Revisiting the Transmission Range Model in Mobile Networks based on IEEE 802.11a/g

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***Abstract*—Do we correctly simulate mobile networks like MANETs and DTNs? Is the simulation result of mobile networks reliable? In this letter, we start from these questions and point out the critical defect on the widely used transmission range model which is on the basis of mobile network simulations. As an alternative, we propose a realistic transmission range model considering the mobility and channel estimation error, and confirm that the simulation results can be completely different from what we have believed so far. We claim that the network protocols known best in mobile networks should be revisited with the proposed model.**

***Index Terms*—Wireless multi-hop networks, mobility, cross-layer, transmission range, channel estimation.**

I. INTRODUCTION

THE mobile networks such as MANETs and DTNs has been studied extensively in the last decade. However, compared to the numbers of papers, we hardly see tangible implementations in the real world. There could be several reasonable excuses like lack of attractive applications, premature hand-held device technology, uncooperative nature of humans due to the resource constraints in their devices. However, we find the major reason in the mobile network research itself because the simulations we carried out so far have critical defect in the transmission range model. Even though we have known that the link quality is degraded by the mobility of nodes, only few of the huge amount of research effort has considered it seriously in the simulations.

On communication link quality, there are many interacting factors such as distance between nodes, various types of channel fading and errors. In conventional transmission range model, path-loss, one cause of large-scale fading, is considered solely and it has been used widely in popular mobile network simulators like NS-2 [1], GloMoSim [2]. On the other hand, other affecting factors are rarely considered in mobile network simulations. For networks with fast moving nodes, can we still get valid simulation results? Can we propose a best working protocol based on these simulations? We answer these questions.

In this letter, we propose a realistic transmission range model based on IEEE 802.11a/g as a function of the mobility of nodes which considers large-scale, small-scale fading and channel estimation error at the same time and quantify the transmission range degradation compared to the conventional model. Moreover, through the simulations in delay tolerant mobile networks with heterogeneous mobility, we confirm that the proposed model shows completely different performance patterns compared to what we have believed so far.

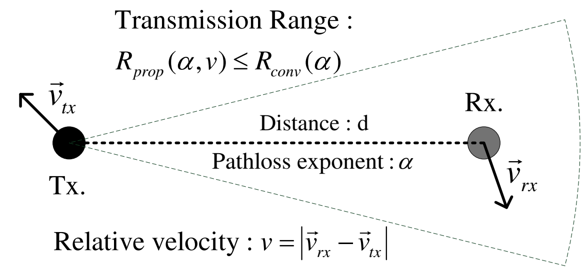

Fig. 1. Transmission range between communicating nodes.

II. CONVENTIONAL TRANSMISSION RANGE MODEL

In the research on wireless networks including mobile networks, the received symbol has been generally given by

$$y = d^{-\alpha/2}s + n, \tag{1}$$

where d, α and n indicate the distance between the transmitter and the receiver, the path-loss exponent and the thermal noise at the receiver, respectively. Fig. 1 shows the transmission range between communicating nodes. The term s denotes the transmitted signal with $\mathbb{E}[|s|^2] = P$, and $n \sim \mathcal{CN}(0, N_0)$. To achieve a certain data rate, the signal to noise ratio (SNR) in the receiver should be over a required SNR (SNR_{req}) as given as:

$$\mathsf{SNR} = \frac{d^{-\alpha} \cdot P}{N_0} \geq \mathsf{SNR}_{req}. \tag{2}$$

Thus, the conventional transmission range (R_{conv}), the maximally allowed distance to satisfy the required SNR, is given as:

$$R_{conv} = \left(\frac{P}{N_0 \mathsf{SNR}_{req}}\right)^{\frac{1}{\alpha}}. \tag{3}$$

III. PROPOSED TRANSMISSION RANGE MODEL

The conventional transmission range model did not consider the small scale fading and the effect of mobility on the transmission range. In this section, we propose a novel transmission range model which considers both the small scale fading and the effect of the relative velocity on the transmission range. In this case, the received symbol is given as:

$$y = hd^{-\alpha/2}s + n, \tag{4}$$

where h denotes the small-scale fading coefficient. We assume that h is Rayleigh distributed with the variance of 1, i.e., $h \sim \mathcal{CN}(0, 1)$. Fig. 2 illustrates the simplified frame structure of general mobile networks such as IEEE 802.11a/g. The frame consists of the long training part and the data part.

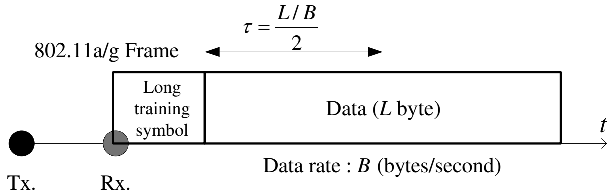

Fig. 2. Simplified frame structure of mobile networks

Long training part is used for the channel estimation and the estimated channel from the training part is used for the equalization of the entire data part [3].

Let $\hat{h}$ be the estimated channel from the training symbols. For the mathematical simplicity, the channel estimation error is assumed to be resulted from only the time varying effect of the wireless channel. Hence, the estimated channel is assumed to be the same as the real channel unless the real channel does not vary. Due to the time-varying channel, it holds $h = \hat{h}+\varepsilon$. If the channel does not vary, then $\hat{h}$ is surely equal to h. However, if channel varies quickly because of the user mobility, the correlation between the estimated channel and the real channel decreases, and the detection error tends to occur. Using a zero-forcing equalizer, the recovered symbol can be expressed as:

$$\hat{s} = \frac{1}{\hat{h}}y = \frac{1}{\hat{h}}(hd^{-\alpha/2}s+n) = d^{-\alpha/2}s + \frac{\varepsilon}{\hat{h}}d^{-\alpha/2}s + \frac{n}{\hat{h}}, \quad (5)$$

where the term $\frac{\varepsilon}{\hat{h}}d^{-\alpha/2}s$ is caused by the channel mismatch. Thus, the signal to noise ratio (SNR) considering the channel estimation error due to the time varying channel is given as:

$$\widetilde{\mathsf{SNR}} = \frac{|\hat{h}|^2 d^{-\alpha}P}{|\varepsilon|^2 d^{-\alpha}P + N_0} = \frac{|\hat{h}|^2 P}{|\varepsilon|^2 P + N_0 \cdot d^{\alpha}}. \quad (6)$$

The random variables h and $\hat{h}$ are jointly complex Gaussian with the correlation factor: $\rho = \frac{1}{\sigma^2}\mathbb{E}[h^*\hat{h}] = J_0(2\pi f_d \tau)$, where f_d and τ indicate the maximum Doppler frequency and the time difference between the moment of channel estimation and the moment of data transmission, respectively [4]. In this letter, we assume that $\tau = L/2B$, where L and B indicate the data length in byte and the data rate, respectively, as shown in Fig. 2. The maximum Doppler frequency can be expressed as:

$$f_d = \frac{f_c v}{c}, \quad (7)$$

where f_c, v, and c denote the carrier frequency, relative velocity of communicating nodes (m/s), and the velocity of light, respectively. Thus, f_d increases as the relative velocity increases. $J_0(\cdot)$ represents the 0-th order Bessel function of the first kind. Consequently, the random variables $\hat{h}$ and ε are also jointly complex Gaussian processes with variances $\sigma_1^2 = \sigma^2$ and $\sigma_2^2 = 2\sigma^2(1-\hat{\rho})$, respectively, and the correlation factor $\hat{\rho} = (\rho-1)/\sqrt{2(1-\rho)}$. The joint distribution of $\hat{h}$ and ε is expressed as:

$$f_{|\hat{h}|,|\varepsilon|}(x,y) = \frac{4xy}{(1-\tilde{\rho})}\exp\left[-\frac{1}{1-\tilde{\rho}}\left(\frac{x^2}{\sigma_1^2}+\frac{y^2}{\sigma_2^2}\right)\right] \cdot I_0\left(\frac{2xy\sqrt{\tilde{\rho}}}{(1-\tilde{\rho})\sigma_1\sigma_2}\right), \quad (8)$$

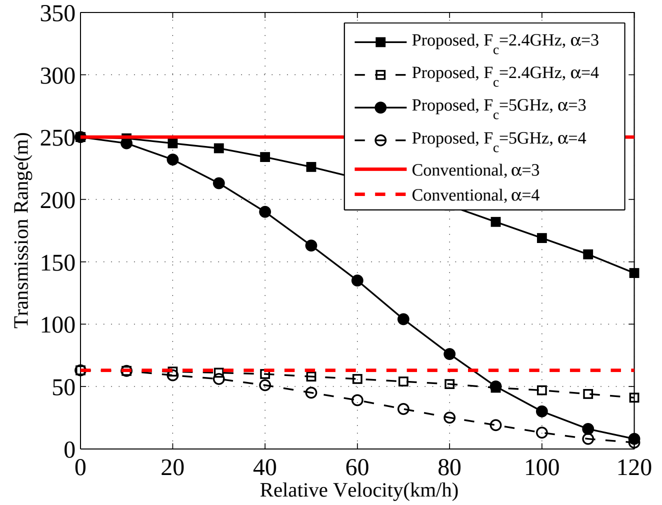

Fig. 3. Transmission range for varying relative velocity of communicating nodes.

where $I_0(\cdot)$ denotes the 0-th order modified Bessel function and $\tilde{\rho} = \mathbf{cov}(x^2,y^2)/\sqrt{\mathbf{Var}(x^2)\mathbf{Var}(y^2)}$ (note that $\tilde{\rho}$ is defined as the power correlation factor) [5]. By using Eq. (8), we can derive the average SNR:

$$\mathbb{E}\left[\widetilde{\mathsf{SNR}}\right] = \int_{x=0}^{\infty}\int_{y=0}^{\infty}\frac{|\hat{h}|^2 P}{|\varepsilon|^2 P + N_0 \cdot d^{\alpha}} \cdot f_{|\hat{H}|,|\Delta|}(x,y)\,dxdy. \quad (9)$$

Therefore, the proposed transmission range (R_{prop}) is defined as the maximum distance between transmitter and receiver such that $\mathbb{E}\left[\widetilde{\mathsf{SNR}}\right] \geq \mathsf{SNR}_{req}$.

Fig. 3 shows the transmission range of a node according to its relative velocity. We assume that $\tau = 0.833ms$ which is derived by using the time interval between the long training symbol and the mid point of the data packet with length of 1250 bytes transmitted through 6Mbps in IEEE 802.11a/g specification. The required SNR in the receiver is set to be 3dB and $P = 80$mW. In Fig. 3, we consider the case that $\alpha = 3, 4$. The path-loss exponent (α) is equal to 3 in the typical suburban area and is equal to 4 in the typical urban area [6]. The conventional transmission range model is regardless of the relative velocity. In the proposed transmission range model, as the relative velocity increases, the channel estimation error increases and the average received SNR decreases and the transmission range decreases. If the carrier frequency increases, the sensitivity to the channel estimation error increases. In all cases, the relative velocity has considerable impact on the transmission range.

IV. Performance Evaluation

A. Packet Relaying Architecture

In this section, we verify the effect of proposed transmission range model in a delay tolerant network (DTN), one of the most active research area in mobile networks. We design a DTN based on 2-hop relaying as follows. All nodes move based on RWP (random way point) [7] mobility patterns with heterogeneity factor β. For a given β, β fraction of nodes have high velocity and $1-\beta$ fraction of nodes have low velocity. Nodes in the network consist of one source node, one destination node and relay nodes. While all nodes are moving around, the source node tries to transmit as many packets as possible to the destination node. Whenever the source node meets the destination node, it transmits packets as much as it can during the destination is within the transmission range. In addition, whenever the source node meets one of the relay nodes, it transmits packets also and asks them to deliver the packets to the destination node. When the relay node meets the destination node, it delivers the packets in the buffer as much as it can. We define the capacity of this network as the amount of packets that the destination has received until the end of a simulation.

B. Simulation Results

We performed simulations where 100 randomly distributed nodes are moving around the $3000m \times 3000m$ square area during 10 hours. Among nodes, β fraction of highly mobile nodes move with an urban driving speed, 60 km/h, and the other low mobile nodes move with a walking speed, 10 km/h. In that setting, the proposed transmission range model for 5 GHz and 2.4 GHz with $\alpha = 3, 4$ which represent 802.11a and 802.11g respectively are compared with the conventional transmission range model. The performance of each simulation setup is averaged over 1000 repetitions and shown in Fig. 4 and 5 with 95% confidence interval.

Interestingly, the capacity of mobile networks with the proposed transmission range model shows completely different patterns according to β compared to the conventional model. In the simulations, two major factors due to mobility are contending. One is inter-contact time [8] or probability of contact between nodes and the other is connection duration. When nodes are highly mobile, overall inter-contact time decreases and the probability of contact increases. At the same time, the connection duration between communicating nodes for transmitting packets tends to decrease. In the conventional model, RWP with high mobility shows more capacity in our setting because the effect of increased probability of contact between nodes overwhelms the effect of decreased duration of connections. On the other hand, in the proposed model, RWP with high mobility shows much less or equal capacity according to the carrier frequency because the effect of decreased transmission range deteriorates the duration of connections more severely so that it dominates or equalizes the benefit of increased probability of contact as shown in Fig. 4. In Fig. 5, due to the short initial transmission range incurred by high path loss exponent, mobility of nodes which affects the probability of contact has more impact to the results but it still shows similar tendency.

V. Conclusion

In this letter, we propose a transmission range model which considers large-scale, small-scale fading and channel estimation error at the same time based on IEEE 802.11a/g for the realistic performance evaluation and capacity estimation of mobile networks. The proposed model can be easily modified to other wireless communication systems because it is given by general mathematical formula. To evaluate the proposed model, we design a DTN packet relaying framework based on the popular 2-hop relaying scheme in mobile networks with heterogeneous RWP mobility. Through simulations, we found that the capacity of networks with fast moving nodes is severely degraded and it is very far from the expected result from the conventional model.

Hence, we claim that the performance evaluations of network protocols in mobile networks especially with heterogeneous mobility models need to be revisited with more realistic model.

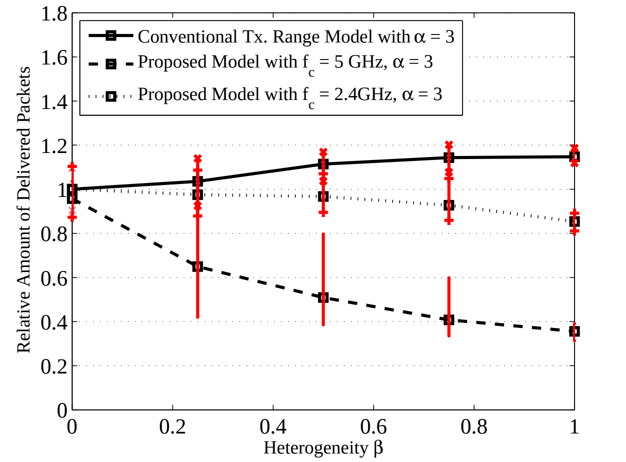

Fig. 4. Relative amount of delivered packets for $\alpha = 3$ with 95 % confidence interval. The performance of RWP with low mobility is set to be 1.

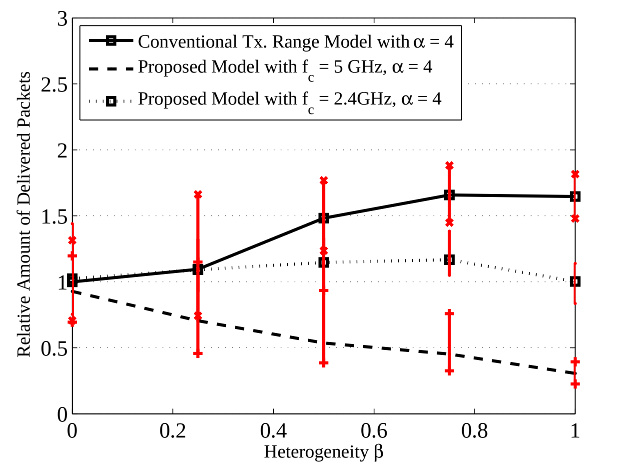

Fig. 5. Relative amount of delivered packets for $\alpha = 4$ with 95 % confidence interval. The performance of RWP with low mobility is set to be 1.

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