in the test cases considered, there is no clear correlation between the packet delivery rate and the RSSI value at the receiver nodes.

4.2 Correlation between the packet delivery rate and the idle bandwidth (BW_{idle}).

Then the correlation of BWidle value of the nodes (i.e. from passive monitoring technique) and packet delivery rate (i.e. from active probing technique) was investigated through another 20 test cases.

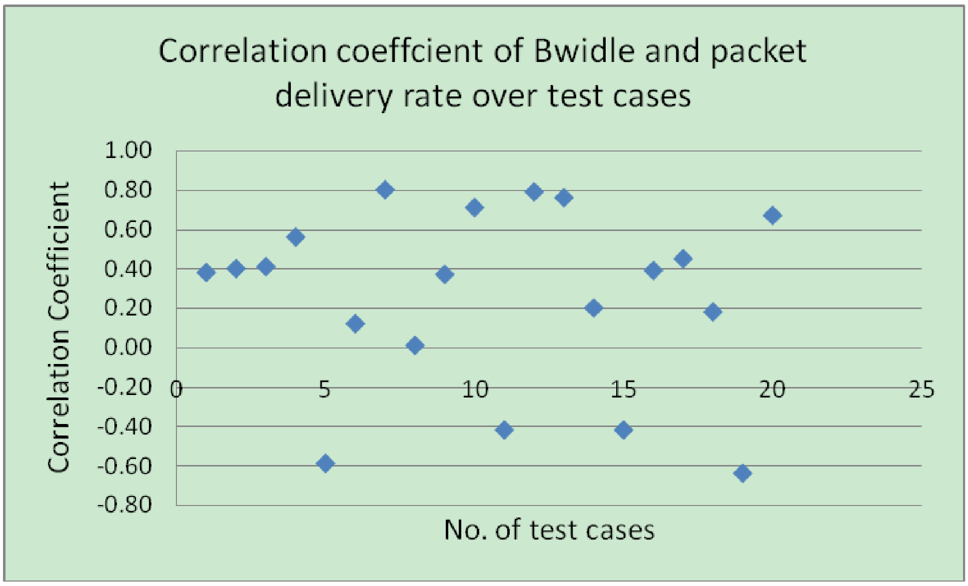

Figure 3: Correlation coefficient of BW_{idle} and packet delivery rate over all test cases.

As can be seen in Figure 3, there is no discernible correlation between the packet delivery rate and the idle bandwidth for the test cases considered. From these first two results, it is believed that a single performance metric obtained from passive monitoring is insufficient to establish a correlation with those from active probing.

4.3 Combining Passive Measurements

In order to more accurately reflect the link performance observed by passive monitoring technique, the RSSI value and the BW_{idle} value are combined and normalised as follows:

$$F(RSSI, BWidle) = \frac{RSSI * BWidle}{30} \quad (2)$$

The reason that the factor 30 is used to normalize the function is that the MADWiFi driver, used in these experiments, specifies that the RSSI of a strong signal will have a value of 30.

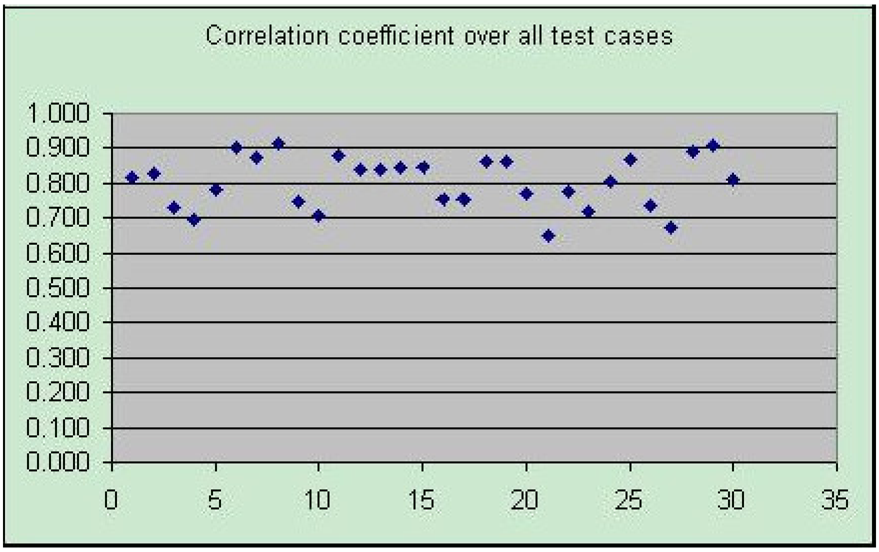

Figure 4: Correlation coefficient of the combined function and packet delivery rate over all test cases.

As shown in Figure 4, a high degree of correlation can be observed with a correlation coefficient between 0.7 and 0.9. This indicates that passive monitoring can have a good correlation with active probing if the combined function is used for the passive monitoring measurements.

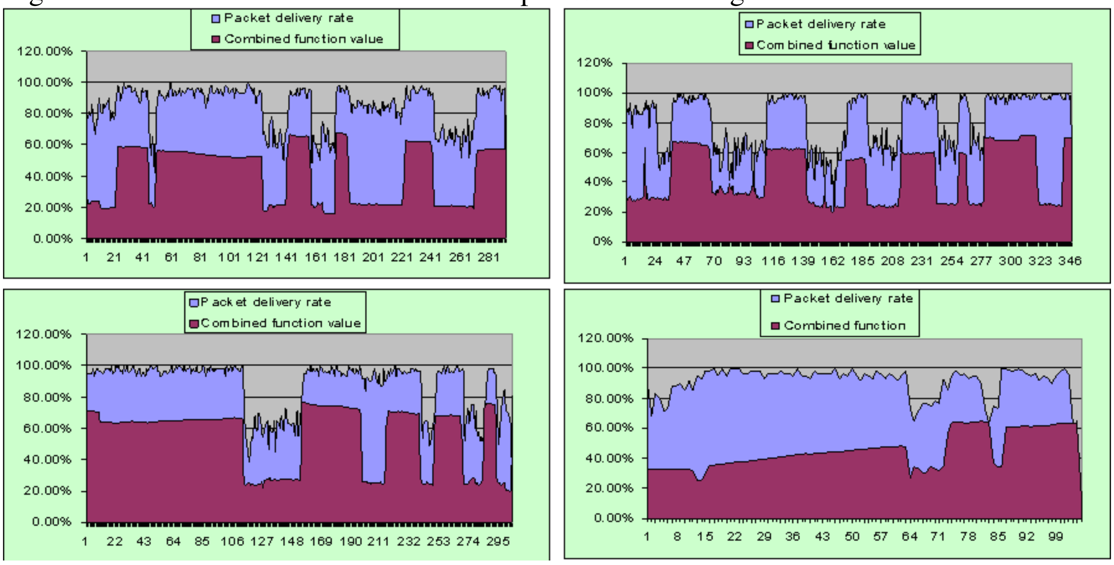

Figure 5: Variation in the combined function value and packet delivery rate over time.

The variation in the network load is produced by the third node is the experiment producing a steam of bursty traffic. Figure 5 provides a better graphical insight into this result where it shows how both the packet delivery rate and the combined function values react to the variation in background traffic load. It can be observed that during the course of the experiments, their reaction to this variation are quite similar, this indicates that both passive monitoring and active probing techniques can accurately reflect the network performance.

5 Conclusions

In this paper we have presented an experimental study of the correlation between active probing and passive monitoring techniques used in WMNs. We evaluated the correlation between packet delivery rate with different performance metrics obtained by using passive monitoring technique. To summarize, we have made the following observations:

1. We have observed a high degree of correlation between the combined function (i.e. passive monitoring) and packet delivery rate (i.e. active probing).

2. Active Probing and Passive Monitoring can be used interchangeably to measure link performance. For example, active probing can be used when the network load is low and passive monitoring when the network load is high (in order to avoid the overhead associated with active probing).

More passive metrics could be added into the combined function to provide for an even higher degree of correlation between the two techniques. We also believe these results will be useful where it becomes necessary to study the link performance in multi-channel/multi-radio WMNs.

Acknowledgements:

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