A Study of Spatial Packet Loss Correlation in 802.11 Wireless Networks

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Abstract

This report examines the spatial correlation of packet loss events in IEEE 802.11 wireless networks. We confirm previous experimental studies that showed low correlation of loss for receivers that are far from the transmitter, but we found that the correlation falls with increasing distance between the receivers being correlated and the transmitter, i.e. loss can be highly correlated for receivers close to the transmitter.

1 Introduction

Packet loss is an important issue for almost all kinds of networks. A great amount of research has been done to study the average packet loss rate, or the packet loss probability. However, a more fine-grained study of the issue: *packet loss correlation*, also attracts the interest of the many researchers. [2, 4, 5]

There are two kinds of packet loss correlation, namely *temporal correlation* and *spatial correlation*. The temporal loss correlation is a measure of the packet loss pattern over time, it is often related to the issue of consecutive packet loss or the burstiness of packet loss. However, for multicast/broadcast communication, in which a single packet has multiple receivers, it is also useful to measure the extent to which loss/reception by different receivers is correlated. One application is in using one receiver to help another recover packets that have been lost, which is most feasible when there is a low spatial correlation. We focus on spatial correlation between *receivers* of a single transmission; other work [2] has investigated whether separate transmitters have correlated packet losses when observed at a single receiver.

The spatial correlation between receivers is important for its effect on the performance of error recovery protocols. If there is low correlation in loss between receivers that are near each other, then when one receiver loses a packet, it may be able to recover it from a nearby receiver. Thus, local retransmission is more effective when losses are less spatially correlated.

The spatial loss correlation of 802.11 has been studied through experimental approaches [3, 4], in which low spatial correlation of packet loss are found. However, the cause of the low correlation remain unexplored. In this paper, we set out to understand the spatial packet loss correlation in 802.11 networks and to find the main factors that affect the correlation. In the rest of this paper, the term *(*loss correlation) specifically refers to the spatial correlation of packet loss in 802.11 wireless networks.

2 Formal definition of loss correlation

Previous works [2, 4] have measured correlations in terms of conditional probabilities, where the higher the probability of one device receiving a packet *given that another device received the packet* relative to the probability of the device receiving the packet (without knowledge of the other device receiving the packet), the higher the spatial correlation.

Reis et al [3] "found loss between the majority of pairs of receivers to be roughly independent, such that loss at one receiver was not generally a good indicator of loss elsewhere. This is consistent with other studies [2]". Salyers et al [4] wrote "In our experiments, we found that the correlation of loss between multiple closely located (within one λ) receivers is low with the majority of loss instances only occurring at one of the receivers." However, their data suggests otherwise: With a 0.1% loss rate, the probability of loss at one receiver on the condition that another receiver (less than one wavelength away) lost the packet, ranged between 0.2 and 0.3, i.e. 200 or 300 times higher than the unconditional probability of loss.

Another measure of correlation that has been used to study the correlation of loss to wired multicast receivers [5] is the correlation coefficient. In statistics, the

Table 3.1: Qualnet 802.11 Parameters

Category	Parameter	Value
Wireless Channel	Frequency	5.9GHz
	Channel bandwidth	10MHz
	Path loss model	Two-Ray
	Shadowing model	Log normal
	Shadowing mean	4.0dB
	Fading model	Rayleigh
PHY	Data rate	6Mbps
	Modulation	QPSK
	Coding rate	1/2
	Data bits per OFDM symbol	48
	Radio sensitivity	-85dBm

correlation coefficient is often used to study the statistical relationship between two random variables. If we have a set of sampled data pairs (x_1, y_1), ..., (x_n, y_n) for two random variables X and Y, the correlation coefficient (r) is calculated as:

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{X})(y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{Y})^2}} \tag{2.1}$$

where $\overline{X} = \sum_{i=1}^{n} x_i, \overline{Y} = \sum_{i=1}^{n} y_i$. The correlation coefficient ranges from -1 to 1. $r = 1$ only if X and Y have a positive linear relationship, and $r = -1$ only if the two have a negative linear relationship. If X and Y are independent, $r = 0$.

Similar to the definition in [5], we define a binary random variable X. For a certain broadcast packet and a receiver, $X = 0$ if the packet is received by the receiver, $X = 1$ if the packet is lost by the receiver. For receiver j and k, the correlation coefficient ($r_{j,k}$) of X_j and X_k represent the correlation of the two receivers losing the same packet. If $r_{j,k} = 1$, the two receivers always lose the same packet; if $r_{j,k} = -1$, the two receivers always have the opposite reception status of the same packet (one receives, the other loses); if $r_{j,k} = 0$, the packet loss of the two receivers are totally uncorrelated.

3 Simulation and Discussion

We setup a simulation environment in which 300 nodes are uniformly distributed in 20×1000m area, which represents a road in a vehicular network. We divide the whole area into 50 cells that are reasonably small (20×20m). The cells are used to group receivers that are close to each other, in order to determine the correlation of the loss that they experience. Each node transmits a 100-byte broadcast packet every 100ms. The simulation is performed using Qualnet [1] software, the parameters used are listed in Table 3.1.

For comparison with existing works, e.g. Salyers et al [4], we first considered how the probability of packet loss varies with distance, both the unconditional probability of loss, as well as the probability of loss at one receiver on the condition that another receiver in its cell lost the packet. Our simulations (Figure 3.1) show a more moderate correlation than reported by [4]: With unconditional probability of loss between 0.35 and 0.5 (for varying distances

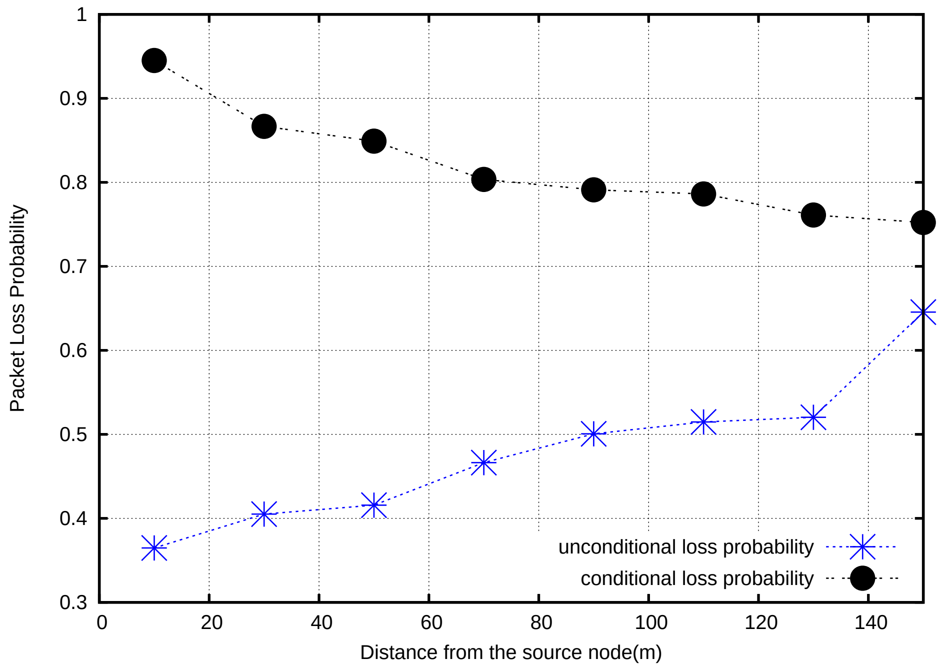

Figure 3.1: (Un)Conditional probability of loss as a function of distance from the transmitter

from the transmitter), the conditional probability of loss ranged from 0.95 to 0.75, i.e. 1.5 to 3 times the unconditional probability of loss.

We also measured correlations using the correlation coefficient: For each transmitted packet, we calculate the average correlation coefficient between each pair of receivers in every cell. We plotted the average correlation coefficient according to the distance between the packet sender and the selected cells. The results are shown in Figure 3.2. It can be observed that the correlation decreases with the distance between the packet sender and receivers.

Such an interesting phenomenon gives us a clue to find the main factors affecting the loss correlation. For a packet to be successfully received, the received signal strength has be high enough so that the signal can be correctly decoded. If we assume that the receivers have the same ambient noise and interference level[1], and each receiver has the same radio hardware, then a possible reason for low loss correlation is that the variance of the received signal strength of the receivers is high enough so that some of them correctly decode the signal while others fail to do so (packet loss happens). The higher the variance, the less correlated the receivers' reception status (received or lost) will be.

To check our hypothesis that the loss correlation in a small area is mainly affected by the variance of received signal strength, we also calculate the average standard deviation of the power of received signal for each cell. The result is shown in Figure 3.3, which confirms that relationship between the loss correlation and the variance of received signal strength.

[1] this assumption is valid if the receivers are located closely in a small area

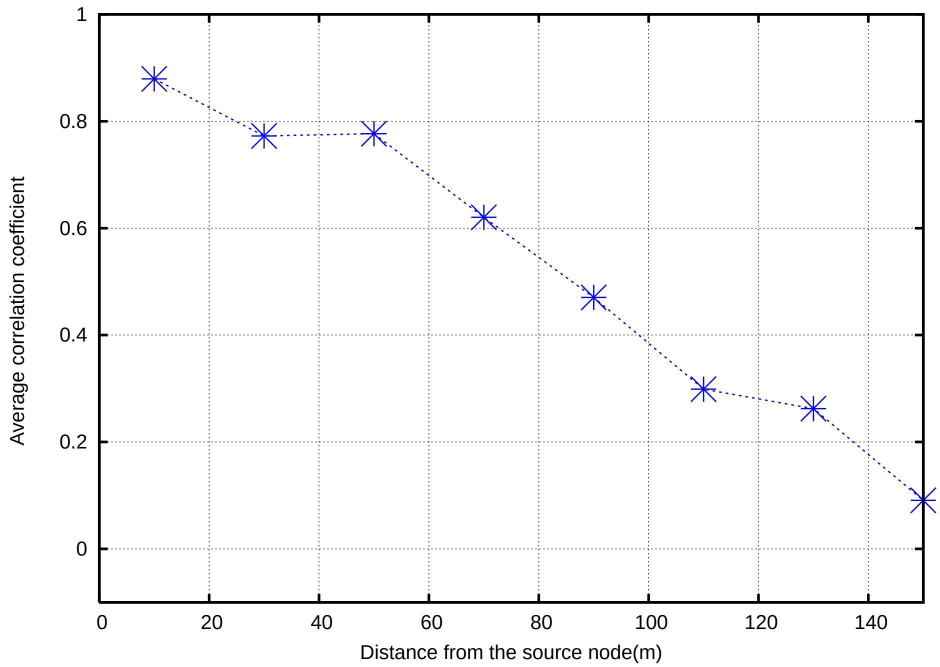

Figure 3.2: Correlation coefficient when vehicle density is 300veh/km

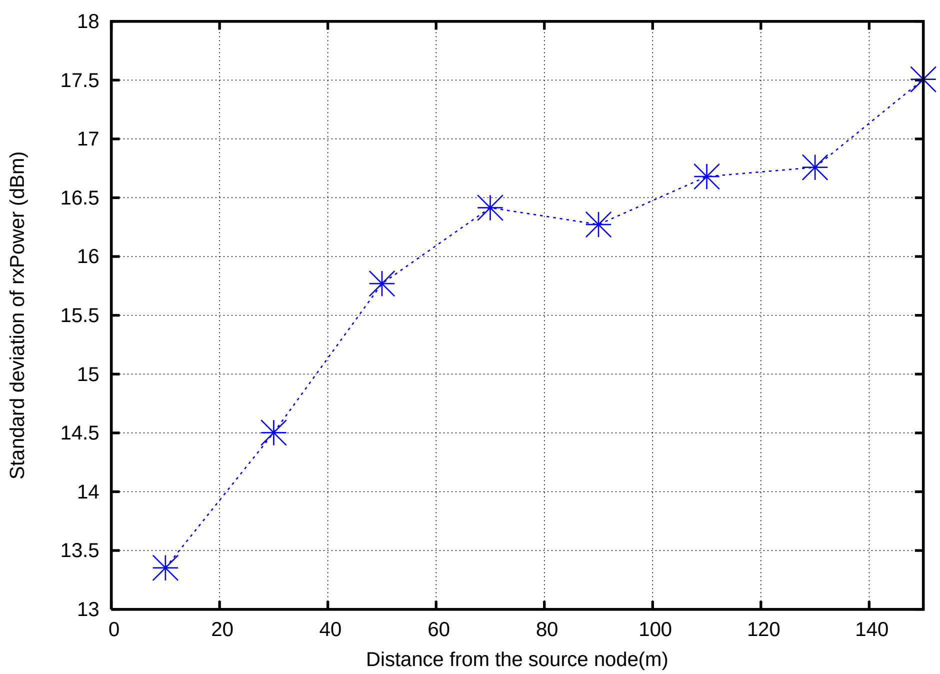

Figure 3.3: Standard deviation of receiving power

4 Conclusion

We found that the correlation falls with increasing distance between the receivers being correlated and the transmitter, i.e. loss can be highly correlated for receivers close to the transmitter.

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