SNR-based Link Quality Estimation

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***Abstract*—The ability to accurately estimate wireless link quality is critical to the performance of routing protocols and rate adaptation algorithms in wireless mesh networks. Current link quality estimation methods utilize the packet delivery ratio (PDR) measurement of periodic broadcast probes sent at the lowest transmission rate. However, the estimated link quality does not readily translate to the performance of unicast data traffic at higher transmission rates. In this paper, we propose the use of a measurement-based signal-to-noise ratio (SNR) model to estimate wireless link quality in terms of its PDR performance. Using broadcast traffic measurements at the lowest transmission rate, we construct an "SNR profile" that characterizes the relationship between the PDR metric and the SNR values computed at a node. We show how we can use the SNR profile to predict the PDR performance at different transmission rates. More importantly, we argue that the frame delivery ratio (FDR) at the MAC layer is a better link quality metric compared to PDR, and show that our proposed approach can use an SNR profile generated with broadcast traffic, to accurately estimate the FDR performance of unicast data traffic at different transmission rates. This then allows us to also accurately estimate the maximum achievable throughput of a wireless link at those rates.**

I. Introduction

In 802.11-based wireless mesh networks, nodes typically form multiple communication links with its neighbours. Estimating the quality of these wireless communication links is an important consideration towards the optimal operation of the network. Various metrics have been defined as indicators of the quality of wireless links. For example, routing protocols use link quality metrics like hop count, ETX [1] or ETT [2] to discover high quality routing paths. Rate adaptation algorithms utilize link quality metrics like signal strength [3] and packet delivery ratio (PDR, ratio of number of packets received to the number of packets sent) [4] in order to select the optimal transmission (modulation) rate to use.

Link quality estimation is usually performed via the use of broadcast probes [1] [2]. Nodes periodically exchange probe packets with neighboring nodes, and the quality of a link is then estimated by computing the PDR over the link. However, it has been shown that broadcast probe packets are unable to capture the characteristics of unicast data transmissions [5] [6]. Therefore, it is difficult to use link quality estimation via broadcast probes to accurately predict the link performance when actual unicast data transmissions are used. In addition, probe packets are typically transmitted at the lowest transmission rate, and the estimated link quality at this rate is assumed to reflect the link quality at higher rates. However, due to the different modulation and coding techniques used at different transmission rates, broadcast probe packets that are successfully received at the lowest transmission rate do not necessarily mean that unicast data packets would also be successfully received at higher transmission rates [5] [6].

In this paper, we propose the use of a measurement-based signal-to-noise ratio (SNR) model to estimate wireless link quality in terms of its PDR performance. Using two nodes on our indoor wireless testbed, we first construct an "SNR profile" that characterizes the relationship between the PDR metric and the SNR values computed at a node. In our approach, we estimate wireless link quality by first computing the SNR values of received packets, and then looking up the corresponding PDR on the SNR profile. Our first contribution in this paper is in showing that we can use an SNR profile constructed with broadcast packets at the lowest transmission rate, to estimate/predict the PDR performance of data traffic sent at higher transmission rates. In terms of predicting the PDR performance of unicast data traffic, we argue that the frame delivery ratio (FDR) at the MAC layer is a better link quality metric compared to PDR. This is because the FDR metric does not mask the frame retransmissions at the MAC layer, unlike the PDR metric. Following from this, our second contribution in this paper is in using an SNR profile constructed with broadcast traffic to estimate the FDR performance of unicast packets at the MAC layer. Finally, we also show that the product of the estimated FDR and the theoretical maximum throughput (TMT) [7] of the wireless link, can be used to estimate the link's maximum achievable throughput [8]. Experimental results obtained via tests on our wireless testbed, confirm the accuracy and practicality of our proposed approach.

An advantage of our proposed approach is that it can use existing data traffic when it is present, or periodic beacons (HELLO messages or 802.11 management frames) emitted by the nodes, in order to estimate the link quality. Therefore, our approach does not introduce any new active probe packets. Our experiment results show that even with a traffic load of 1% of the link's transmission rate (emulating the infrequent periodic beacons), by computing the SNR of packets received at a node, we can accurately estimate the link quality by looking up the corresponding PDR on the SNR profile.

The rest of the paper is organized as follows. We present our SNR-based link quality estimator in Section II, and evaluate the performance of our proposed approach in Section III. We briefly discuss related work in Section IV, and provide our conclusions and future work directions in Section V.

Fig. 1: Network setup for SNR profile construction

II. An SNR-based Link Quality Estimator

A. Constructing the SNR Profile

Our link quality estimator is based on an SNR profile that maps the SNR values computed at a node to the PDR metric. The SNR profile is a characteristic of the radio card, and is the same for all radio cards of the same model/type [9]. In our proposed approach, we first construct an SNR profile using the nodes on our indoor wireless testbed. Fig.1 shows our wireless testbed, consisting of a sender node *S* and a receiver node *R*. Both nodes are equipped with the Wistron Neweb CM9 Atheros 802.11a/b/g mini-PCI cards with the AR5213A chipset, and run on Linux (kernel version 3.1.0 and ath5k driver). Each node has an 8 dBi omni-directional antenna attached either directly to the radio card (on the receiver *R*) or to a Lab Brick variable attenuator (on the sender *S*). By varying the attenuation value on the variable attenuator, we are able to control the quality of the wireless link (from a perfect link to a completely disconnected link). In all our experiments, we configure both nodes to operate in the 802.11a mode with transmssion power fixed at 15 dBm. We configure the nodes to operate on a 5 GHz channel that is unoccupied by other 802.11 networks.

Using the *iperf* tool, the sender *S* broadcasts saturated UDP traffic (1024 bytes) at the lowest transmission rate of 6Mbps to the receiver *R*. As mentioned before, the quality of the link is controlled by varying the attenuation on the link, which impacts the received signal strength (RSS) of the packets received at node *R*. We run this experiment for 60 seconds for every attenuation value. At the end of the 60 seconds experiment, we measure the PDR, the mean RSS of packets received, and the mean noise floor at the receiver *R*. Packet traces are captured with the *tcpdump* tool, which allows us to retrieve the RSS and noise floor measurement values from the radiotap header attached to each packet.

The SNR value is computed as $\frac{RSS}{NF}$, where *RSS* is the mean received signal strength of the sender's packets that are received at the receiver, and *NF* is the mean noise floor at the receiver *R*. For every attenuation value on the sender-receiver link in Fig. 1, we plot the tuples {PDR, SNR}. Fig. 2 shows the SNR profile constructed via the use of a 6Mbps broadcast transmission. We see that there is a strong correlation between the PDR performance and the SNR values. For low SNR values ($\leq$ 5dB), the PDR is zero, while for high SNR values ($\geq$ 10dB), the PDR is 100%. There is a narrow transition region of approximately 4-5dB width where the PDR increases rapidly from zero to 100%.

B. Estimating Link Quality on a Lightly-loaded Link

To estimate/predict the PDR metric, we would need to first measure the SNR of packets received at a node, and use the SNR value to lookup the corresponding PDR on the SNR profile. For example, looking at the SNR profile in Fig. 2, if the computed SNR is 7.5dB, then the corresponding PDR metric is 50%. In our proposed approach, the SNR values can be computed from existing data traffic when it is present, or from periodic beacons (HELLO messages or 802.11 management frames) that are broadcasted by the nodes. Thus, our proposed approach does not introduce any new active probe packets. To evaluate the accuracy of the PDR metric estimation when we use periodic beacons, we send a lightly-loaded UDP broadcast stream from sender *S* to receiver *R* in Fig. 1. The offered load is set at 1% of the link's 6Mbps transmission rate, and we measure the PDR and compute the mean SNR for the packets received at receiver *R* at the end of every second. This is to emulate the infrequent periodic beacons. Fig. 3 shows the comparison between the SNR profile in Fig. 2 and the measured PDR for a lightly-loaded UDP traffic. We

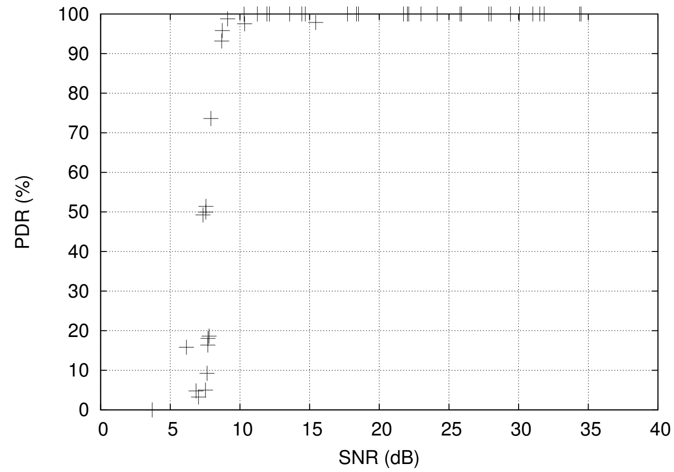


Fig. 2: SNR profile

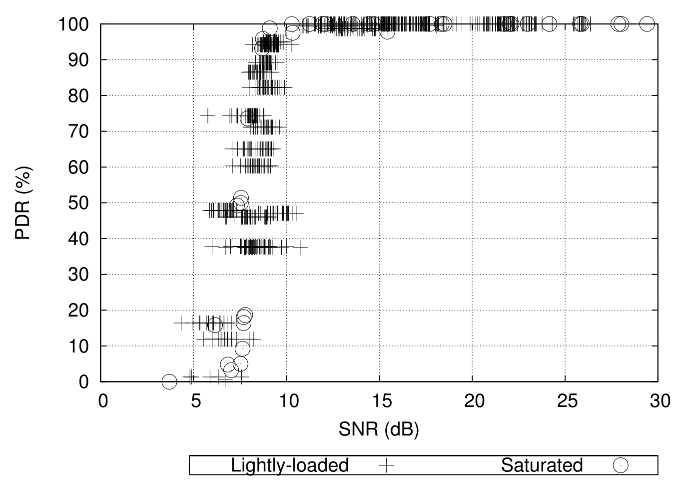
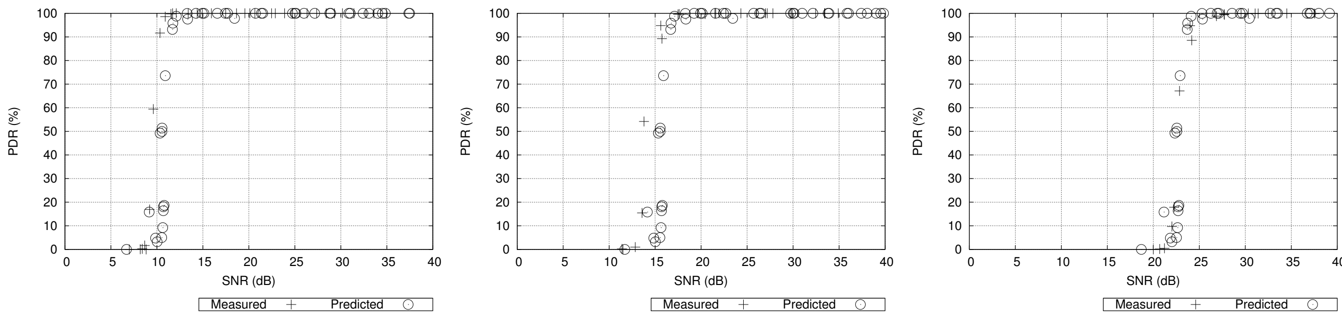


Fig. 3: Comparison of SNR profile (constructed with saturated UDP traffic) with the measured PDR for a lightly-loaded UDP stream (1% offered load), at 6Mbps transmission rate



(a) 12Mbps (b) 24Mbps (c) 48Mbps

Fig. 4: Using a broadcast-based 6Mbps SNR profile to predict broadcast PDR performance at 12Mbps, 24Mbps, and 48Mbps

TABLE I: Receiver sensitivity at different transmission rates

TX. rate (Mbps)	6	9	12	18	24	36	48	54
RX. sens. (dB)	-88	-87	-85	-83	-80	-75	-73	-71

see that even though there are some slight dispersions in the measured {PDR, SNR} tuples for the lightly-loaded UDP traffic (due to measurements being taken every second), overall the shape/curve of the measured PDR plot closely matches the SNR profile constructed with saturated UDP traffic. This result shows that our proposed approach can utilize SNR measurements from existing periodic beacons in order to predict the PDR metric of a link, by looking up the SNR profile.

III. Performance Evaluation

A. Estimating Link Quality for Traffic Sent at Higher Transmission Rates

In the previous section, we have constructed an SNR profile using broadcast traffic sent at the lowest transmission rate of 6Mbps. We note that for a link operating at higher transmission rates, it would require a higher SNR value in order to obtain the same PDR performance as when it is operating at the 6Mbps transmission rate. For example, a 54Mbps link would require a higher SNR to achieve a PDR of 90%, compared to a 6Mbps link. This indicates that we can possibly estimate the PDR performance of traffic sent at higher transmission rates, by simply shifting the plot in the SNR profile (shown in Fig. 2) to the right. The challenge is to know by how much the plot is to be shifted to the right. We conjecture that this is dependent on the differences in the receiver sensitivity values for different transmission rates[1], as shown in Table I. Following our conjecture and the information given in Table I, if we want to predict the PDR performance at a transmission rate of 24Mbps, we can do so by right-shifting the plot in the SNR profile by 8dB and then use the resultant new plot.

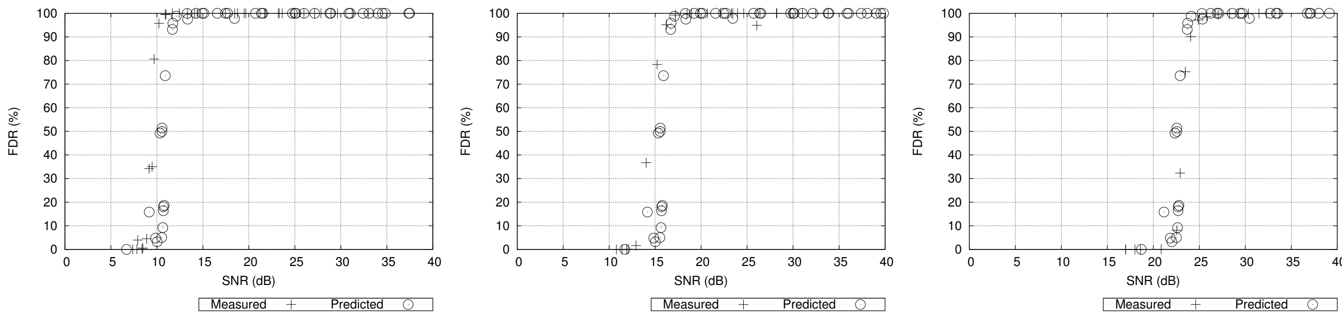
In order to verify our conjecture, we send a saturated UDP broadcast stream at higher transmission rates from the sender *S* to the receiver *R* in Fig. 1. We measure the PDR and compute the mean SNR of packets received at the receiver *R* at the end of the 60 seconds experiment. In Fig. 4, we compare the measured PDR plot with the predicted PDR plot (obtained by right-shifting the plot in the SNR profile) for the transmission rates 12Mbps, 24Mbps, and 48Mbps. We see that the predicted PDR plots can be used to closely estimate the measured PDR values. This is an important observation because in a wireless mesh network, link quality estimation typically uses periodic beacons that are sent at the lowest transmission rate. Rather than only being able to predict the link quality at the lowest transmission rate, using our approach, we can now use the SNR measurements of these beacons to predict the PDR performance of traffic sent at higher transmission rates.

B. Estimating Link Quality for Unicast Data Traffic

In the previous section, we have shown how we use the SNR profile to estimate the PDR performance of broadcast traffic at different transmission rates. We note that since broadcast packets do not require retransmissions at the MAC layer, the PDR at the application layer is exactly the same as the frame delivery ratio (FDR) at the MAC layer. FDR is defined as the ratio of number of MAC layer frames received (including duplicates) at the receiver node, to the number of MAC layer frames transmitted (including retransmissions) at the sender node. However for unicast traffic, the PDR is typically higher than the FDR, due to the frame retransmissions at the MAC layer. Taking these different characteristics of broadcast and unicast traffic into account, we argue that FDR is a better link quality metric compared to PDR. Two links with the same PDR performance at the application layer can have vastly different FDR performance at the MAC layer. This is because the FDR metric does not mask the frame retransmissions at the MAC layer, unlike the PDR metric.

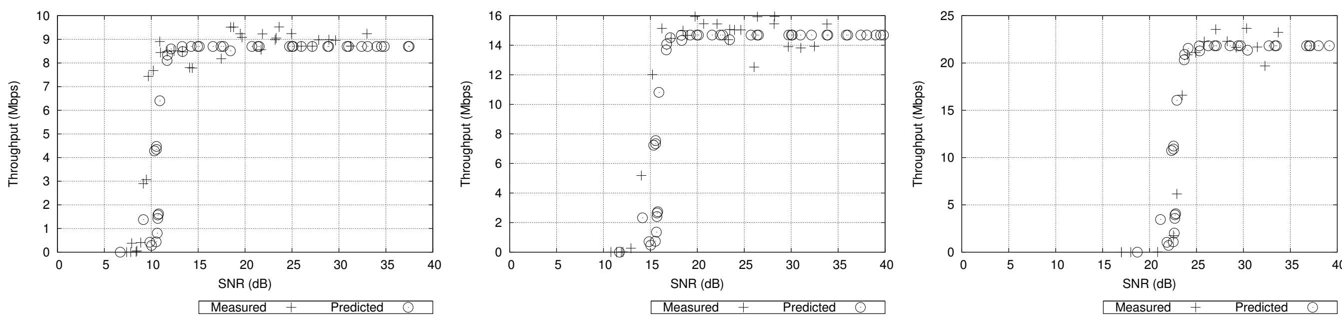
We also note that the SNR profile constructed with broadcast traffic, is in actual fact, mapping the relationship between the FDR metric at the MAC layer and the SNR values. This in turn means that we can use the broadcast-based SNR profile to estimate the FDR performance of unicast data traffic. To evaluate this, we run a series of experiments where the sender *S* transmits saturated UDP **unicast** stream to the receiver *R* in Fig. 1. We measure the FDR metric at the MAC layer, and

[1] http://resources.mini-box.com/online/AOC-MPCI-WI-CM9/specs.html



(a) 12Mbps (b) 24Mbps (c) 48Mbps

Fig. 5: Using a broadcast-based 6Mbps SNR profile to predict FDR performance for unicast data traffic sent at 12Mbps, 24Mbps, and 48Mbps



(a) 12Mbps (b) 24Mbps (c) 48Mbps

Fig. 6: Using a broadcast-based 6Mbps SNR profile to estimate the maximum achievable throughput for unicast data traffic sent at 12Mbps, 24Mbps, and 48Mbps

compare it with the predicted FDR from the SNR profile. Fig. 5 shows this comparison for the transmission rates 12Mbps, 24Mbps, and 48Mbps. We see that the predicted FDR plots are close fits with the measured FDR plots. These results show that the broadcast-based SNR profile can be used to accurately estimate the measured FDR performance of unicast packets at the MAC layer.

C. Estimating the Maximum Achievable Throughput

While the previous section has shown how our approach can be used to estimate the FDR performance at the MAC layer, here we extend it to estimate the maximum achievable throughput (MAT) of a wireless link. We argue that MAT is a better link quality metric compared to FDR, simply for the reason that for some applications like video streaming, throughput is a better performance indicator compared to FDR. [8] has shown that the MAT metric can be computed as follows:

$$MAT = FDR * TMT \tag{1}$$

where TMT is the theoretical maximum throughput (TMT) of the wireless link. TMT is defined as the upper limit of the throughput that can be achieved at the MAC layer on an IEEE 802.11 link, subject to perfect and error-free conditions [7]. The TMT values for different modulation/transmission rates can be computed using Eqn. (5) in [7].

Using the estimated FDR results from Section III-B, and the TMT values from [7], we compute the MAT metric using Eqn. (1) for the transmission rates of 12Mbps, 24Mbps, and 48Mbps. We compare our predictions with the measured throughput in Fig. 6. We see that the predicted throughput plots closely match the measured throughput plots. These results show that we can use an SNR profile constructed via broadcast measurements at the lowest transmission rate, to accurately estimate the maximum achievable throughput of a wireless link at higher transmission rates.

IV. Related Works

Many wireless link quality metrics have been proposed, especially in the context of routing protocols. Newer metrics like ETX [1] or ETT [2] have been shown to perform better than the traditional hop count metric [10]. The ETX and ETT metrics rely on the computation of the PDR of broadcast probes transmitted on the link. Broadcast probes are typically used because of their low overhead cost. However, the probes are usually transmitted at the lowest transmission rate, and therefore have different characteristics compared to the actual unicast data traffic that are transmitted at higher transmission rates [5] [6]. In contrast, our proposed approach can use either existing unicast data traffic (if present) or periodic broadcast beacons (HELLO messages or 802.11 management frames) to estimate link quality. We also demonstrate how our proposed approach can be used to translate the link quality estimation based on broadcast probes at the lowest transmission rate, to estimate the actual performance of unicast data traffic at higher transmission rates.

Wireless link quality metrics based on signal-to-noise ratio (SNR) have also been proposed [9] [11]. In these works, a PDR/FDR vs. SNR mapping table (profile) is constructed for all possible transmission rates in 802.11a. They show that SNR is a good predictor of the wireless link quality. However, the focus of the work in [9] is more on the challenges that the authors faced in constructing the profile, in particular the bugs that were discovered in the employed MadWifi driver. In addition, in both [9] and[11], no measurement result was shown to evaluate the accuracy of using the SNR profiles to estimate the link quality. In contrast to these works, we show how we use an SNR profile constructed with broadcast probes at the lowest transmission rate, to predict the FDR performance of unicast data traffic at higher transmission rates.

V. Conclusion

In this paper, we have proposed a simple and practical measurement-based approach utilizing the SNR model to estimate wireless link quality in terms of its packet/frame delivery ratio performance. Our approach does not introduce any new active probe packets. Instead, it can rely on existing data traffic (if present), or use periodic beacons (HELLO messages or 802.11 management frames) emitted by the nodes. The main idea behind our approach is an SNR profile that maps the SNR values computed at a node to the PDR metric. The SNR profile is a characteristic of the radio card, and as such, can be constructed offline in lab tests. During network operation, we measure the SNR of packets received at a node, and use the SNR value to lookup the corresponding PDR on the SNR profile.

We have shown how we use our approach to translate link quality estimation based on broadcast probes at the lowest transmission rate, to accurately estimate the actual link performance when unicast data traffic is sent at higher transmission rates. We have also extended our approach to estimate the maximum achievable throughput of a wireless link at different transmission rates. We have validated our approach via experiments conducted on our indoor wireless testbed. Our proposed approach is practical, simple and accurate, and has the potential to significantly improve the performance of routing protocols and transmission rate adaptation algorithms.

In terms of future work, we plan to extend our approach to estimate the link quality in the presence of interference. We also have plans to integrate our link quality estimator within a routing protocol (e.g. OLSR) and compare its performance with other routing metrics like ETX and ETT.

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