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Estimation of Interference in Wi-Fi Networks

Prajakta D. Patil[1], M. M. Wankhade[2]

Student, E & TC, Sinhgad College of Engineering, Pune, India[1]

Professor, E & TC, Sinhgad College of Engineering, Pune, India[2]

Abstract: The rapid proliferation of wireless devices has led to an increased usage of Wi-Fi. But at the same time, the issue of interference in highly loaded scenarios cannot be neglected. Interference is a major cause of degradation of capacity and thus performance in 802.11 wireless networks. The knowledge, of which links in the network interfere with one another, and to what extent, is important to improve, or even to estimate the performance of these networks. This paper presents a technique to estimate the interference in Wi-Fi networks with the help of hidden Markov model. Wireless traffic traces are captured through sniffer and analysed using a machine learning approach to conclude about the carrier-sense relationship between network nodes. To add to it, an estimation of deferral probabilities helps to understand the interference relationships. The effectiveness of the technique is evaluated using ns2 simulation which shows that this method expresses interference relations with the help of metrics such as probability of deferral, packet delivery ratio etc. in a better manner.

Keywords: 802.11 protocol, interference, hidden Markov model, carrier sense.

I. INTRODUCTION

Wireless networks such as 802.11 have enjoyed an increased adoption rate in recent years, and their deployed base continues to grow. Initially envisioned to support mobile devices, wireless has also proved popular in more static settings that involve PCs and laptops in homes and offices as it removes the hassle of wiring. Wi-Fi performance degrades due to wireless interference in loaded networking scenarios [10] [11]. A fundamental issue in these networks is interference, in which transmissions from one sender-receiver pair affectthose of other pairs. The achievable capacity of a wireless network is interference limited [1]. Interference defines the spatial boundaries for spectrum reuse, and it directly impacts the assignment of senders to channels [2], network capacity [1], and routing choices [3].

Research has been done in the past to understand the wireless interference in theory; real network deployments are yet to implement it. This paper presents a technique to understand and estimate the wireless interference between network nodes and links. The goal is to accomplish this passively i.e. without placing any monitoring device at the access point or without installing monitoring software on clients. This is done because active measurements affect (and are affected by) network traffic. The passive method includes creating a Wi-Fi network scenario using ns2 simulator. The wireless frame traces are captured by sniffer, which are then analysed to get information about interference relations. Fig. 1 shows the overview of the approach.

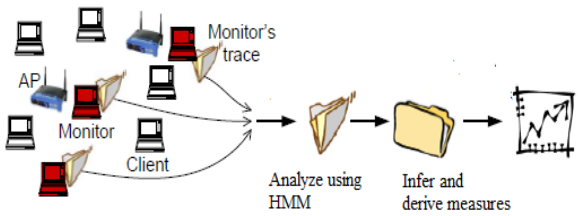

Fig.1 Overview of approach

One way of estimating interference among links in a wireless network can be described informally as below: If a set of wireless links is given, determining whether (and by how much) their aggregate throughput will decrease in two cases. First, when all the links are active simultaneously and second, when they are active individually. Comparing both these cases will lead to the conclusion [5]. Interference is considered as degradation in performance or disruption of communication. Interference impacts the sender by reducing its maximum sending rate, and it impacts the receiver by reducing the probability of receiving a packet successfully by causing collisions [4]. Fig. 2 shows the sender-side interference and receiver-side interference in the transmission from two senders.

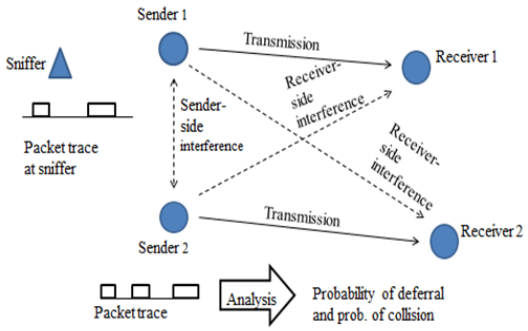

Fig. 2 Transmission from two senders [6]

The packet trace is analysed to infer about the interference relations in terms of probability of deferral and probability of collision. In wireless networks, interference is better expressed interms of probabilities because of the inherent fluctuation ofthe signal power due to fading effects and probabilisticdependency of error rates with signal to interference plusnoise ratio (SINR). Therefore, sender-side interference is expressed in terms of probability of deferral [6].

II. RELATED WORK

Interference can be readily measured by placing saturated traffic on two links simultaneously and measuring the aggregate throughput. The amount of interference is indicated by the decrease in throughput due to the interference from the other transmission. This approach is done with few measurements

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than required in [5]. Some methods require active measurements as in [7]. The other methods follow some modelling steps to reduce the number of measurements. The approach followed is 1) measure Received Signal Strength(RSS) on each link by broadcast transmission of beacons, 2) carry out a profiling study describing the deferral and packet capture behaviour, 3) develop a suitable MAC-layer model. The above steps lead to the estimation of interference between active links and link capacities in presence of interfering traffic [6].

Charles Reis, et al. [8] present practical models for physical layer behaviours of packet reception and carrier sense with interference in static wireless networks. The inputs to these models are measurements from a real network. The basic idea is to perform measurements in an N-node network with N trials. Each sender transmits in turn and receiver's measure RSSI values and packet counts which are easily achievable with the help of wireless cards. The low-level models for packet reception and carrier sense are formulated by considering to the conventional idea of SINR (signal to interference plus noise ratio). The 802.11 characteristics are investigated, both in a controlled setting with attenuators built on a network. Packet delivery and interference are predicted by the models for different sets of transmitters with similar node placements.

Jitendra Padhye, et.al [5] proposes a simple empirical estimation methodology that can predict pairwise interference using few measurements. This method can be applied to any wireless network having omnidirectional antennas. The metrics defined in this paper are Link Interference Ratio (LIR) and Broadcast Interference Ratio (BIR). LIR is defined to be the ratio of aggregate throughput of the links when they are active simultaneously, to their aggregate throughput when they are active individually. This metric takes values between 0 and 1. The value of LIR when 1 indicates that the links do not interfere because the aggregate throughput does not decrease inspite of both the links being active at the same time. BIR is the ratio of the combined delivery rates to the individual delivery rate i.e. the total delivery rate with a pair of nodes as the sender to the delivery rate with a single node as the sender. The supposition is that the BIR is a good approximation of LIR.

Lili Qui, et.al [9] develops a general model in the presence of interference from other nodes in the network which estimates the throughput between arbitrary pairs of nodes. The measurements required for the model are taken from the underlying network to be more accurate compared to the abstract RF propagation model. The proposed model in this paper consists of three components - a) An N-node Markov model, b) A model of packet-level loss rates, c) Sender and receiver model with unicast transmissions. The model in this paper takes RF profile and traffic demands as inputs and provides the sending and receiving rates of each node as output. The concept of one-hop traffic is focused in this paper, which is the traffic sent over only one hop and not routed further.

III. METHODOLOGY

A. Problem statement

In 802.11 networks, interference can occur either at the sender-side or at receiver side. The sender-side interferenceleads to delay of the transmission due to carrier sensing. It also reduces the sender's sending capacity by being in its carrier sense range. In case of receiver-side interference, overlapped packet transmissions cause collisions at the receiver. This results in retransmission. Both the cases require the sender to go through a backoff period in addition, when the medium is sensed idle which leads to decrease in the throughput capacity of the network [6].

B. Objectives

To attain the objective of estimating the interference relations between nodes, the following goal has to be met. The goal is to 1) identify instances where a pair of nodes attempt to transmit simultaneously, and 2) infer the deferral behavior of node during such instances.

C. Approach

The basic approach consists of modeling the 802.11 MAC-layer operations of two sender nodes in the network via a Markov chain. The parameters of this chain i.e. the state transition probabilities are estimated from the trace using the method based on Hidden Markov Model. These parameters can help to conclude about the deferral probabilities.

The 802.11 MAC-layer operations of each sender node (say X or Y) can be modelled via a Markov chain. A sender node, say X, is found in one of the following four states -"idle," "backoff," "defer," and "transmit." The essence of the 802.11 MAC protocol lies in these four states. Fig. 3 shows state transition diagram for a single sender. CS = 0 (CS =1) means that the carrier is sensed idle (busy). Q = 0 (Q =1) means that the interface packet queue is empty (nonempty). The inter-frame spacing's (e.g., DIFS) are purposely ignored to keep the chain simple. In the rest of the paper, the four states are denoted as I, B, D, and T for the sake of simplicity [6].

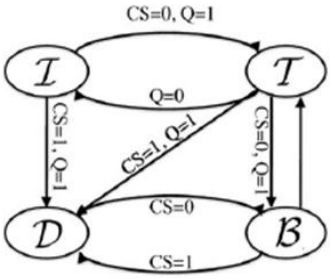

Fig. 3 State transition diagram for a single sender [6]

Since the state transitions of the Markov chain for a given sender is impacted by the transmissions from other nodes, a Markov model of a single sender is not enough to get the complete picture of the network behavior. Instead, a combined Markov model needs to be considered. Since the focus is mainly on determining the pair wise interference relationships, a combined Markov chain for only a pair of nodes, say X and Y is considered. Each state in this Markov chain is a two-tuple consisting of the states of X and Y. For example, the state where X transmits and Y defers would be (T, D). Out of 16 possible states in theory, five states are not legal (e.g., [D, D], [D, B] etc.), leaving 11 possible states [6]. Fig. 4 shows the combined Markov chain for two nodes.

The state transition probabilities between certain states in this Markov chain are determined by the deferral probabilities

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between X and Y. For example, transition probabilities from state (B,B) to state (T,D) or (T,B) would depend on deferral probability of Y with respect to X. This can be explained with the help of an example. Assume that Y carrier senses X (or Y can sense X's transmission) perfectly. Then when X moves from B to T state (i.e., starts transmitting as soon as the backoff interval is over), Y must also move from B to D as it defers to X's transmission by freezing its backoff countdown timer. If instead Y never carrier senses X, it will remain in the B state. The deferral probability of X and Y depends on the number of instances when either of the nodes moves to D state [6].

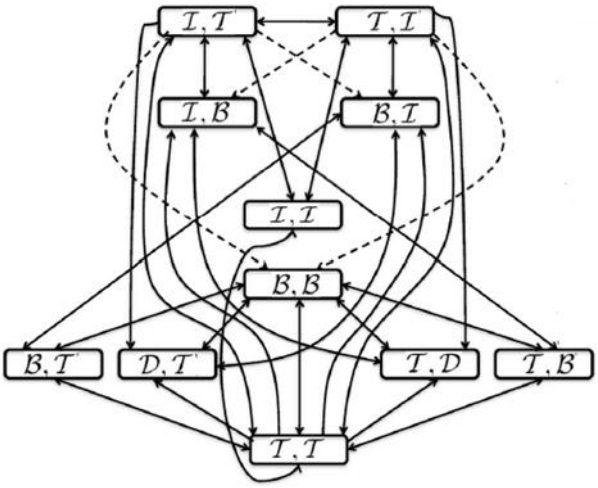

Fig. 4 Markov model of the combined MAC layer behaviour of two nodes [6]

The state transition probabilities of the combined Markov chain depend on the deferral behaviour between the two nodes under consideration. Thus, if the unknown state transition probabilities are learned, the deferral relations are got as a result. The states of the Markov chain are not directly visible in the trace. Instead a set of observation symbols are visible. Four observation symbols are possible in the trace depending on whether X or Y transmits:
i: neither X, nor Y transmitting
x: X transmits
y: Y transmits
xy: both X and Y transmit
Each of the 11 states in this Markov chain is mapped to one of the four observation symbols. This mapping is not unique as more than one state can map to the same observation symbol. For example, both states (I, I) and (B, B) map to the symbol i. Similarly, both (B,T) and (D,T) map to symbol y. Each packet in the packet trace is time stamped with the arrival time at the sniffer along with other information including the id of the sender, size of the packet, and the rate at which it wastransmitted. This information in the trace is parsed to obtain the sequence of observation symbols for the two senders under consideration [6].

D. Interference relations

Transitions into any state with a defer component (i.e., states such as (D, *) and (*, D) indicate interference. Similarly, the absence of interference is indicated by transitions into any state of the set {(B, T) (T, B) (T, T)}. Thus the sender side interference can be interpreted as the total probability of transition into the interfering states. The deferral probability, p_d, is given by-

$$\frac{P(D,T) + P(T,D)}{(P(D,T) + P(T,D) + P(B,T) + P(T,B) + P(T,T))} \quad (1)$$

Equation 1 captures the probability of being in the interfering states when one of the two nodes is transmitting. A symmetric link is assumed in this case between a node pair [6].
Collisions due to the receiver-side interference can be detected by tracking retransmissions in the trace. The retransmitted packets can be identified with the help of the "retransmit bit" in the frame header. A retransmitted frame, say R, can be correlated back to the original frame, say P, that has not been received correctly as both these frames carry the same sequence number. A potential cause of collision is overlapping of P with any frame S, sent by a different sender. If P does not overlap with any other frame, the packet loss is due to wireless channel errors rather than collisions. Sufficient statistics need to be built up to determine receiver-side interference because of the probabilistic nature of packet capture. This is because frames like S and P—even when overlapping—may not always result in a collision. Thus, the receiver-side interference between two links or the probability of collision pc can be determined as the ratio of the collision count and the overlapped-frame count [6].

IV. SIMULATION AND RESULTS

Simulation is carried out with the help of Network simulator version 2.34 and Fedora as the operating system. The simulation parameters are shown in Table 1. 802.11 wireless scenarios is created wherein 50 nodes are considered. Sniffer is used which captures the traffic trace. Evaluation is carried out by comparing the technique of this paper with profile [7] and window based schemes [6] used in the past.

TABLE I SIMULATION PARAMETERS

Parameters	Values
Terrain area	1000 X 1000
No. of nodes	50
Energy	100 joules
Data rate	2 Mbps
Packet size	512 bytes
Simulation time	200

Traffic is created using CBR as the application traffic and the transport agent used is UDP. The performance metrics are as follows:

A. Packet Delivery Ratio

The packet delivery ratio (PDR) is defined as a ratio of numbers of data packets reached to target over the network to number of packets generated. A high packet delivery ratio indicates that the numbers of lost packets are less. Fig. 5 demonstrates that the lost packets for HMM method are less compared to the profile and window based scheme. As a result, the receiver-side interference is low for HMM method.

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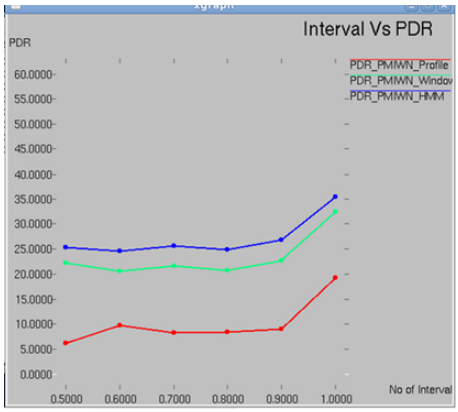

Fig. 5. PDR v/s No. of interval

B. Probability of deferral (p_d)

This parameter indicates about the delayed transmission of the sender node.

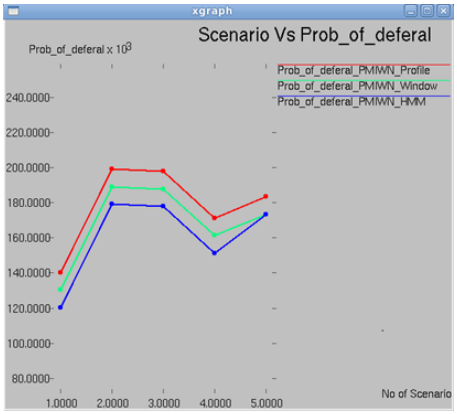

Fig. 6. Scenario v/s Probability of deferral

It essentially captures the probability of being in the interfering states when one of the two nodes is transmitting. Thus, the probability of deferral should be low. As the probability of deferral is low, sender-side interference is less with HMM method compared to profile and window based scheme. Fig. 6 shows graph of probability of deferral for different scenarios.

C. Throughput

Throughput is defined as the in data packets received by sink nodes to time from first packets generated at a source to last packet received by sink nodes. The greater value of throughput states superior performance.

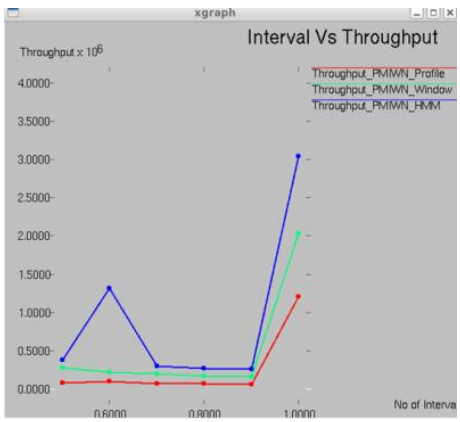

Fig. 7. Throughput v/s no. of interval

Fig. 7 shows the throughput of the PMIWN_HMM method to be high, compared to the profile and window method. Better throughput indicates that the interference is less.

D. Routing overhead

It refers to the data bits added to user-transmitted data, for carrying routing information and error correcting and operational instructions. The value of routing overhead in the protocol should be low. Fig. 8 shows that the routing overhead for the HMM method is minimum compared to the profile and window schemes.

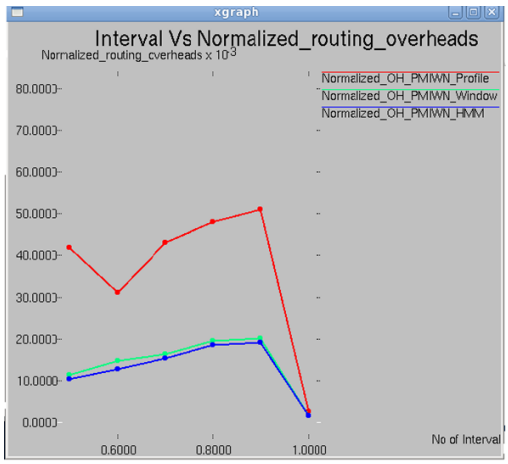

Fig. 8. No. of interval v/s routing overhead

V. CONCLUSION

The estimation of interference in an 802.11 network is carried out with the help of hidden Markov model. The estimation of deferral probability at the sender-side plays a major role in inferring the interference in the network links. The advantage of this technique is that it is passive and does not disturb the live network. The performance metrics show that the technique used in this paper is effective compared to the profile and window schemes. There is indeed some limitation of the technique because the deferral behavior is estimated assuming only pairwise interference and has ignored physical interference arguing that the improvement in accuracy is relatively minor. Moreover, interference relationship can be used for efficient network design and capacity allocation. This interference can contribute to the total physical interference in the network which can increase the user experience.

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