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Fast packet size adaptation based on Rician distribution mobility range estimation

Dong-Chul Go and Jong-Moon Chung[a)]

School of Electrical & Electronic Engineering, Yonsei University, Seoul, KOREA

a) *jmc@yonsei.ac.kr*

Abstract: A dynamic algorithm to optimize the packet size in wireless mobile networks using Rician distribution estimation (RDE) of the mobility range is presented. The packet size adaptation algorithm is based on an estimation of the bit error rate (BER) and the dynamic link distance statistics to maximize the communication performance through automatic repeat request (ARQ). The results using the dynamically estimated probability density function (PDF) of the link distance show significant improvement in both throughput and utilization when used in rapidly changing mobile environments.

Keywords: packet size, Rician distribution, mobile network

Classification: Wireless circuits and devices

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1 Introduction

Packet size adaptation can have significant effect on the performance in error-prone mobile communications. In [1], an algorithm that optimizes the packet size without requiring *a priori* information of the channel condition is presented, where the channel status is estimated from the number of retransmission requests. The packet size to maximize the throughput performance is chosen using maximum likelihood estimation based on a uniform distribution of the BER. The results show that when a small number of history packets (M) are used in [1] an under/over estimation occurs, which leads to a performance degradation. In [2], channel estimations are based on Beta distribution of the link distances, which is obtained from Gauss-Markov mobility

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movement in circular areas. The proposed scheme of [2] uses the estimation of stationary link distances, which leads to a performance improvement compared to [1]. However, the scheme of [2] does not have sufficiently quick adapting capability to accurately estimate highly dynamic channel characteristics of a mobile station (MS). In this letter, the algorithm of [1] and [2] are extended, where the optimal packet size is chosen by an algorithm based on estimations of the channel from the number of retransmission requests and the dynamic link statistics obtained from the MS's movement characteristics.

2 Distribution of link distance

In establishing reliable communications to a rapidly moving MS, accurate estimates of the location information can be effectively used to determine the optimal wireless transmission conditions. In this letter, estimations of link distance are utilized to determine the optimal packet size for selective-repeat ARQ communications. The location of the MS is represented in two dimensional (2D) coordinates where the randomly moving MS occasionally identifies its position. General position estimation errors will result in a 2D independent Gaussian distribution. In this case, the link distance PDF will follow a Rice distribution

$$f_d(d) = \frac{d}{\sigma^2} \exp\left(\frac{-(d^2+r^2)}{2\sigma^2}\right) I_0\left(\frac{-(dr)}{2\sigma^2}\right) \tag{1}$$

where r is the estimated link distance, σ^2 is the variance of a 2D independent Gaussian error, and I_0 is the modified Bessel function of the first kind with order zero. The link distance distribution of (1) was examined based on extensive Gauss-Markov mobility (GMM) model simulation. In Fig. 1, the link distance and movement range of 10^8 nodes are analyzed using GMM with the tuning parameters (ψ) of 0.25, 0.75, and 0.95 to represent various mobile conditions [2]. The link distance PDF is based on unit-variance Gaussian variable GMM movement with an average speed $v_m = 5$ units per sample time (T). Using curve-fitting, the relation between Rice PDF and GMM parameters of Fig. 1 can be approximated by

$$\begin{cases} \sigma = AT^B \\ r = av_mT + b \end{cases} \tag{2}$$

where the estimated parameters, organized in (ψ, A, B, a, b) form, are (0.25, 1.16, 0.57, 0.87, 1.64), (0.75, 0.93, 0.83, 0.9, 2.1), and (0.95, 0.31, 1.22, 0.96, 1.65).

3 Dynamic packet size control scheme

Same as in [1] and [2], in this letter the optimal packet size for a selective repeat ARQ protocol is chosen based on the estimated channel condition to maximize the throughput and efficiency performance. The BER p needs to be estimated from the packet error rate $q = Q/M$ derived from the number of

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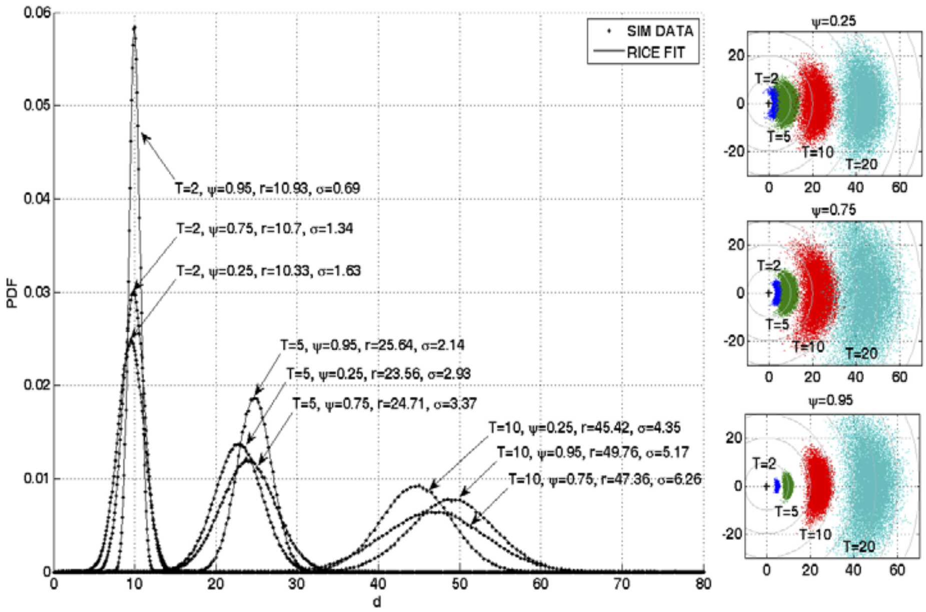

Fig. 1. Rice distribution of the link distance estimation with GMM.

retransmission requests Q and the number of packet transmissions M. The efficiency (EFF) of the proposed scheme can be written as

$$EFF_q(k) = \int_0^1 \frac{h}{k+h}(1-p)^{(k+h)} P[p|q]dp \tag{3}$$

where k is the packet payload size to optimize, h is the packet header size, and $P[p|q] = \frac{P[q|p]P[p]}{P[q]}$. To derive $P[q] = \int_0^1 P[q|p]P[p]dp$ we use $P[q|p] = \{1-(1-p)^{(k+h)}\}$, which is the conditional probability of q for a given BER of p. To solve (3) the distribution of the BER ($P[p]$) is needed. In [1], $P[p]$ is a uniform distribution and in [2] a Beta distribution is applied. In this letter $P[p]$ is derived from the Rician link distance of (1) extracted from the mobility characteristics of the 2D position error. The RDE-based packet control scheme operates as follows:

Step 1: Compute $EFF_q(k)$ based on Q, M, k, (1), and (2).

Step 2: Find $k = \arg\max_k EFF_q(k)$ by deriving the k that satisfies $\frac{\partial EFF_q(k)}{\partial k} = 0$ and $\frac{\partial^2 EFF_q(k)}{\partial^2 k} \geq 0$. In case the derivatives are difficult to derive, k can be derived using a numerical search algorithm.

Step 3: Estimate BER $\hat{p} = 1-\exp(-h/(k^2+kh))$ based on k and optimal packet size calculation for a given BER [1].

Step 4: Estimate r from $\hat{p}$.

Step 5: Recalculate (1) based on the estimated r and σ values.

Step 6: Send M packets with packet size $(k+h)$.

Step 7: Repeat steps $1 \sim 6$.

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4 Performance analysis

In the simulation, the same parameters and conditions of [2] were applied to the proposed scheme and [1]. The path-loss power-law model (with path-loss factor α) was used [2], the packetizing scheme is based on IEEE 802.11 protocol specifications [3], and the signal to interference and noise ratio (SINR) to BER relations are based on QualNet5.0 simulator's IEEE 802.11 [4]. The received power of the signal at node j sent from node i at time t can be represented as $P_{rx}(d_{ij}(t)) = P_0 d_{ij}(t)^{-\alpha}$, $i \in G(t)$ where $d_{ij}(t)$ is the link distance between node j and i at time t, $G(t)$ is the transmission group including all nodes which transmit signals at time t, and P_0 is the fixed transmission power. The interference power at node j influencing the signal sent from node i to node j at time t can be obtained from $I_{ij}(t) = P_0 \sum_{j=1,j\neq i}^{\forall n \in G(t)} d_{ij}^{-\alpha}$. Then the mean interference power is $I_m = P_0 N_G \int_0^{\infty} d^{-\alpha} f_d(d) dd$, where N_G is the average number of transmitting nodes and $f_d(\cdot)$ is the distribution of link distance where the Beta distribution of [2] can be utilized. The proposed scheme and the schemes of [1] and [2] are compared in Figs. 2 and 3 for the interference range of -120 (low level of $G(t)$) ~ -90 (high level of $G(t)$) dBm [2].

Fig. 2 shows the efficiency of both the proposed scheme and the performance of [1] and [2], based on the observation range of practical interest and for $\alpha = 2$, 4, and 6. The efficiency of the proposed scheme is proven to be significantly better than that of [1] and [2] for various interference and path-loss conditions.

Fig. 3 shows the efficiency gain of the proposed scheme and [2] over the efficiency performance of [1]. As all values of the proposed scheme are better than [1] and [2], it can be concluded that always a positive performance gain can be obtained by using the proposed scheme, where the performance gain in efficiency increases as the observation size decreases. In addition, it is shown that as the mean interference increases, the obtainable advantage

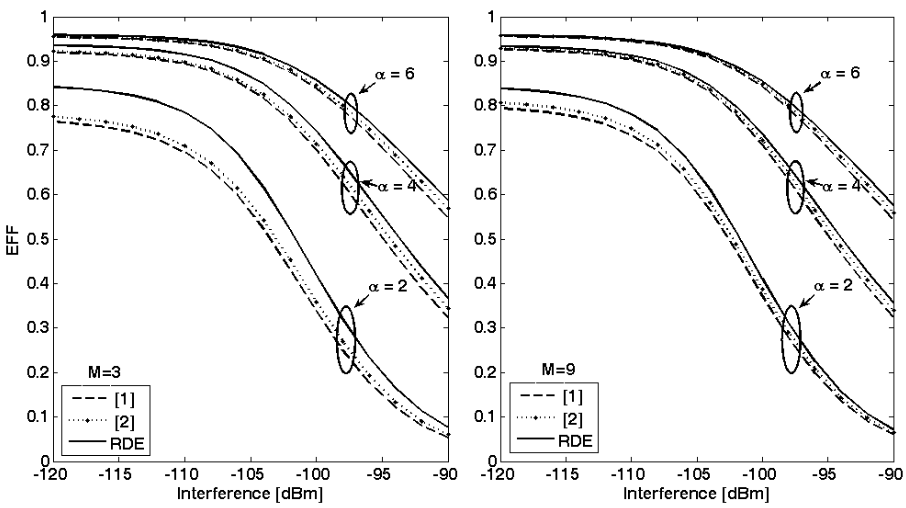

Fig. 2. Efficiency of the proposed scheme, [1], and [2] for M=3 and 9.

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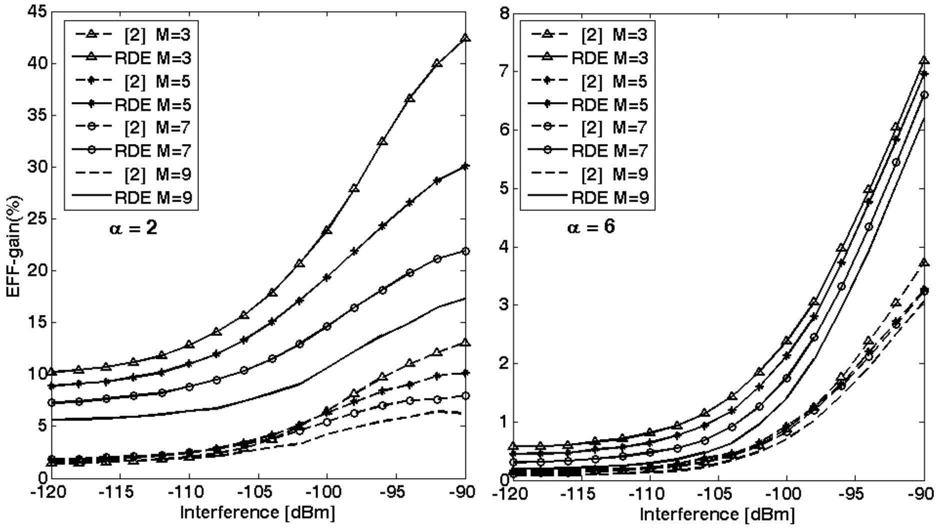

Fig. 3. Efficiency gain of the proposed algorithm and [2] compared to [1] for $\alpha = 2$ and 6.

in efficiency gain increases. This demonstrates that the proposed adaptive packet size control scheme provides a significant advantage in efficiency over [1] and [2] when the channel condition is poor and rapidly changes. In addition, it is shown that as the observation period size decreases, the efficiency gain increases. This shows that the proposed scheme is more effective than [1] or [2] in rapidly changing mobile channel environments where instantaneous adaptation has to be conducted from channel estimations based on very limited recent channel status information (CSI).

5 Conclusion

In this paper, the algorithms of [1] and [2] are extended to enhance the estimation accuracy based on short history observation in rapidly changing mobile wireless communication environments. Results confirm that using RDE of link distances for optimal packet control in selective repeat ARQ results in an efficiency gain compared to [1] and [2] under all conditions of interest and especially a significant gain is obtained when the observation period size and/or path-loss exponent is small.

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