802.11 메쉬 네트워크의 토폴로지 맵 구축
(Topology Map Construction in 802.11 Networks) - Extended Abstract

요 약 이 논문은 802.11 를 기반으로 하는 무선 메쉬 네트워크에서 캐리어 센싱과 링크 간섭 관계를 포함한 네트워크 토폴로지 맵을 구축하는 방법인 RBP (RSS-based Prediction) 를 소개한다. 무선 신호 세기정보를 사용하는 RBP 는 메쉬 네트워크에서 성능을 예측하고 향상시키기 위한 네트워크 관리를 가능케 한다. 측정 및 예측 오버헤드는 네트워크를 구성하는 노드의 개수에 선형적으로만 비례한다. 이 논문에서는 또한 RBP 가 어떻게 다양한 전송 rate 에서 캡쳐 효과를 고려하는 지와 통신 범위 바깥에 존재하는 간섭노드의 존재를 감지하는 지를 소개한다.

키워드 : 802.11, 토폴로지 맵, 캐리어 센싱, 간섭, 캡쳐 효과

Abstract We demonstrate a new methodology, dubbed RBP (RSS-Based Prediction), that predicts 802.11 wireless network topology such as the relation of carrier sense and interference. RBP, based on radio signal strength, helps to manage wireless mesh networks e.g. to estimate and enhance throughput. The measurement complexity increases only linearly with the number of wireless nodes. In addition, we show how RBP considers the physical layer capture with multiple PHY bit rates, and detects the source of interference that is out of the communication range..

Key words : 802.11, topology map, carrier sensing, interference, capture effect

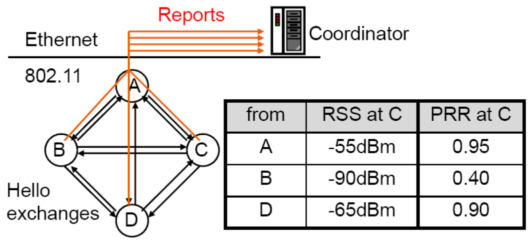
1. Introduction

Estimating a network topology of a wireless network is crucial for network management and performance analysis. Most of the wireless network performance modeling work (e.g. [1]) defines and uses two topological graphs: a link connectivity graph and a link conflict graph. While the link connectivity (between nodes) information is relatively easy to estimate, estimating link conflict information from real deployed wireless mesh networks is more challenging. Especially in contention-based 802.11 networks, each link conflict is embodied as a combination of carrier sense and interference relations.

Previous work has predicted the interference and carrier sense ranges based on the distance between the nodes. However, measurement results [2] from a real network show that the distance does not have a strong correlation with the quality of the wireless links. Moreover, most of the existing work presumes the carrier sense (CS) range is always symmetric between the two nodes. However, with a non-negligible probability, one sender senses the other sender’ s transmission but not vice versa in real networks.

Thus, we need to consider a measurement-based approach. Link Interference Ratio (LIR) and Broadcast Interference Ratio (BIR) [8] are one of the first measurement-based, instead of distance-based, schemes that estimate interference between two wireless links that do not share end-points. Both LIR and BIR, with different measurement complexities, accurately estimate the amount of pairwise link interference. However, as will be shown in Section IV, they do not indicate the fairness between the two links. They cannot differentiate cases when a link dominates the medium from when both links share the channel equally, as long as the aggregate goodput of the two links of both cases are the same.

The key measurement metric to figure out CS and interference relations is the received signal strength (RSS) among nodes. In this proposal, we propose and demonstrate an RSS-based prediction (RBP) methodology that estimates the CS and interference relations between every pair of two directional links in the network. We use a centralized coordinator that collects measurement data from each wireless node and performs the estimation.



from	RSS at C	PRR at C
A	-55dBm	0.95
B	-90dBm	0.40
D	-65dBm	0.90

Fig. 1. RBP operation

2. RBP: RSS-based Prediction

As illustrated in Fig. 1, every node broadcasts hello messages at the lowest PHY rate (6 Mbps in our 802.11a testbed) at a scheduled time (one node at a time), and the RSSs of the messages are measured by its neighbor nodes. Also, to quantify the physical layer capture, we measure packet reception ratios (PRRs) from a number of data packets with different PHY bit rates. With commodity 802.11 wireless LAN cards, we obtain an RSS value only when a received packet is correctly decoded. Thus, those nodes that are within an estimating node's interference range but outside its reception range cannot be accounted for in the RSS measurements. To address this problem, we use high-power (HP) and normal-power (NP) hello broadcast as introduced in Radio Interference Detection (RID) [3]. Each node performs hello broadcast twice; once each with high and normal power levels. The NP level is used for actual data communications, and HP is Y dB higher than the NP level. If a NP hello is received, its RSS is measured and reported to the coordinator. If only a HP hello is received, the node infers the link's RSS with NP hello by Y dB from the RSS of HP hellos, and reports the result to the coordinator.†

Thus, our scheme generates 2n message overhead, where n is the number of the nodes in a wireless network. This linear measurement complexity is one of the advantages of the proposed scheme.

Once the RSSs and PRRs are collected, the coordinator first identifies directional links in the network and estimates their qualities based on the collected RSSs and PRRs of between nodes. Then, the coordinator predicts the CS and interference relation for each link pair by comparing the RSS measurements with CS/interference power level thresholds to be detailed later. Our network visualization tool based on GUESS [4] takes the estimated link quality, CS, and interference information as inputs and exhibits the estimated network topology as illustrated in Fig. 2. This tool can show a set of contending nodes for each node and a set of hidden interferers for each link.

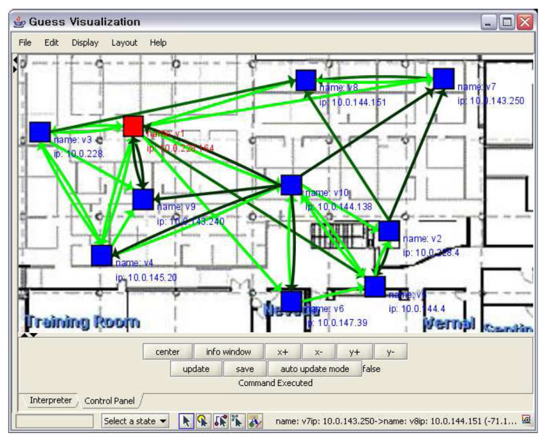


Fig. 2. Predicted network topology

3. CS and Interference Models

Based on our thorough experimental investigation on carrier sense and physical layer capture (PLC), we suggest CS and interference models as a function of an RSS. In addition, we observe that PLC and interference thresholds are affected by the CS relation and this finding is considered into the interference prediction component of RBP.

3.1. CS Model

According to our previous measurement study[5], we can quantify and express the degree of CS as a function of RSS. Let us consider two contending nodes A and B. When the RSS of the contending packet from node B is larger than a certain threshold,

† Please note that our RSS measurements are in dBm scale.

potential sender A begins to carrier sense and defer its own transmission. As the RSS of B’s packet is increasing, A’s carrier sense probability almost linearly increases. If the RSS is larger than the second threshold (which is higher than the first one), A carrier senses B’s packets almost perfectly. Thus, based on the RSSs of hello exchanges, we predict the degree of carrier sense between nodes.

3.2. Interference Model

Likewise, we can estimate the degree of interference of node A on a link B→C as a function of signal-to-interference ratio (SIR), which is defined as “RSS from B to C minus RSS from A to C.” That is, we compare the RSS of intended sender B and the RSS of interferer A measured at receiver C. If the SIR goes below a certain SIR threshold, A completely interferes C’s reception of packets from B. As SIR goes above the SIR threshold, the physical layer capture (PLC) in 802.11 occurs and the probability that B’s packet is successfully received at C increases despite A’s simultaneous transmission. If SIR is above the second SIR threshold (which is higher than the first one), the reception probability of B’s packet reaches almost one.

From the experimental results, we observe that the SIR threshold for PLC is determined by two factors: 1)PHY bit rate and 2) arrival timing between the sender’s and interferer’s packets at the receiver. We measured the capture SIR thresholds for different PHY bit rates of the sender and observed that higher PHY rates requires higher SIR thresholds for capture. As for the arrival timing, for example, when a sender B’s packet arrives at the receiver C before an interferer A’s packet, the capture threshold is lower (or easier to survive the interference from A) than the capture threshold of when the B’s packet arrives later than A’s. Fig. 3 shows the different capture thresholds for multiple PHY rates measured when only sender B carrier senses interferer A, which means B’s packets always arrive earlier than A’s packets.

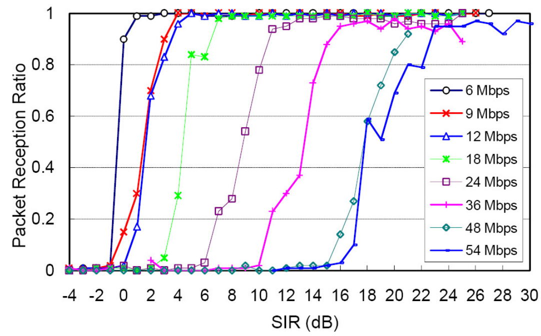


Fig. 3. PRR of link B→C with interferer A for multiple 802.11a PHY rates. Only B carrier senses A, not vice versa.

An interesting fact we have observed is that the CS relation affects the arrival timing. If B and A carrier sense each other, collision (thus interference and capture) hardly occurs. If only B senses A’s transmission while A does not, B’s packets are always transmitted ahead of A’s packets, but not vice versa. If neither B nor A senses the other, their transmission (and arrival) timing will be randomly distributed.

In conclusion, we can model the degree of interference from node A to link *B→C* as a function of SIR, PHY rate of B, and the CS relation between B and A. Once the carrier sense and interference relations are estimated, we are capable of estimating the link throughput.

4. Performance Evaluation

We evaluate the accuracy of RBP on the 11-node 802.11a mesh network testbed in Seoul National University. Small-form factor singleboard computers [6] with mini-PCI 802.11a cards using Atheros chipset [7] are used to create the testbed.

We first perform hello broadcast for every node to transmit 200 hello packets twice with high-power and normal-power levels, which takes less than 3 minutes. This is the measurement time overhead of RBP in our instantiation. We predict the CS and interference metrics based on the RSS of the hello exchanges. To verify the accuracy of RBP, we perform measurements for the node-pair carrier sensing test and the link-pair interference test. The entire experiment took about 9 hours.

4.1. Prediction Accuracy

To effectively evaluate RBP accuracy, we devised CS metric and interference metric as described in [5]. We compare the predicted metrics based on RSS and the measured metrics.

For the 110 directional node pairs in our 11-node testbed, the mean prediction error is 0.03. We note that 13% of the node pairs exhibit asymmetric CS relation in SNU testbed and 17% in the HPL testbed. These numbers support the significance of asymmetric CS study. As for the interference estimation, with the high-power probing, the overall median and mean prediction error is 0.01 and 0.14, respectively.

4.2. Overhead Comparison

Above discussion on the verification of RBP prediction gives us an insight on the measurement overhead. In our 10-node testbed, RBP requires 20 hello broadcasts for high-power/normal-power probing. When we measure broadcast throughput and goodput for the CS verification, 90/2=45 node pairs must be examined and each pair examination requires at least three times broadcast. Thus 135 broadcasts are required in total. One may sense that this 135-time broadcast overhead is same for the BIR test. In the same manner, 152 pair of links must go through three times measurements. Thus 456 broadcast measurements are required, and this number is same with the LIR measurements while LIR performs unicast and our interference test performs broadcast. Please recall that LIR requires $\mathcal{O}(n^4)$ examinations and BIR requires $\mathcal{O}(n^2)$ examinations: in our testbed, RBP, BIR and LIR incur 10, 135 and 456 times broadcast transmission/measurement overhead, respectively.

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