Enhanced Wireless Mesh Networking for ns-2 simulator

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ABSTRACT

The ns-2 simulator has limited support for simulating 802.11-based wireless mesh networks. We have added the following new features at the MAC and PHY layer of ns-2: (i) cumulative interference in SINR (Signal to Interference and Noise Ratio) computation, (ii) an accurate and combined shadow-fading module, (iii) multi-SINR and multi-rate link support, (iv) auto rate fallback (ARF) for rate adaptation, and (v) a framework for link probing and link quality estimation as required by most mesh routing protocols. We have made these modules publicly available. In this paper, we present an overview of these new features.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication; C.2.5 [**Computer-Communication Networks**]: Local and Wide-Area Networks; I.6 [**Computing Methodologies**]: Simulation and Modeling

General Terms

Design

Keywords

Wireless network, Wi-Fi, 802.11, mesh network, network simulation

1. INTRODUCTION

Researchers working in the area of wireless communications heavily rely on simulations to evaluate the performance of proposed algorithms. This is primarily because setting up large scale wireless testbeds, and ensuring repeatability across multiple testbeds is a difficult task. The ns-2 simulator [3] is one of the most widely used network level simulator for wireless research, since it is publicly available, and is open source. Users can add new modules to ns-2 with relative ease, and there is a large user community and active mailing lists for both users and developers. Other open source simulators such as, SWAN [14], JIST [2], Glomosim [1], and commercial simulators such as, Qualnet [5], and Opnet [4] are also popular among researchers.

The focus of this paper is the simulation of 802.11-based wireless mesh networks in ns-2. As pointed out in [17, 14, 6], the current implementation of MAC and PHY-layer wireless models in ns-2 *does not* abide by the following principles of wireless communication.

1. The computation of SINR (Signal to Interference and Noise Ratio) should take into account the sum of the strengths of all the interfering signals instead of just the strongest interfering signal [17].

2. The channel gain model should be comprehensive in that it should include distance based path loss, location dependent shadowing, and velocity dependent fading [16, 17, 14, 6].

3. The channel gains could be different in either direction due to shadow-fading, and the simulator should model such asymmetric link conditions [14].

4. The simulator should also model fluctuations in the capacity of a link due to time variations resulting from fading [14].

Furthermore, ns-2 only allows for a common and fixed data rate for all the links in a mesh network. In real 802.11 hardware, depending on the channel conditions, a rate adaptation algorithm such as Auto Rate Fallback (ARF) [10] chooses the highest possible data rate among the eight candidate data rates (6, 9, 12, 18, 24, 36, 48 and 54 Mbps) to suit the current channel conditions. Each of these data rates have a different SINR requirement; the higher the SINR, the higher the sustainable data rate. A wireless link simulator should have support for such multi-rate and multi-SINR link model with link rate adaptation. Support for multi-rate links with ARF was contributed in [19], however this code relies on comparing the received signal strength to fixed thresholds for determining successful reception. Received power based decision is inaccurate since in real systems, the SINR determines the success/failure of a transmission.

To overcome the above mentioned limitations, we have added the following new features to ns-2 (version 2.30):

1. Cumulative interference along with noise power for an accurate SINR-based reception model,

2. Combined shadow-fading with an accurate shadowing model (current shadowing model of ns-2 is inaccurate, and furthermore, it cannot be used in combination with the fading module),

3. Multi-SINR and multi-rate 802.11 a/g links,

4. Auto-rate fallback (ARF) algorithm for rate adaptation (currently, ns-2 only supports links with fixed rate), and

5. A framework for link quality estimation using unicast and broadcast probes as required by most mesh routing protocols such as, ETX [8], ETT [9], and ETP [13].

Our contributed modules are publicly available [12].

2. NEWLY ADDED FEATURES TO NS-2

In this section, we discuss the newly added features, and how each of those features result in a more accurate simulation of real life wireless links.

2.1 Cumulative Interference and Noise

The PHY-layer quality of a link is determined by the SINR of the link. If node i is transmitting to node j, and $\mathcal{T}_i$ is the set of other nodes that transmit concurrently with i, then the SINR of link (i, j) is given by,

$$\mathrm{SINR}_{(i,j)} = \frac{P_{ij}}{\sum\limits_{k \in \mathcal{T}_i} P_{kj} + \mathcal{N}_0},$$

where the P_{mn} is the received power at node m when node n is transmitting. In the current implementation of ns-2 (version 2.30), instead of computing SINR of each packet, the received power of the desired packet is compared with the received power of the strongest interfering packet. The packet reception is assumed to be successful only if the ratio of the powers is greater than a threshold SINR. Thus, in addition to not taking into account the noise power, the current implementation also fails to compute the strength of the *cumulative* interference [17]. In our implementation, we keep track of the received power from *all* the concurrent transmissions, and add it to the noise power at the receiver to compute the exact SINR. The receiver noise power is to specified as a fixed parameter at the beginning of the simulation.

2.2 Combined Shadowing and Fading

When node i transmits to node j at a power level P, the received power at node j is given by (see [16])

$$P_{ij} = P \cdot c d_{ij}^{-\alpha} \cdot 10^{-\frac{X}{10}} \cdot \mathbf{W}_t^2. \tag{1}$$

In the above, the second term is the fixed distance-dependent path loss term with a path loss exponent α, the third term is the random lognormal shadowing, while the third term is the stochastic time-varying fading. In the current ns-2 implementation, there is a bug in the implementation of the shadowing module [6], whereby the shadowing term is assigned a newly generated random variable during every new packet transmission. In reality, the shadowing gain between two nodes is random, but fixed as long as the two nodes are stationary [16]. Furthermore, the contributed fading modules [15, 18] cannot be used in combination with the inbuilt shadowing module. We corrected the shadowing implementation of ns-2 so that (i) the shadowing gain is not recomputed during each packet transmission, and (ii) the shadowing and fading modules can be used together so that the comprehensive channel gain model in Eq. (1) can be simulated.

Note that the above modifications are suitable only for mesh networking scenarios where the mesh nodes are stationary, and the shadowing gains are not time-varying. However, the movement of other objects in the vicinity of the mesh nodes results in time variation in the received signal strength. This time variation can be captured through the fading term. The velocity of the objects in the neighborhood of mesh nodes determines the nature of fading [16], and the fading modules contributed in [15, 18] can take this into account.

Index	1	2	3	4	5	6	7	8
Rate, Mbps	54	48	36	24	18	12	9	6
SINR, dB	24.6	24	18.8	17	10.8	9	7.8	6

Table 1: SINR requirements for different data rates for 802.11a/g

2.3 Multi-SINR and multi-rate links

One of the most significant limitations of the mesh networking support in the current version of ns-2 is that all the link rates have to be set to a common value. In reality, depending on the environment, different mesh links within the same mesh network have different data rates. The inability of the current implementation to support multi-rate links results in simulation settings that are far from reality. For example, it is highly unlikely that in a mesh network with 20 nodes, all the links support a data rate of 54 Mbps. The data rate that can be supported on a link depends on the SINR of the link. Table 1 shows eight discrete data rates supported by 802.11 a/g for different SINR values [20]. Each of these data rates use a different modulation-coding scheme.

We have implemented the multi-rate, multi-SINR module whereby it is possible to simulate truly heterogeneous (and hence realistic) mesh network settings whereby links have diverse SINR and data rates. The operational data rate of each link can either be statically set, or can be determined dynamically during the course of the simulation using a rate adaptation algorithm (discussed next).

2.4 Link Rate Adaptation

Although 802.11 a/g support eight discrete data rates, the choice of the highest sustainable rate is not obvious, since the channel conditions vary all the time. In order to opportunistically use the highest sustainable rate on a given link, rate adaptation algorithms such as, Auto Rate Fallback (ARF) [10], Adaptive Auto Rate Fallback (AARF) [11], and SampleRate [7] have been designed. These algorithms probe the link quality by trying a higher data rate every so often. If the transmission on this rate succeeds, the link is operated on the probed rate. If the transmission fails, the radios continue to operate at the current rate. Such algorithms aim at adapting the transmission rate to the current channel conditions, and thus automate the rate selection process. We have implemented the basic ARF algorithm [10] in our contribution. Implementation of more advanced rate adaptation algorithms such as, AARF [11], and SampleRate [7] is part of ongoing and future work.

In Fig. 1-5, we demonstrate the working of ARF. We consider an 802.11g link between two stationary mesh nodes separated by 100m. The transmit power is 20dBm, the noise power is -96dBm, and the path loss exponent is assumed to be 3. CBR packets are sent from one of the nodes to the other node. We simulate a Rayleigh fading channel between the two nodes. The dotted lines indicate the SINR threshold for each of the data rate. If the SINR is above this threshold, packets transmitted at the corresponding data rate can

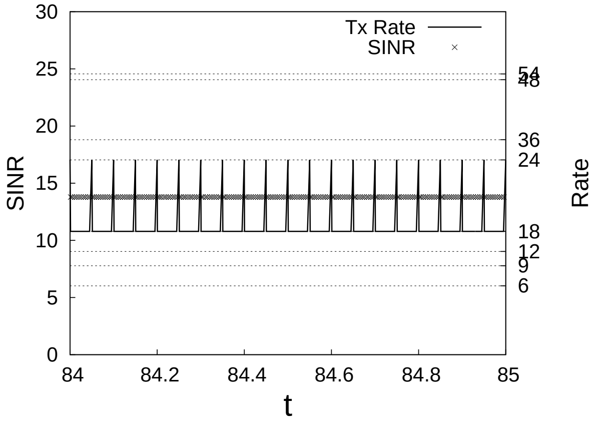

Figure 1: Velocity of 0 m/s.

be successfully decoded. The transmitter should adapt its data rate to the SINR at the receiver so that the link always operates at the highest sustainable rate.

When the velocity parameter of the fading model is set to zero, i.e., when there is no fading, the channel gain is constant. Consequently, as shown in Fig. 1, ARF uses the highest sustainable data rate of 18Mbps. Once every ten packets, tries the next higher rate (which is 24Mbps). When this probe transmission fails due to insufficient SINR, the algorithm drops back to the previous rate. In Fig. 2-5, we note that as the velocity parameter is increased, the time variations in the received signal strength, and hence the SINR increase. The ARF algorithm tries to adapt to these time variations. When the fading is slow (e.g., 0.2m/s in Fig. 2), the algorithm quickly adapts to the current channel conditions, and picks the highest sustainable rate at almost all times. However, when the channel is changing rapidly (e.g., 0.8m/s in Fig. 5), the algorithm 'lags' behind the channel variations. Also note that there are short periods during which the link is in a bad fade, and the SINR is not high enough to sustain even the lowest data rate of 6Mbps. This leads to complete link outage during which the receiver cannot decode any packets (e.g., period between $t = 84$ and $t = 84.1$ in Fig. 2). During such a period, the transmitter drops down to the lowest possible data rate (6Mbps), and keeps retransmitting the dropped packets (until the maximum retry count).

2.5 Framework for link quality estimation

Most mesh routing protocols such as, ETX [8], ETT [9], ETP [13] rely on periodic probing for link quality estimation. In the actual implementation of these routing protocols, periodic broadcast or unicast packets are transmitted on the links. Many simulation studies use deterministic settings whereby no online measurement/monitoring modules are used during the progress of the simulation However, in presence of random and time-varying shadow-fading, we need support for measurement/monitoring modules so that the routing decisions based on link measurements reflect the dynamism of the environment.

We have therefore added support to ns-2 for generating periodic link quality probe packets (using a modified `ping` agent). The agents allow us to collect link-level statistics such as, RSSI, sustainable data rate, packet loss percentage

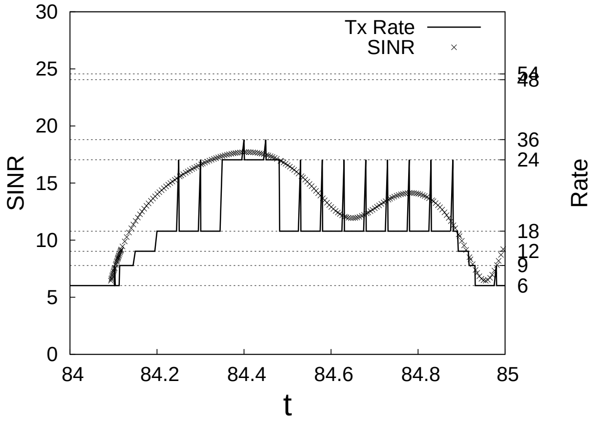

Figure 2: Velocity of 0.2 m/s.

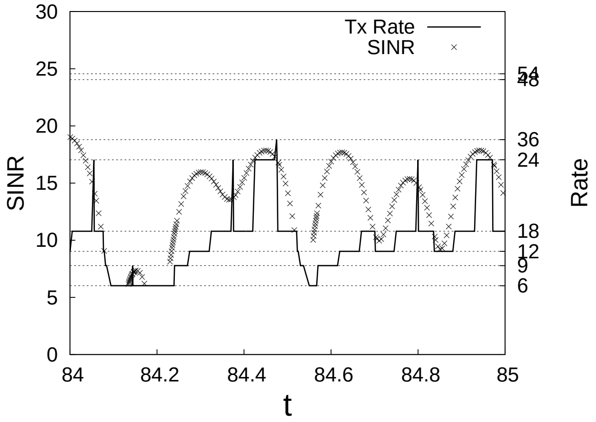

Figure 3: Velocity of 0.4 m/s.

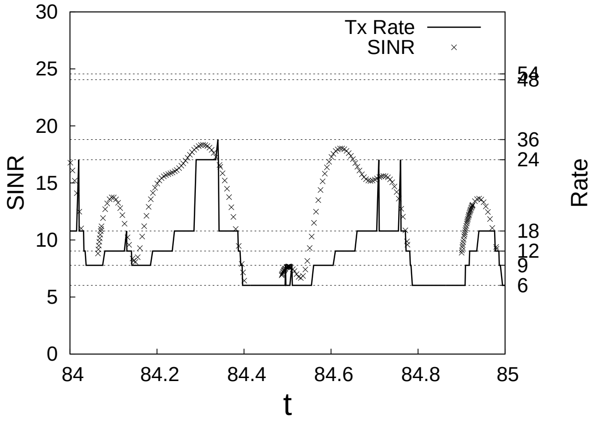

Figure 4: Velocity of 0.6 m/s.

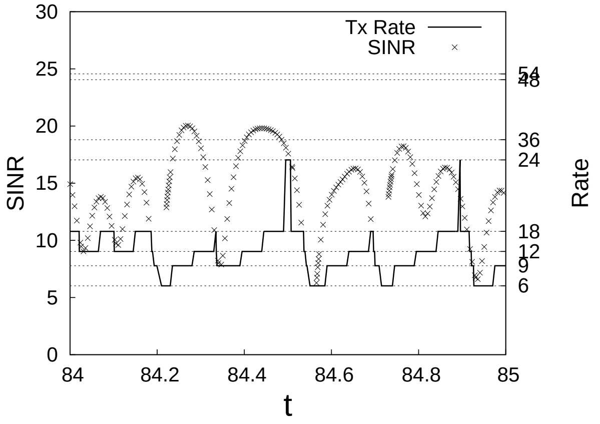

Figure 5: Velocity of 0.8 m/s.

etc. of the probed links. We believe that this framework can be further extended to allow monitoring of other quantities of interest.

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