On the Impact of Noise on Mobile Ad Hoc Networks

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ABSTRACT

Network simulators such as NS-2, Glomosim, and OPNET are extensively used to validate and evaluate the performance of network protocols for mobile ad hoc networks (MANETs). For accurate simulations, realistic signal propagation and noise models should be used to simulate the radio channels in MANETs. A significant amount of emphasis is put on the correctness of signal propagation, while the ambient noise (due to external sources) is modeled as a constant noise. Based on the noise levels measured in a wireless ad hoc network testbed, we present two analytical models to describe the noise levels in a real network: a generalized extreme value (GEV) random process model and a Markov chain model. We incorporate GEV noise model in the Glomosim network simulator and show that it impacts the network performance significantly.

Categories and Subject Descriptors

C.4 [**Computer Systems Organization**]: Performance of Systems—*Measurement techniques, Modeling Techniques*

General Terms

Measurement, Performance

Keywords

Mobile Ad Hoc Networks (MANETs), Noise Measurement, Noise Modeling, Routing Protocols

1. INTRODUCTION

Recent advances in wireless communication technology and portable devices have generated a lot of interest in mobile ad hoc networks (MANETs). A MANET is a collection of wireless devices moving in seemingly random directions and communicating with one another without the aid of an established infrastructure. To extend the reachability of a node, the other nodes in the network act as routers. Thus, the communication may be via multiple intermediate nodes between source to destination. The design of routing and other protocols that cope up with the unreliability of wireless channels and node mobility has been investigated extensively.

In most cases, network simulators such as NS-2 [10], Glomosim [3], and OPNET [16] are used to evaluate the performance of proposed protocols in literature. A few recent studies investigated the deficiencies of simulation studies by examining the signal propagation in simulation versus in an actual ad hoc network [15, 2]. However, the background noise models used in the current simulators have not received any attention. In particular, the current simulators use a low, constant value and ignore the fluctuation of background noise due to external sources. (Noise accumulated from competing distant transmissions is modeled extensively as part of the simulation. The three major simulators model the same based on the signal propagation model they use.) In a real ad hoc network, however, the background noise level can vary significantly. Since the 2.4 GHz band used by 802.11b and 802.11g is unlicensed, many different types of equipment may use (e.g., cordless phones, cell phones, radio frequency based remote controllers, etc.) or generate noise (e.g., microwave ovens and other electrical devices) in these frequencies, either accidentally or deliberately. In addition, other wireless devices, which do not belong to the investigated wireless network but use the same radio spectrum for their communication, increase the background noise ("interference"). A few recent studies investigated static multihop wireless networks [17, 1] and several new path metrics and routing techniques were proposed to improve network throughput [9, 11, 4]. In [19], the authors presented practical models based on measurements of received signal strength (RSS) values and delivery probability in static wireless networks. These models can predict packet delivery and throughput in the same network for different sets of transmitters with the same node placements. However, how background noise fluctuates and affects RSS is not given.

In this paper, we present measurement and analytical modeling of background noise for wireless routers in an ad hoc network testbed. The measured data show that the background noise for wireless device changes frequently and can be extremely high at times. We show that the actual noise seen over a period of time by a wireless node can be modeled by the generalized extreme value (GEV) random process. We also model the noise changes as a Markov

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chain and evaluate the accuracy of the proposed Markov noise model. We incorporated the simpler GEV noise model in the Glomosim simulator and evaluated the performance of popular ad hoc routing protocols such as Ad hoc on demand distance vector routing protocol (AODV) [18] and dynamic source routing (DSR) [13] for mobile ad hoc networks. Compared to the default constant noise model, the proposed GEV noise model impacts the network performance significantly. The reason is that temporary but high, fluctuating noise levels can disrupt the transmission of a packet by an intermediate node, though the route is still valid when the noise level subsides. This causes the transmitting node to conclude that the route is broken and trigger a route discovery requiring network-wide flooding of control packets.

The rest of the paper is organized as follows. Section 2 presents the measurement and modeling of background noise for wireless devices. Section 3 shows the impact of noise fluctuation on MANET's performance. Section 4 concludes the paper.

2. NOISE MODELING

In this section, we measure and model the background noise for wireless devices.

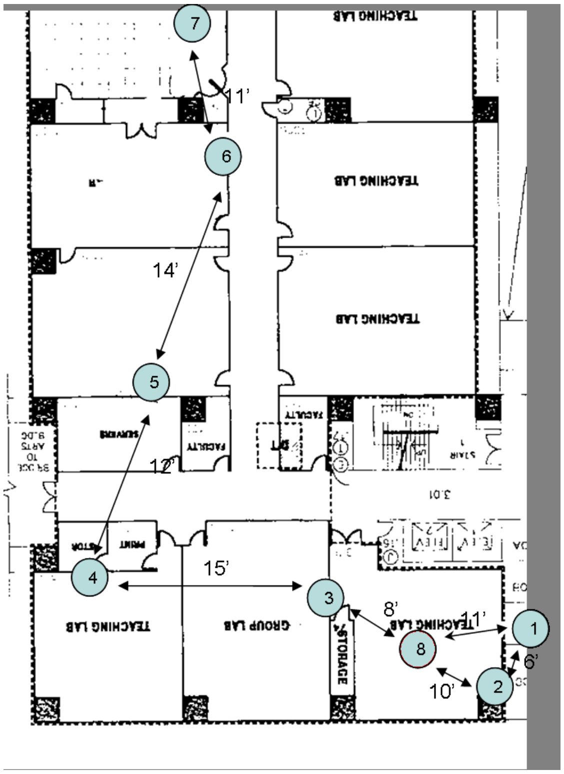

Figure 1: Network testbed indicated by circles for wireless nodes over a background of room layout.

2.1 Background Noise Measurement

We used a wireless network testbed to measure the background noise. The testbed consists of 8-node Linksys wrt54g Wi-Fi routers [8] placed in various rooms and laboratories in the department, as shown in Figure 1. The wrt54g routers have a built-in 4-port 100 Mbps Ethernet switch, an 801.11g access point, a 200 MHz MIPS processor, and 12 MB of usable RAM and 4 MB of flash memory, which serves as the disk memory [20]. We reprogrammed the routers using OpenWrt linux [6, 5]. All 8 routers use the same ssid (which is different from other Wi-Fi devices in the building-wide 802.11b/g production network) so that they can communicate among themselves only. We obtain the current noise level using the *wl* program that comes with the router and the noise information is sent to a specified desktop machine via the Ethernet. Due to the overhead of noise sampling, we could only sample noise for every 100 ms in a router. Figure 2 shows the noise data sampled from one of the 8 routers in the testbed (node 6 in Figure 1). The noise levels are much higher than the default ambient noise levels used in current simulators. (The current simulators model interference from other nodes' transmissions, whereas the ambient noise is generated by independent external sources in the environment surrounding the node.) Also, the noise fluctuates and at times reaches very high values. The noise data gathered from other routers have the same distribution and nearly identical histogram charts.

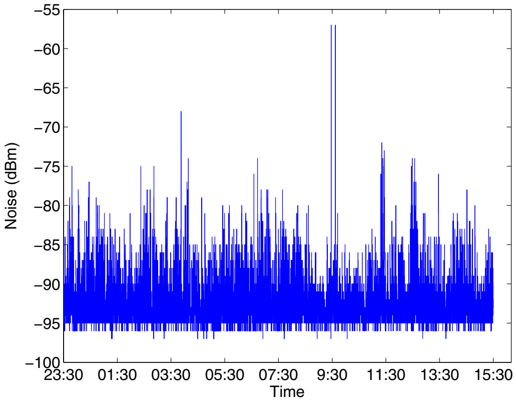

Figure 2: Background noise changes for 16 hours (11:30 pm to 3:30 pm the next day).

2.2 GEV Noise Model

We used MATLAB [21] to analyze and model the noise levels captured in the measurement. MATLAB has an extensive library of distributions including Gaussian, gamma and lognormal. In such diverse fields as image processing, architectural acoustics, and electronic music, it is often assumed that noise conforms to Gaussian distribution. But we found that neither Gaussian nor any of the commonly used distributions such as gamma and lognormal model the noise levels seen by wireless routers accurately. Further investigation revealed that the generalized extreme value (GEV) distribution [14] models this background noise fairly accurately. The GEV distribution has cumulative distribution function (CDF)

$$F(x;\mu,\sigma,\xi) = \exp\{-[1+\xi(\frac{x-\mu}{\sigma})]^{-1/\xi}\} \qquad (1)$$

$$\text{for } 1+\xi(\frac{x-\mu}{\sigma}) > 0$$

where μ is the location parameter, the scale parameter $\sigma > 0$ and the shape parameter ξ. The shape parameter ξ governs the tail behaviour of the distribution. The probability density function (PDF) is, consequently

$$\begin{aligned} f(x;\mu,\sigma,\xi) &= \frac{1}{\sigma}[1+\xi(\frac{x-\mu}{\sigma})]^{-1/\xi-1} \\ &\quad \exp\{-[1+\xi(\frac{x-\mu}{\sigma})]^{-1/\xi}\} \qquad (2) \\ &\quad \text{for } 1+\xi(\frac{x-\mu}{\sigma})>0 \end{aligned}$$

Figure 3 gives the frequency or histogram diagram for the sampled noise data from router 6 and two histogram curves corresponding to the Gaussian distribution and GEV distribution with estimated parameter values. We used *normfit* and *gevfit* in Matlab [21] to obtain the maximum likelihood estimates of the parameters for the Gaussian distribution and GEV distribution, respectively. We also drew the *quantile-quantile plot* between the randomly generated data according to the estimated distributions and the empirical data. If the theoretical distribution (GEV, in this case) accurately models the empirical data (sampled noise, in our case), then the quantile-quantile plot would be linear [12]. Figure 4 shows that the points from GEV distribution fall closer along their reference line than the points from Gaussian distribution. Therefore, GEV distribution models the measured noise data better than the Gaussian distribution. The estimated parameters of GEV distribution for the sampled data from router 6 are:

$$\mu = -93.768\ dBm, \sigma = 1.579, \text{ and } \xi = 0.179.$$

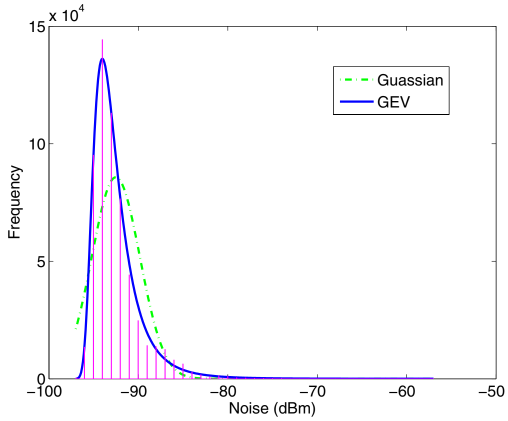

Figure 3: Histogram of the noise data gathered from a router in the ad hoc network testbed. Histograms using Gaussian and GEV distributions with best estimated parameters are also indicated.

The sampled data from other routers can also be modeled using GEV distribution with slightly different parameter values. This is to be expected since the environmental noise changes slightly for different labs or offices even on the same floor of a building.

We varied the parameters σ and ξ to see how it impacts the GEV PDF curve. The noise levels sampled from all routers fall between -100dBm and -55dBm. First, we study the impact of ξ on GEV density function. We fix values of μ and σ to be -93.768 dBm and 1.579 respectively. Given $-100 \le x \le -55$, in order to satisfy $1+\xi(x-\mu)/\sigma > 0$, ξ must fall in the range $(-0.0407, 0.2534)$. We choose ξ = -0.04, 0.179, and 0.25 and plot the GEV density functions as given in Figure 5. Figure 5 shows that ξ only affect the tail behavior of the distribution slightly. Next, we fix the values of μ and ξ to be -93.758 dBm and 0.179 respectively and vary σ. In order to satisfy $1+\xi(x-\mu)/\sigma > 0$, we obtain $\sigma > 1.116$. We choose three different values for σ (1.12, 1.579, and 3) and plot three GEV distribution curves as given in Figure 6. Figure 6 shows that σ affects the GEV distribution significantly. Note that if we fix σ and ξ and vary μ, μ will not change the shape of GEV distribution function and it only shifts the function curve. This property can be easily seen from GEV density function given in (2).

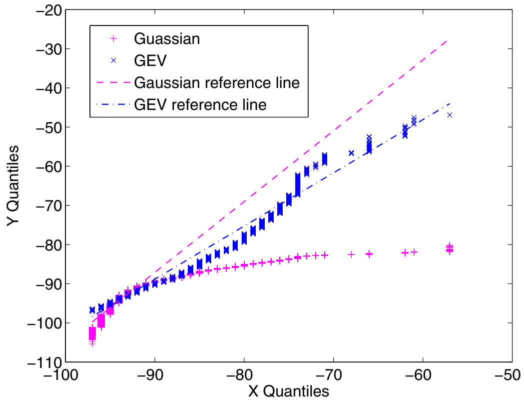

Figure 4: Quantile-Quantile plot between generated data and the empirical data.

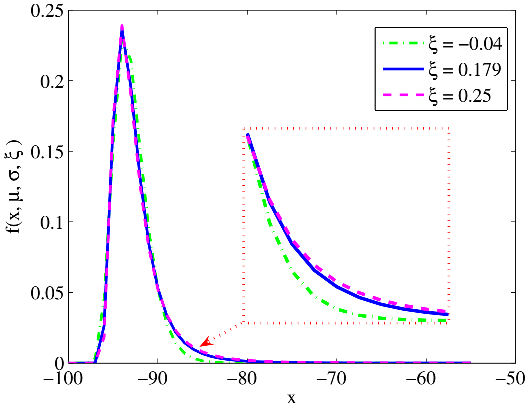

Figure 5: GEV distribution function curves with different values of ξ ($\mu = -93.768$, $\sigma = 1.579$).

2.3 Markov Noise Model

In this section, we derive a Markov chain model from the noise data gathered from testbed. The noise levels from sampled data fall between -100dBm and -55dBm, all values are integer. Each noise level can be considered as a single state in a Markov chain. For simplicity, we assume that the noise levels are integer and in the range [-100 -51] dBm, and thus there are total 50 different states. From a given state

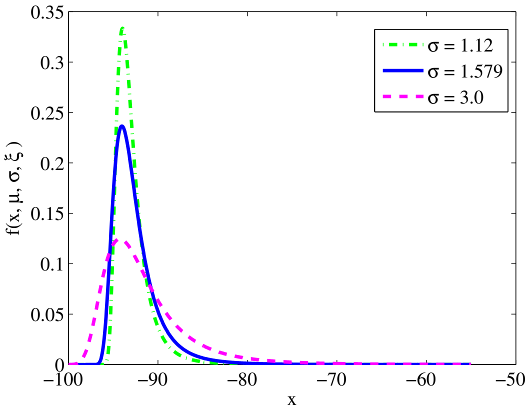

Figure 6: GEV distribution function curves with different values of σ ($\mu = -93.768$, $\xi = 0.179$).

(current noise level), it is possible to jump to another state (the followed noise level) with certain probability, as shown in Figure 7.

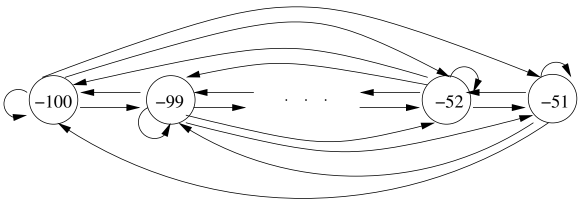

Figure 7: Noise state transition graph.

From the sampled data, we can compute the transition probabilities from each noise level to others, and thus obtain a noise level transitional probability matrix P (size:50×50). Let p_{ij} denote the transitional probability that next noise level is j given current noise level i. We calculate p_{ij} in the following way. Let C_i denote the total number of noise level i appeared in the sampled data (excluding the last noise level i if it is the final noise level in the whole sampled data). Let C_{ij} denote the total number of times that noise level i is immediately followed by noise level j in the sampled data. Then $p_{ij} = C_{ij}/C_i$. We can use P to generate noise data in network simulators. To evaluate the accuracy of the Markov model, we computed the transitional matrix P, using the same sampled data used for GEV modeling, and obtained a new histogram of noise levels predicted by the Markov model. Figures 8 and 9 show the histograms for original noise data and generated noise data from Markov model, respectively. Quick visual inspection reveals that their histograms are very close. We also drew quantile-quantile plot between original data and generated noise data, as shown in Figure 10. Figures 8, 9 and 10 show that the proposed Markov model can model the noise data fairly accurately. When noise level is over -70dBm, Y value does not match well in Figure 10. However, this does not affect the accuracy of our model too much since (i) noise levels over -70dBm take only very small portion of total sampled data; (ii) when noise levels are high enough, they have same impact on network performance. The proposed Markov model, with state transition probabilities estimated from the noise data collected from a representative real ad hoc network, can be incorporated into simulators to simulate larger ad hoc networks with more realistic noise models.

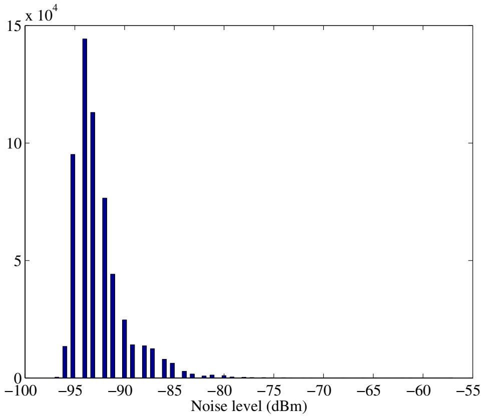

Figure 8: Histogram for noise data gathered from a router.

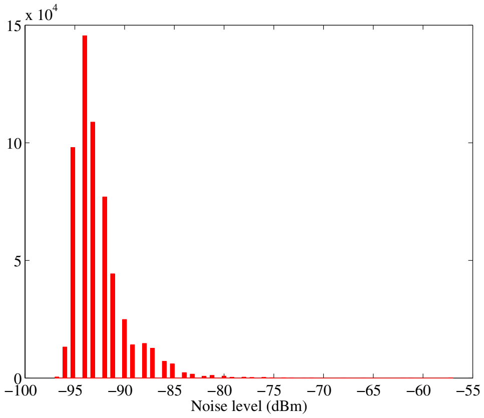

Figure 9: Histogram for noise data generated from Markov model.

3. IMPACT OF NOISE ON PERFORMANCE

We used the Glomosim simulator, v2.03 [3] to evaluate the impact of GEV noise model on mobile ad hoc networks. The impact of the Markov noise model will be studied in a future work. We compared the network performance using both AODV and DSR routing protocols for CBR traffic over UDP with and without the GEV noise model. The noise generator can be easily implemented using the inverse transform technique [12]. The background noise level for each node is determined every 100 ms using the GEV distribution with the parameters that best model the experimental data. However, nodes have different initial noise levels to ensure that the noise levels for different nodes differ at any given time. It is noteworthy that the default noise model in Glomosim is a constant value -100.47 dBm corresponding to $290(K)$ temperature (i.e., 290 - 273.15 = 16.85^oC). For the purpose of comparison, we also simulated networks with constant -100.47 dBm or -93.768 dBm background noise levels. We have not modified the signal propagation and interference noise models used by Glomosim. Various

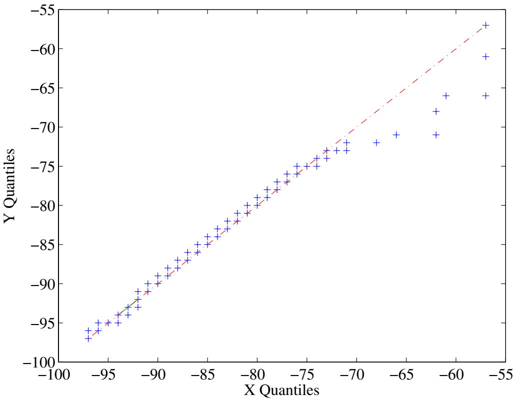

Figure 10: Quantile-Quantile plot between generated data from Markov Model and the empirical data.

Number of Nodes	50
Node Speed	[1-19]m/s
Node Mobility	Modified Random Waypoint
Pause Time	0 second
Field Size	900 m × 560 m
Radio Range	250 m
MAC	802.11
Number of Traffic Pairs	20
Traffic Load	100-400 Kbps (CBR/UDP)
Routing Protocol	AODV, DSR
Data Packet Payload	500 bytes
Link BW	2 Mbps
Noise Models:	
Glomosim default	-100.47 dBm (constant)
Constant noise	-93.768 dBm
GEV noise model:	
μ	-93.768 dBm
σ	1.579
ξ	0.179

Figure 11: Simulation Parameters.

simulation parameters used are listed in Figure 11. The modifications to random way-point model for node mobility [7] are used to avoid clustering of nodes in the middle and gradual decay of average node speed. The following metrics are used to evaluate the performance.

- *Packet Delivery Ratio.* The fraction of data packets sent that are received at the corresponding destination nodes.

All experiments were run for 900 seconds. Each configuration was repeated 20 times and the results were averaged; the 95%-level confidence intervals are indicated for all data points.

Figures 12 and 13 give the packet delivery ratios for AODV and DSR protocol with constant background noises -100.47 dBm and -93.768 dBm and the GEV noise model. The delivery ratios with different constant background noises are nearly the same until the network saturates at about 300 Kbps load. The performance with GEV noise model is much lower; the delivery ratio decrease about 26% at low traffic load (50 kbps) to 37% at high traffic load (300 kbps) for DSR protocol, and about 20% for AODV protocol. The degradation in performance is due to temporary channel disruptions caused by unexpected high noise levels.

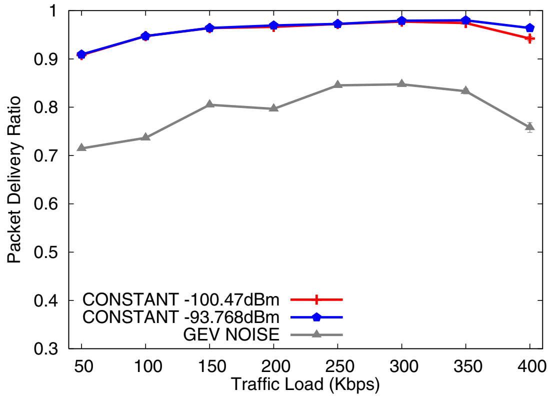

Figure 12: Packet delivery ratio vs. traffic load (AODV).

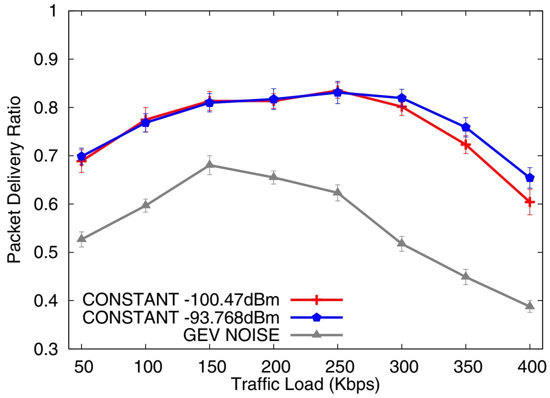

Figure 13: Packet delivery ratio vs. traffic load (DSR).

4. CONCLUSIONS

Network simulators such as NS-2, Glomosim, and OPNET are extensively used to validate and evaluate the performance of network protocols for MANETs. For accurate simulation-based performance evaluation, realistic signal propagation and noise models should be used to simulate the radio channels in MANETs. While the accuracy of signal propagation models in the commonly used simulators such as NS-2, Glomosim and OPNET are invested extensively, the noise models are too simplistic and inaccurately reflect real network conditions.

In this paper, we presented a measurement of background noise for wireless routers in an ad hoc network testbed. We showed that the actual noise seen over a period of time by a wireless node can be modeled by the generalized extended value (GEV) random distribution and also can be modeled by a discrete-time Markov chain. We incorporated GEV noise model in the Glomosim simulator and evaluated the performance of a MANET with popular routing protocols, AODV and DSR, for UDP traffic. Compared to the default constant noise model, the GEV noise model degrades the network performance significantly due to routes being temporarily disrupted by high, fluctuating noise levels.

In future, we intend to analyze the impact of Markov noise model on network performance in simulators. We also intend to model signal transmission levels and incorporate more realistic parameterized signal propagation models to complement the noise models we proposed. This should enable us to design effective mechanisms that tolerate temporary high background noise in actual ad hoc networks.

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