An *In-situ* Measurement Approach for IEEE 802.11 Wireless Multihop Networks

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***Abstract*—A wireless multihop network is a communications network composed of nodes equipped with wireless interfaces and organized in an ad hoc manner. It has become an attractive and practical solution for providing flexible and extended wireless coverage over large areas. Measurement of physical layer quantities can provide useful information for cross-layer optimization and design of networking protocols. In this paper, we present a cost-effective approach for performing physical-layer and link-layer measurements by exploiting the capabilities of inexpensive commercial-off-the-shelf (COTS) wireless routers and open-source software tools. Our experimental results show that the measurements made using inexpensive wireless routers are consistent with theoretical models and hence reliable. It is therefore possible to utilize the measurements to devise models or algorithms that will improve the performance of networking protocols.**

I. INTRODUCTION

A *wireless multihop network* is a communications network comprising nodes equipped with wireless interfaces and organized in an ad hoc manner. A node can either be a router or any computer with routing or forwarding capabilities. Nodes that are out of direct transmission range of one another can communicate through intermediaries or relay nodes in a multihop manner.

In recent years, wireless multihop networks have become an attractive and practical solution for providing flexible and extended wireless coverage over large areas [1]. Several worldwide projects have employed this paradigm to build community networks [2]. Such networks are expected to provide broadband data rates while supporting large numbers of users. Networking protocols must therefore be designed to provide high throughput and allow the number of users to scale.

Satisfying these challenging requirements requires a good understanding of the characteristics of wireless links under different conditions or parameters such as sender transmit power, sender-receiver distance, sender transmit data rate, etc. The collection and analysis of these measurements can help in deployment planning of wireless networks [3], and aid in optimizing their performance.

Fig. 1. Wireless router and accessories used in the testbed. Left: One node is composed of one Compex WP54G router, one 12V rechargeable lead battery and one plastic container to protect the hardware from rain. Right: Actual deployment of the node in the test site.

In this paper, we present a cost-effective approach at performing physical-layer and link-layer measurement studies by exploiting the capabilities of inexpensive commercial-off-the-shelf (COTS) wireless routers and open-source software tools. Our measurement approach is *in-situ* as we rely solely on the instrumentation and measurement capabilities of the wireless routers. There are several benefits of this approach: (i) it is cost-effective as no additional instruments are needed to perform the measurement; (ii) since the measured quantities are provided by the router itself, they can be used to perform cross-layer optimizations without the need for additional device to be attached to the routers. The disadvantage of this approach is the accuracy and reliability of the physical-layer measurements. However, our results demonstrate that the measurements made from these inexpensive wireless routers are consistent with theoretical expectations.

The rest of the paper is organized as follows: Section II describes the wireless multihop testbed including the hardware and software. Section III discusses the setup and configuration of the important aspects of the testbed. Section IV presents the preliminary measurement results obtained and Section V concludes the paper.

TABLE I
RADIOTAP HEADER FIELDS SUPPORTED BY MADWIFI

1	Data Rate
2	Channel Frequency
3	Channel Type (Spectrum and Modulation)
4	Receive Signal Strength in dBm
5	Noise Floor in dBm
6	Receive Signal Strength (RSS)
7	Antenna Used

II. TESTBED

The testbed comprises eight wireless nodes arranged in a linear or string topology and separated from each other by 50 m. The nodes are mounted on a wooden tripod that provides a height of 50 cm from the ground. We conducted experiments in an outdoor open field. The string topology is motivated by our goal to obtain the following measurements: (i) *receive signal strength* (RSS); and (ii) *packet error rate* (PER) at different sender-receiver distances. In the experiments, we let one of the routers send packets while the rest of the routers receive.

A. Hardware

Each wireless node is composed of one Compex NetPassage WP54G router, one 12V rechargeable lead battery and one plastic container to protect the hardware from rain (see Figure 1). We chose the Compex router for several reasons: (i) it uses the Atheros AR5212 chipset which allows the measurement of per-packet receive signal strength; (ii) the Atheros chipset driver source codes are publicly available in an open-source project called *madwifi* [4]; and (iii) the Compex router is supported by *OpenWRT* [5], a small footprint Linux distribution suitable for wireless routers.

B. Software

The original Compex firmware is replaced with the OpenWRT distribution (Kamikaze version 7.07) [5]. OpenWRT provides a fully writable filesystem with package management facilities to install other programs that are required by our project. We developed a UDP-based constant-bit-rate (CBR) application to generate packets at a specified sending rate and packet size. At the receiving nodes, we used *tcpdump* [6] to capture received packets into a dump file. When the network interface is configured in monitor mode (see Section III), tcpdump is also able to capture physical layer information such as noise floor and RSS into the dump file.

Controlling the various parameters of the wireless interface card is accomplished with the use of *wireless-tools* package [7]. In particular, this package provides a tool called *iwconfig* that can be used to adjust the transmit power, data rate, channel, and mode of operation, among others.

III. CONFIGURATION

To accomplish our goals of obtaining physical and link layer measurements using the wireless routers, we needed to configure the routers to operate in *monitor* mode[1]. In this mode, the device driver prepends physical layer information in the form of *radiotap header* [8] to every captured packet. In addition, this mode also allows the capture of corrupted frames. Table I shows the madwifi-supported radiotap header fields.

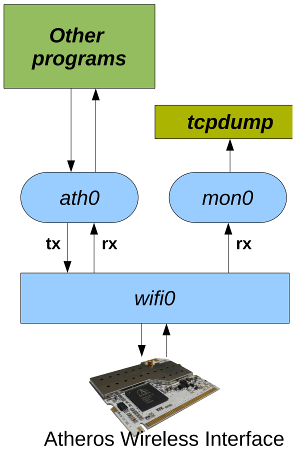

Fig. 2. Wireless interface configuration: *mon0* operates in monitor mode and is used by tcpdump for capturing packets while *ath0* operates in ad hoc mode and used by other applications for sending/receiving.

TABLE II
EXPERIMENTAL CONFIGURATIONS

Traffic	Type	CBR
	Sending Rate	25 packets/sec
	Packet Size	1400 bytes
MAC/PHY	Protocol	IEEE 802.11b
	Data Rate	1, 11 Mb/s
	Channel	6 (2.437 GHz)
	Transmit Power	1, 4, 7, 10, 13, 16, 19 dBm

The disadvantage of operating an interface in monitor mode is that data transmission is not possible using the interface. However, this is easily overcome with the use of Atheros madwifi driver, which allows the creation of more than one virtual interface on top of a single physical interface [4]. More importantly, these virtual interfaces can operate in different modes. We exploited this capability to create two virtual interfaces, one to operate in ad hoc mode and another to operate in monitor mode, as shown in Figure 2.

Table II summarizes our experimental configurations in greater detail.

IV. RESULTS

In this section, we present the preliminary measurement results obtained from the testbed. The data presented were collected over several runs which spanned several days of experimentations.

A. Receive Signal Strength

Figures 3 and 4 show the average receive signal strength (RSS) over different sender-receiver distances. In general, the results show that as the sender to receiver distance increases, the receive signal strength decreases. At 50 m, the average

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[1] The madwifi driver allows several mode of operation: (i) access point; (ii) station; (iii) ad hoc; (iv) ad hoc demo or pseudo-ibss; and (iv) monitor [4].

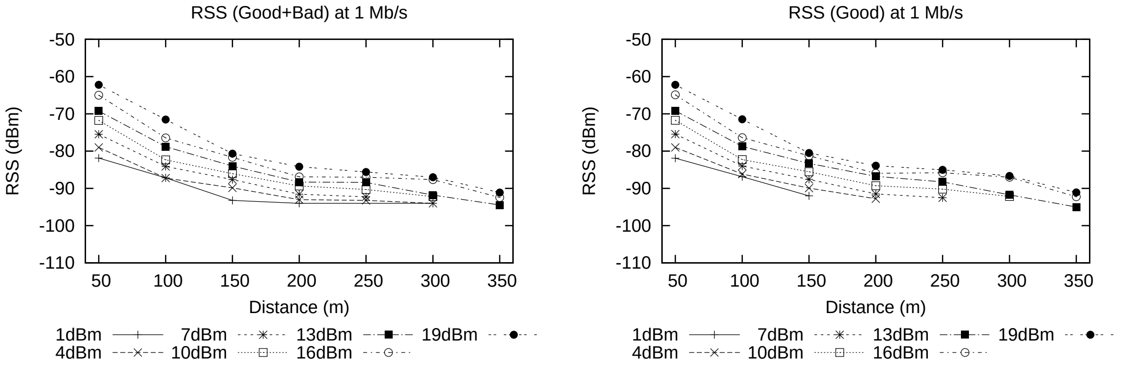

Fig. 3. Receive signal strength of (a) all received packets and (b) good-CRC packets over different sender-receiver distances at 1 Mb/s.

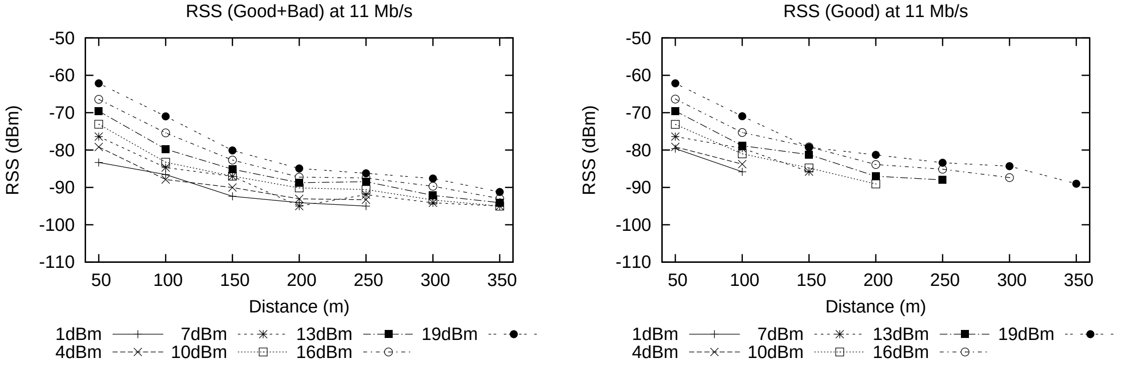

Fig. 4. Receive signal strength of (a) all received packets and (b) good-CRC packets over different sender-receiver distances at 11 Mb/s.

RSS is approximately in 3 dB intervals, which is equal to the intervals in transmit power at the sender. However, at greater distances, the RSS separation decreases. This suggests that the RSS measurements closer to the sender are more reliable.

The RSS at 1 Mb/s (Figure 3(a)) and 11 Mb/s (Figure 4(a)) for all received packets (i.e., both corrupted and correctly-received packets) do not show any significant difference. This indicates that the RSS is not affected by the data rate. However, when we consider the RSS of correctly-received packets only (Figures 3(b) and 4(b)), we can see that there is a difference. Specifically, at 11 Mb/s, it is obvious that the minimum RSS at all distances is around 5 dB above the noise floor whereas at 1 Mb/s, the minimum RSS is around 1 dB. This difference is expected since 11 Mb/s requires higher signal to noise ratio for correct reception compared with 1 Mb/s.

To ascertain the validity of these measurement results, we plot the receive signal strength as predicted by the two-ray ground reflection model [9] in Figure 5. Comparing this with the RSS of all received packets at both 1 and 11 Mb/s, we can see that the absolute values are not equal with the experimental results lower by around 10 dB at 50 m. However, if we consider the trend especially from distances between 50 m and 150 m, we can see that the experimental results are very close to the theoretical results. Beyond 150 m, the experimental results tend to merge to -95 dBm (which is the sensitivity of the receiver.) This could imply that higher RSS values tend to be more reliable than RSS values that are close to the receiver sensitivity.

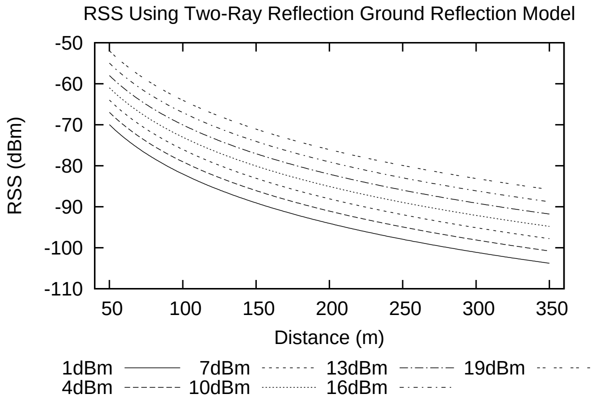

Fig. 5. Receive signal strength using two-ray ground reflection model over different sender-receiver distances.

B. Packet Error Rate

The previous results show that RSS measurements using inexpensive COTS wireless routers are indeed meaningful and correspond to theoretical models. Therefore, we can use this information to develop schemes to improve the performance of network layer protocols. However, for RSS measurements to

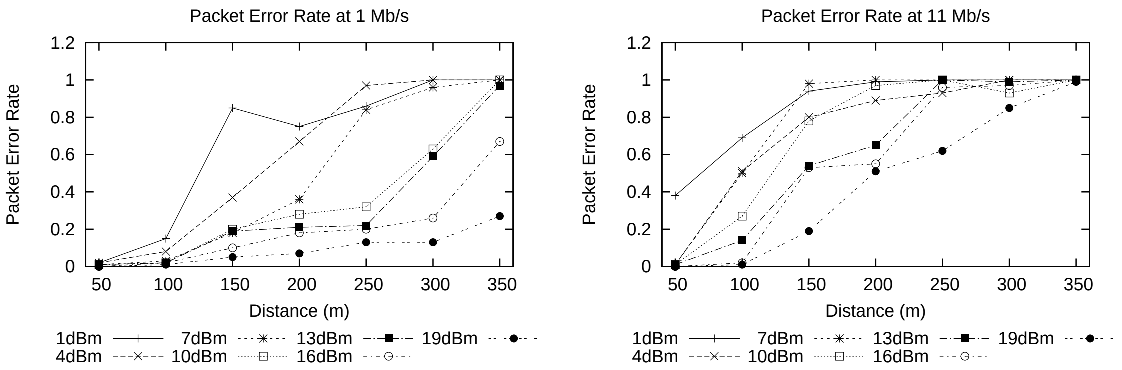

Fig. 6. Packet error rate at (a) 1 Mb/s and (b) 11 Mb/s over different sender-receiver distances.

be meaningful, they must be correlated with some network layer performance metric. In this section, we attempt to correlate RSS with packet error rate (PER), computed as the ratio of the number of corrupted packets over the total number of received packets.

Figure 6 shows the PER over different sender-receiver distances. The results show three clear trends. Firstly, as the sender-receiver distance increases, the PER also increases. Secondly, as the transmit power increases, the PER decreases. Lastly, the higher data rate of 11 Mb/s generally shows higher PER compared with 1 Mb/s.

The first two observations can be easily explained by the RSS measurements obtained previously. In the first observation, longer sender-receiver distance results in lower RSS. In the second observation, higher transmit power results in higher RSS. Lower RSS causes higher packet error rate while higher RSS causes lower packet error rate.

The higher PER observed for 11 Mb/s compared with 1 Mb/s is due to the fact that 11 Mb/s requires higher noise margin for correct reception. From Figures 3(b) and 4(b), we can see that 11 Mb/s requires at least a 5 dB margin whereas 1 Mb/s requires at least a 1 dB margin.

In summary, based on the results on RSS and PER, it is possible to devise a model or algorithm that can predict the PER given RSS as an input. The model/algorithm can then be implemented and deployed on the wireless routers. The same configuration technique discussed in Section III can be used obtain measurements *in-situ*. Obviously, the model/algorithm will utilize the monitor-mode virtual interface for it to obtain physical layer information. Other work has also shown that RSS measurements can be used to predict packet delivery [10] and to improve “neighbour selection” strategies [11].

V. CONCLUSION

A wireless multihop network is a communications network composed of nodes equipped with wireless interfaces and organized in an ad hoc manner. It has become an attractive and practical solution at providing flexible and extended wireless coverage over large areas. Measurement of physical layer information can be useful for cross-layer optimization. In this paper, we presented a cost-effective approach at performing physical-layer and link-layer measurement studies by exploiting the capabilities of inexpensive commercial-off-the-shelf (COTS) wireless routers and open-source software tools. This approach has several benefits: (i) it is cost-effective as no additional instruments are needed to perform the measurement; (ii) since the measured quantities are provided by the router itself, they can be used to perform cross-layer optimizations without the need for additional device to be attached to the routers. The disadvantage of this approach is the accuracy and reliability of the physical-layer measurements. However, our results demonstrate that the measurements made from these inexpensive wireless routers are consistent with theoretical expectations. It is therefore possible to utilize the measurements in devising models or algorithms that will improve the performance of networking protocols.

REFERENCES

[1] T. Salonidis, M. Garetto, A. Saha, and E. Knightly, “Identifying high throughput paths in 802.11 mesh networks: a model-based approach,” in *Proc. IEEE ICNP 2007*, Oct. 2007, pp. 21–30.

[2] E. Efstathiou, . Frangoudis, and G. Polyzos, “Stimulating participation in wireless community networks,” in *Proc. IEEE INFOCOM 2006*, Apr. 200, pp. 1–13.

[3] J. Camp, J. Robinson, C. Steger, and E. Knightly, “Measurement driven deployment of a two-tier urban mesh access network,” in *MobiSys ’06: Proceedings of the 4th international conference on Mobile systems, applications and services*. New York, NY, USA: ACM, 2006, pp. 96–109.

[4] M. Community, “Madwifi: Linux kernel drivers for wireless lan devices with atheros chipsets,” http://madwifi.org/.

[5] O. Community, “Openwrt wireless freedom,” http://openwrt.org/.

[6] T. Community, “Tcpdump/libpcap public repository,” http://www.tcpdump.org/.

[7] J. Tourrilhes, “Wireless tools for linux,” http://www.hpl.hp.com/personal/Jean_Tourrilhes/Linux/Tools.html.

[8] J. Berg, “Radiotap: De facto standard for 802.11 frame injection and reception,” http://www.radiotap.org/.

[9] C. Y. Lee, *Mobile Communications Engineering: Theory and Applications*. New York, USA: McGraw-Hill, 1998.

[10] C. Reis, R. Mahajan, M. Rodrig, D. Wetherall, and J. Zahorjan, “Measurement-based models of delivery and interference in static wireless networks,” *SIGCOMM Comput. Commun. Rev.*, vol. 36, no. 4, pp. 51–62, 2006.

[11] K.-W. Chin, J. Judge, A. Williams, and R. Kermode, “Implementation experience with MANET routing protocols,” *SIGCOMM Computer Communication Review*, vol. 32, no. 5, pp. 49–59, Nov. 2002.