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Relay Selection Considering Successive Packets Transmission in Cooperative Communication Networks

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Relay selection has been regarded as an effective method to improve the performance of cooperative communication system. However, frequent operation of relay selection can bring enormous control message overhead and thereby decrease the performance of cooperative communication. To reduce the relay selection frequency, in this paper, we propose a relay selection scheme to choose the best relay with considering successive packets transmission. In this scheme, according to the length of data packet, data transmission rate and the estimated channel state information (CSI), the best relay is selected to maximize the number of successive packets transmission under the condition that the given symbol-error-rate (SER) is kept. Finally, numerical results show that the proposed relay selection scheme can support the operation of successive packets transmission in cooperative wireless networks and that the maximum number of successive packets transmission is affected by the different network parameters, i.e., data transmission rate, packet length and Doppler frequency at one relay node.

Keywords: cooperative communication, relay selection, channel state information, symbol-error-rate, successive packets transmission

1. Introduction

Cooperative communication has been shown to be a promising method to mitigate the wireless channel impairments by establishing a virtual multiple-input multiple-output (MIMO) system without the need of multiple antennas at one node [1, 2]. In cooperative communication system, there may be multiple relays which assist a source to forward its information to its destination. Therefore, for improving the performance of cooperative communication, it is important to select the optimal cooperating relays among all available relays. Generally, cooperation with more than an optimal relay can obtain better performance, but it can bring more control signaling overhead, and the synchronization process is more difficult. So, as far as implementation is concerned, the best relay selection can substantially reduce the system complexity and overhead. At the same time, it is shown in [3, 4] that the same cooperative diversity gain can be obtained when only the best relay participates in cooperation. In this paper, we also take into account the problems of selecting the best relay.

In recent years, relay selection schemes have been studied extensively and the outstanding works have been reflected in [5-15]. According to the difference in relay selection criterion, we can broadly classify the relay selection schemes into five categories.

(1) Relay selection based on channel state information (CSI): In [5], opportunistic relaying (OR) scheme was proposed to select the best relay in a distributed manner. In OR, each potential relay needs to estimate the exact CSI of two links (source-relay and relay-destination), and two policies (the minimum and the harmonic means of the channel quality of two links) have been proposed to define the selection criterion. However, there exists a delay between the relay selection and actual data transmission, and the CSI used in relay selection can differ from that during data transmission. Fei et al. in [6] studied how to select the relay under the outdated CSI and propose maximum a posteriori (MAP) estimation to predict the actual signal-to-noise ratio (SNR) of each relay during data transmission.

(2) Relay selection based on energy efficiency: In wireless networks, nodes are often equipped with limited battery power. So, energy conservation becomes an important factor in designing relay selection protocols. In [7], power-aware relay selection (PARS) strategies were proposed to maximize the network lifetime. In PARS, three relay selection criteria were proposed to select the best relay, i.e., minimizing the total transmission power, maximizing the residual power and maximizing the ratio of the transmission power to the current residual power. However, the PARS does not combine with the specific protocol to analyze energy consumption, and the energy consumption brought about by the protocol overhead cannot be ignored. Zhou et al. in [8] designed a link-utility-based cooperative MAC (LC-MAC) protocol and analyzed the problems of energy consumption.

(3) Relay selection based on geographical information: In [9], a geographic-based relay selection scheme was proposed to utilize the source-relay and relay-destination distance as criteria to choose the best relay, aiming to minimize the symbol error probability (SEP) at the destination. However, the imperfect geographical information may affect the SEP performance.

(4) Relay selection based on outage probability: In [10], an outage-optimal relay selection (OORS) scheme was proposed. In OORS, the feedback is utilized from the receiver to determine whether relay cooperation is necessary and adaptive forwarding with either amplify-and-forward (AF) or decode-and-forward (DF) protocol is applied. Furthermore, in order to improve the selection fairness among relays, an outage priority based proportional fair scheduling scheme was proposed in [11] without outage performance deterioration.

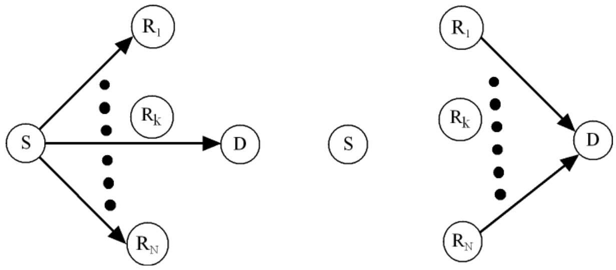
(5) Interference-aware relay selection: When there are multiple source-destination pairs, interference can occur among transmissions and greatly decrease the network performance. Zhu et al. in [12] analyzed the impact of interference on network performance through theory and experiment, and proposed two channel allocation mechanisms to mitigate the impact of interference. However, it is not investigated in [12] how to select the relay under interference condition. Afterwards, in [13-15], the specific interference-aware relay selection schemes were proposed respectively.

To the best of our knowledge, all the proposed relay selection schemes assume that relay selection is carried out once the source sends a data packet, which means that when the source needs to send multiple data packets successively (especially in multi-hop networks, a session, such as voice and video occurred in a source-destination pair, usually need to transmit multiple data packets), relay selection should be carried out repeatedly. It is obvious that frequent operations of relay selection can bring enormous control message overhead and thereby decrease the performance of cooperative communication. To reduce the relay selection frequency, in this paper, we propose a relay selection scheme to choose the best relay, considering successive packets transmission. In this scheme, according to the length of data packet, data transmission rate and CSI, the best relay is selected to maximize the number of successive packets transmissions under the condition that the given symbol-error-rate (SER) is kept. Simulation results show that the proposed relay selection scheme can support the operation of successive packets transmission in cooperative wireless networks and the maximum number of successive packets transmissions is affected by different network parameters, i.e., data transmission rate, packet length and Doppler frequency at one relay node.

The rest of this paper is organized as follows. In Section II, the corresponding system model is presented. In Section III, the best selection scheme is proposed. Afterwards, in Section IV, numerical results of the proposed scheme are given. Finally, in Section V, the conclusions and future work are presented.

2. System Model

As shown in Figure 1, we consider a cooperative wireless network where a source (S) transmits data packets to a destination (D) through the cooperation of N relays ($R_k, 1 \leq k \leq N,$). We assume that all nodes operate in half-duplex AF model over Rayleigh fading model. Let h_{ij} denote the fading coefficient of the channel from node i to node j. We assume that the magnitude $|h_{i,j}|$ follows a Rayleigh distribution. Furthermore, as in [16], we consider a block-fading channel where the channel response remains constant during one data transmission phase and the different channels are independently distributed. It is also assumed that each relay has an accurate estimate of its position.



(a) the first stage (b) the second stage

Figure 1. Cooperative communication system model.

In a cooperative communication system, prior to data packets transmission, the operation of relay selection must be conducted. Here, in order to reduce the system complexity and overhead, we consider the best relay selection scheme. Afterwards, the cooperative transmission is divided into two stages, as follows. In the first stage, the source broadcasts the symbol x with the transmission power P_s to the destination and the relays. Let $y_{s,d}$ and $y_{s,r}$ denote the signals received at the destination and the relays, respectively. We can derive

$$y_{s,d} = \sqrt{P_s} h_{s,d} x + n_{s,d}, \tag{1}$$

$$y_{s,r} = \sqrt{P_s} h_{s,r} x + n_{s,r}, \tag{2}$$

where $h_{s,d}$ and $h_{s,r}$ are the channel coefficients for source-destination and source-relay channels, $n_{s,d}$ and $n_{s,r}$ are the corresponding additive white Gaussian noise with zero mean and the same variance σ_n^2, i.e., $n_{s,d}, n_{s,r} \sim \mathcal{CN}\ (0, \sigma_n^2)$. Furthermore, we model the $h_{s,d}$, $h_{s,r}$ and $h_{r,d}$ as zero-mean, independent, circularly symmetric complex Gaussian random variances with variances $\sigma_{s,d}^2$, $\sigma_{s,r}^2$ and $\sigma_{r,d}^2$, i.e., $h_{s,d} \sim \mathcal{CN}\ (0, \sigma_{s,d}^2)$, $h_{s,r} \sim \mathcal{CN}\ (0, \sigma_{s,r}^2)$ and $h_{r,d} \sim \mathcal{CN}\ (0, \sigma_{r,d}^2)$. According to [6], the $\sigma_{s,d}^2$, $\sigma_{s,r}^2$ and $\sigma_{r,d}^2$ can be expressed as

$$\sigma_{i,j}^2 = (\lambda/4\pi d_0)(d_0/d_{i,j})^\beta, \quad i = s, r, j = r, d \, and \, i \neq j \tag{3}$$

where λ denotes the carrier wavelength, d_0 stands for a reference distance, $d_{s,d}$, $d_{s,r}$ and $d_{r,d}$ are the distance of link source-destination, source-relay and relay-destination respectively, and β denotes the path loss exponent (in this paper $\beta = 3$).

In the second stage, the selected relay amplifies and retransmits the received signal x_r to the destination. According to [17], x_r can be written as

$$x_r = \frac{1}{\sqrt{P_s|h_{s,r}|^2 + \sigma_n^2}} y_{s,r}. \tag{4}$$

Based on (2) and (4), the signal received at the destination is

$$\begin{aligned} y_{r,d} &= \sqrt{P_r} h_{r,d} x_r + n_{r,d} \\ &= \frac{\sqrt{P_s P_r}}{\sqrt{P_s|h_{s,r}|^2 + \sigma_n^2}} h_{s,r} h_{r,d} x + \tilde{n}_{r,d}, \end{aligned} \tag{5}$$

where $\tilde{n}_{r,d} = \frac{\sqrt{P_r} h_{r,d}}{\sqrt{P_s|h_{s,r}|^2 + \sigma_n^2}} n_{s,r} + n_{r,d}$ denotes the actual additive white Gaussian noise of the link relay-destination and $n_{r,d} \sim \mathcal{CN}\ (0, \sigma_n^2)$. Therefore, we have $\tilde{n}_{r,d} \sim \mathcal{CN}\ (0, \omega^2\sigma_n^2)$ and the ω^2 can be expressed as

$$\omega^2 = 1 + \frac{P_r|h_{r,d}|^2}{P_s|h_{s,r}|^2 + \sigma_n^2}. \tag{6}$$

In order to achieve maximum likelihood performance, the destination jointly combines the signal directly from the source in the first stage and that from the selected best relay in the second stage by a maximal ratio combiner (MRC). According to [18], the combined signal y_d can be written as

$$y_d = \frac{\sqrt{P_s} h_{s,d}^*}{\sigma_n^2} y_{s,d} + \frac{\sqrt{P_s P_r} h_{s,d}^* h_{r,d}^*}{\omega^2 \sigma_n^2 \sqrt{P_s|h_{s,r}|^2 + \sigma_n^2}} y_{r,d}, \tag{7}$$

where the superscript * stands for the complex conjugate. According to [18], the SNR γ_d of the combined signal at the destination can be given as

$$\gamma_d = \gamma_{s,d} + \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1}, \tag{8}$$

where $\gamma_{s,d} = P_s|h_{s,d}|^2/\sigma_n^2$, $\gamma_{s,r} = P_s|h_{s,r}|^2/\sigma_n^2$ and $\gamma_{r,d} = P_r|h_{r,d}|^2/\sigma_n^2$ are the instantaneous SNRs of link source-destination, source-relay, and relay-destination, respectively.

3. Relay Selection Scheme

According to [4], outage performance can be optimized by selecting the relay with the best instantaneous SNR. In this section, based on the predicted CSI, we propose a relay selection scheme to choose the best relay, considering successive packets transmission.

3.1. Predicting the Actual Instantaneous SNR Through the Outdated Version

Since there exists a delay between the relay selection and the actual data transmission, we need to consider that the SNRs of the link source-destination, source-relay and relay-destination available at the selection instant $\hat{\gamma}_{s,d}$, $\hat{\gamma}_{s,r}$ and $\hat{\gamma}_{r,d}$, can differ from the actual SNRs during packets transmission due to channel variations. Therefore, it is indispensable to predict the actual $\gamma_{s,d}^{act}$, $\gamma_{s,r}^{act}$ and $\gamma_{r,d}^{act}$ through the outdated $\hat{\gamma}_{s,d}$, $\hat{\gamma}_{s,r}$ and $\hat{\gamma}_{r,d}$. In Figure 2, we give the difference between the outdated and actual SNR at different time points. We can see that when the delay between relay selection and data transmission instant gets larger, the difference between outdated and actual SNR increases, and vice versa.

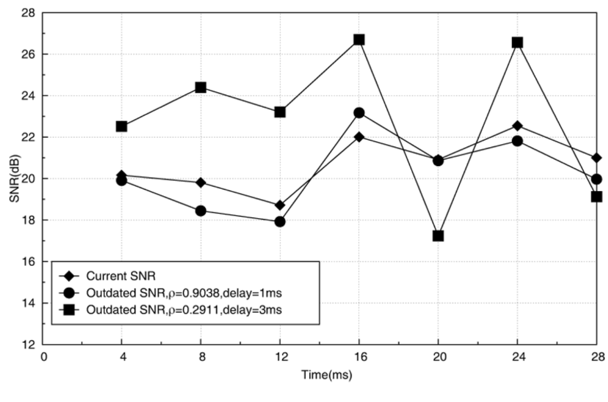


Figure 2. The difference between outdated and actual SNRs.

Let $\hat{h}_{s,d}$, $\hat{h}_{s,r}$ and $\hat{h}_{r,d}$ denote the outdated version of $h_{s,d}$, $h_{s,r}$ and $h_{r,d}$ then, according to [19, 20], $h_{s,d}$ conditioned on $\hat{h}_{s,d}$, $h_{s,r}$ conditioned on $\hat{h}_{s,r}$ and $h_{r,d}$ conditioned on $\hat{h}_{r,d}$ follow a Gaussian distribution:

$$h_{i,j}/\hat{h}_{i,j} \sim \mathcal{CN}(\rho_{i,j}\hat{h}_{i,j}, (1-\rho_{i,j}^2)\sigma_{i,j}^2), \quad i = s, r, j = r, d \, and \, i \neq j \tag{9}$$

One can utilize the minimum mean-squared error (MMSE) estimator to predict the actual SNR, which can be expressed as [19].

$$\gamma_{i,j}^{act} = \rho_{i,j}^2\hat{\gamma}_{i,j} + (1-\rho_{i,j}^2)\overline{\gamma}_{i,j}, \quad i = s, r, j = r, d \, and \, i \neq j \tag{10}$$

where $\hat{\gamma}_{i,j} = P_i|\hat{h}_{i,j}|^2/\sigma_n^2$ and $\overline{\gamma}_{i,j} = P_i\sigma_{i,j}^2/\sigma_n^2$ $(i = s, r, j = r, d \, and \, i \neq j)$. In equations (9) and (10), the parameter $\rho_{i,j}$ is the correlation coefficient between $h_{i,j}$ and $\hat{h}_{i,j}$ $(i = s, r, j = r, d \, and \, i \neq j)$, which has different expressions according to the channel model. Under the Jackes' model, the correlation coefficient $\rho_{i,j}$ can be given by

$$\rho_{i,j} = J_0(2\pi f_D T_{i,j}), \tag{11}$$

where $f_D = vf_c/c$ (v is the relative speed of relay node and c is the velocity of light) denotes the Doppler frequency, $T_{i,j}$ denotes the delay between the selection instant and the data transmission instant from node i to node j $(i = s, r, j = r, d \, and \, i \neq j)$, and $J(.)$ denotes the zero-order Bessel function of the first kind.

3.2. Deriving the SER Under the Actual Instantaneous SNR

Based on the predicted SNR, the predicted SNR γ_d^{act} of combined signal at the destination can be given as

$$\gamma_d^{act} = \gamma_{s,d}^{act} + \frac{\gamma_{s,r}^{act}\gamma_{r,d}^{act}}{\gamma_{s,r}^{act} + \gamma_{r,d}^{act} + 1}. \tag{12}$$

Furthermore, according to [21], the γ_d^{act} can be tightly upper bounded as

$$\gamma_d^{act} = \gamma_{s,d}^{act} + \frac{\gamma_{s,r}^{act}\gamma_{r,d}^{act}}{\gamma_{s,r}^{act} + \gamma_{r,d}^{act}}. \tag{13}$$

Under the cooperation systems with M-PSK modulation (in this paper, we let $M = 4$), we can obtain the SER expression of the AF cooperation systems in terms of the moment generating function (MGF)[21]:

$$P_{ser} \approx \frac{1}{\pi} \int_0^{(M-1)\pi/M} \mathcal{M}_{\gamma_1}\Big(\frac{b_{PSK}}{\sin^2\theta}\Big)\mathcal{M}_{\gamma_2}\Big(\frac{b_{PSK}}{\sin^2\theta}\Big)d\theta, \tag{14}$$

where $\mathcal{M}_{\gamma_1}$ denotes the MGF of $\gamma_1 = \gamma_{s,r}^{act}$, $\mathcal{M}_{\gamma_2}$ denotes the MGF of $\gamma_2 = (\gamma_{s,r}^{act}\gamma_{r,d}^{act})/(\gamma_{s,r}^{act} + \gamma_{r,d}^{act})$, and $b_{PSK} = \sin^2(\pi/M)$.

For Rayleigh fading model, $|h_{i,j}|^2$ is exponentially distributed with parameter $1/\sigma_{i,j}^2$, and the $\rho_{i,j}^2 P_i|\hat{h}_{i,j}|^2/\sigma_n^2$ are independent exponential random variables with parameter $\beta_{i,j}{=}\sigma_n^2/(\rho_{i,j}^2 P_i \sigma_{i,j}^2)$ $(i = s, r, j = r, d\, and\, i \neq j)$. Therefore, we can obtain the probability density function (PDF) of the $\gamma_{i,j}^{act}$:

$$f_{i,j}(x){=}\beta_{i,j}\exp\left(-\beta_{i,j}(x{-}(1{-}\rho_{i,j}^2)\overline{\gamma}_{i,j})\right)\cdot\mathcal{U}(x),\quad i = s, r, j = r, d\, and\, i \neq j \tag{15}$$

where $\mathcal{U}(x) = 1$ for $x \geq 0$ and $\mathcal{U}(x) = 0$ for $x < 0$.

Thus, according to [22], we can derive the expression of $\mathcal{M}_{\gamma_1}$:

$$\mathcal{M}_{\gamma_1}(s) = \frac{1}{1 + sE(\gamma_1)}, \tag{16}$$

where

$$E(\gamma_1){=}\int_0^{\infty} f_{s,d}(x)xdx{=}\frac{\rho_{s,d}^2 P_s \sigma_{s,d}^2}{\sigma_n^2}\exp\left(\frac{1{-}\rho_{s,d}^2}{\rho_{s,d}^2}\right)$$

At the same time, according to Theorem 3 and Theorem 4 in [22] and the PDFs of $\gamma_{s,r}^{act}$ and $\gamma_{r,d}^{act}$, $\mathcal{M}_{\gamma_2}$ can be written as

$$\mathcal{M}_{\gamma_2}(s){\approx}\frac{\beta_{s,r}{+}\beta_{r,d}}{s}\exp\left(\frac{1{-}\rho_{s,r}^2}{\rho_{s,r}^2}{+}\frac{1{-}\rho_{r,d}^2}{\rho_{r,d}^2}\right) \tag{17}$$

As a result, the P_{er} of the AF cooperation systems can be expressed as

$$\begin{aligned} P_{ser}&{\approx}\frac{1}{\pi}\int_0^{(M-1)\pi/M}\frac{(\beta_{s,r}{+}\beta_{r,d})\sin^4\theta}{b_{PSK}(\sin^2\theta{+}b_{PSK}E(\gamma_1))} \cdot\exp\left(\frac{1-\rho_{s,r}^2}{\rho_{s,r}^2}+\frac{1-\rho_{r,d}^2}{\rho_{r,d}^2}\right)d\theta \\ &{\approx}\frac{B}{b_{PSK}^2 E(\gamma_1)}(\beta_{s,r}{+}\beta_{r,d})\exp\left(\frac{1{-}\rho_{s,r}^2}{\rho_{s,r}^2}{+}\frac{1{-}\rho_{r,d}^2}{\rho_{r,d}^2}\right), \end{aligned} \tag{18}$$

where

$$\begin{aligned} B &= \frac{1}{\pi}\int_0^{(M-1)\pi/M}\sin^4\theta d\theta \\ &= \frac{3(M-1)}{8M} + \frac{\sin(2\pi/M)}{4\pi} - \frac{\sin(4\pi/M)}{32M} \end{aligned}$$

3.3. Selecting Relay for Successive Packets Transmission

Let denote the packet length, $R_{s,d}$, $R_{s,r}$ and $R_{r,d}$ denote the data transmission rate for the transmission from source to destination, source to relay and relay to destination. Since, in the first stage of cooperative communication, the source broadcasts the packet to the destination and the relays, we let $R_{s,d}$ be equal to $R_{s,r}$. Here, we assume that the duration of relay selection is short and can be negligible compared with that of data transmission.

Let K denote the number of successive packets transmission for the relay, the $T_{s,d}$, $T_{s,r}$ and $T_{r,d}$ can be expressed as

$$T_{s,d} = T_{s,r} = (K-1)\Big(\frac{L}{R_{s,r}} + \frac{L}{R_{r,d}}\Big), \tag{19}$$

$$T_{r,d} = K\frac{L}{R_{s,r}} + (K-1)\frac{L}{R_{r,d}}. \tag{20}$$

Therefore, when the packet length L is given and the certain data transmission rate R_{s,r_k} and $R_{r_k,d}$ are selected by the *k-th* relay during the relay selection, the *k-th* relay can maximize the K (denoted as $K_{k,\max}$) through the following optimization problem:

$$\begin{aligned} &\text{objective} \\ &\qquad K_{k,\max} = \text{maximize}\, K \\ &\text{subject to} \\ &\qquad (11), (19), (20) \\ &\qquad P_{ser} \leq P_{th} \end{aligned} \tag{21}$$

where P_{th} is the threshold of SER to guarantee the requirement of quality of service from the applications. Finally, the best relay $R_{k_{best}^*}$ with the maximum value of $K_{k,\max}$ among relay candidates should be selected, i.e.

$$k_{best}^* = \arg\max_{1\leq k\leq N}\{K_{k,\max}\}. \tag{22}$$

It is noted that, to select the best relay, we can adopt the OR scheme to select the relay in a distributed way. More specifically, when S has data packets to send, it first sends a request to send (RTS) frame after sensing the channel to be idle. This frame is an extension of the regular RTS frame of the IEEE 802.11 standard, which carries the length L of data packets. The RTS frame from the source allows for the estimation of instantaneous wireless channel $h_{s,r}$ at each relay. When D receives the RTS, it gives permission to send (CTS) frame, announcing that the medium is reserved for the transmission. The CTS frame is also an extension of the regular CTS frame and includes the instantaneous $h_{s,d}$. The CTS frame from the destination allows for the estimation of instantaneous $h_{r,d}$ at each relay. At the same time, according to the estimate of $h_{s,r}$, $h_{s,d}$ and $h_{r,d}$, each relay k can decide on the appropriate data transmission R_{s,r_k} and $R_{r_k,d}$. After that, each relay k applies the optimization problem (21) to derive the value of $K_{k,\max}$. Since the best relay $R_{k^*_{bext}}$ should be selected, we can employ backoff scheme of the IEEE 802.11 standard to select the best relay. That is to say, the backoff time of each relay k is inversely proportional to its $K_{k,\max}$ value and the relay that first expires its backoff timer will be regarded as the best relay So, the best relay will first broadcast the ready to help (RTH) frame, and the other relay that hears the RTH frame will give up the cooperation.

4. Computational Effort and Complexity

According to the optimization problem (21), we give the following algorithm in Table 1 to maximize the K at one candidate relay node. Here, without loss of generality, we assume that the variance σ_n^2 of noise is equal to 1, the variance $\sigma_{s,d}^2$, $\sigma_{s,r}^2$ and $\sigma_{r,d}^2$ of channel coefficients is also equal to 1, and let $P_s = P_r = P$. In addition, we also assume that the carrier frequency is 2.4GHz, which is adopted by IEEE 802.11b/g. So, the Doppler frequency f_D is determined by the speed v of the relay node. For example, if let $v = 45km/h$ and $v = 90km/h$, we have $f_D = 100Hz$ and $f_D = 200Hz$.

In Table 1 it is shown that the time complexity of the algorithm is $O(K_{th}N_B)$, where K_{th} is the upper bound of K and N_b is the loop times for computing zero-order Bessel function of the first kind. Here, we can set $K_{th} = 50$ and $N_B = 15$ to compute the $K_{\max}$. Therefore, the computational effort is not large and complex. In addition, compared with other OR schemes, the complexity of the proposed scheme is mainly embodied in the computational effort to implement the algorithm. However, this complexity will be counteracted by the advantage of supporting the successive packets transmission.

Algorithm: maximize the K

Input: L, $R_{s,r}$, $R_{r,d}$, v, P and P_{th}
Output: the maximum value of K
$M = 4$; K= 1;
$b_{PSK} = \sin^2(\pi/M)$;
$B = 3(M-1)/8M + \sin(2\pi/M)/4\pi - \sin(4\pi/M)/32M$;
While $(K < K_{th})$ **do**
  $D_1 = BesselJ(0, 2\pi f_D(K-1)(L/R_{s,r} + L/R_{r,d}))$;
  $D_2 = D_1$;
  $D_3 = BesselJ(0, 2\pi f_D(KL/R_{s,r} + (K-1)L/R_{r,d}))$;
  $$D_4 = B/(b_{PSK}^2 SNR^2 D_1^2)(1/D_2^2 + 1/D_3^2)exp(\\ = -(1-D_1^2)/D_1^2 + (1-D_2^2)/D_2^2 + (1-D_3^2)/D_3^2;$$
  if $(D_4 > P_{th})$ **then**
    $K_{\max} = K - 1$;
    break;
  end
  K=K+1;
end

Table 1. The algorithm to maximize the K.

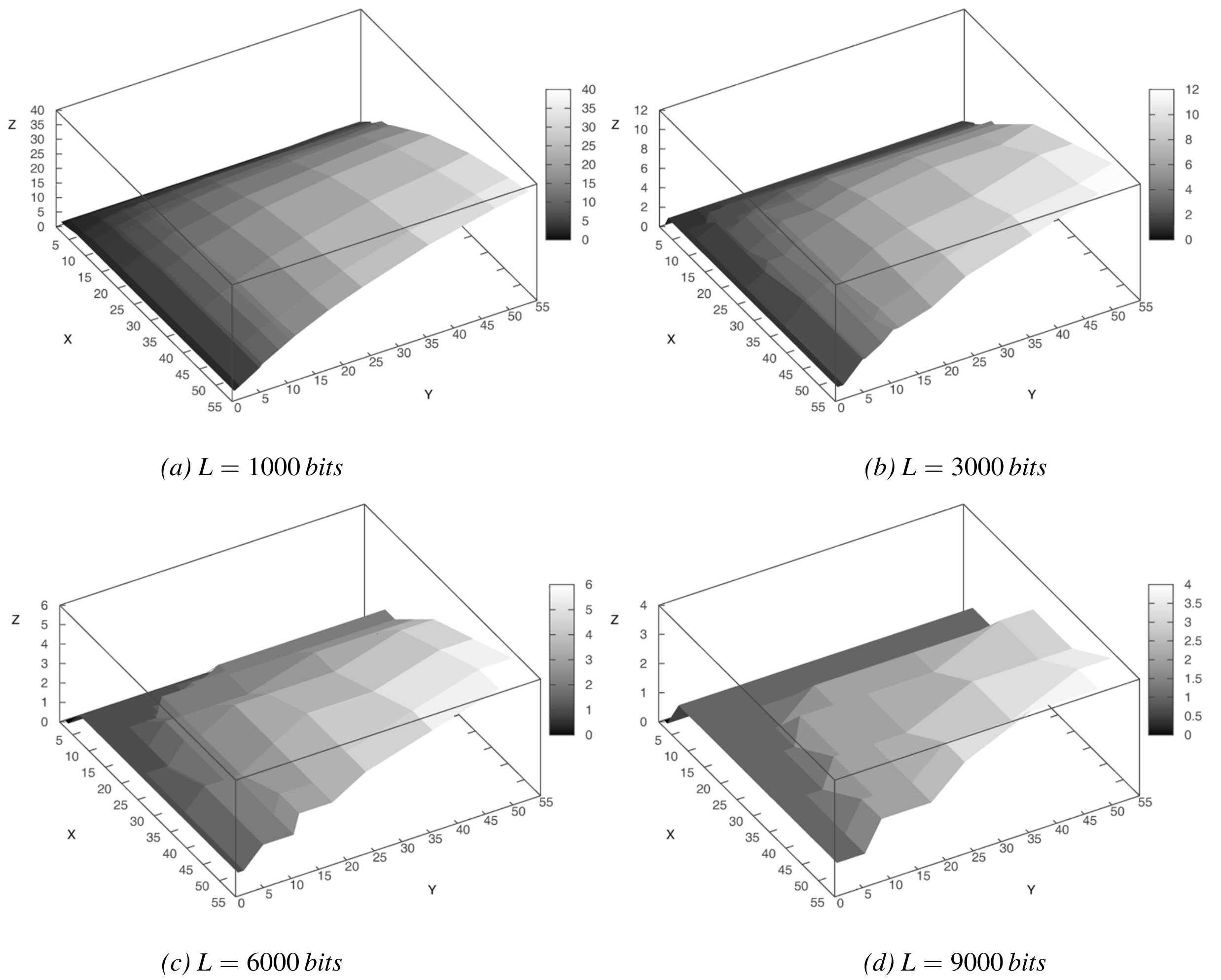
5. Numerical Results

In this section, we perform computer simulations to illustrate the above theory analysis.

Note here that our main aim is to validate whether the proposed relay scheme can support the operation of successive packets transmission. So, we need to observe whether we can obtain the maximum value of K (larger than 1) and how the maximum value of K is affected by some networks parameters. In the following simulations, we give results about the effect of the data transmission rate (here, the values of $R_{s,r}$ and $R_{r,d}$ are taken from the set [1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48, 54] which are adopted by IEEE 802.11g), packet length L, the common SNR P/σ_n^2 (denoted as SNR_{comm}) without fading, the relative speed v of relay node, and the threshold P_{th} of SER on the maximum value of K.

In all simulations, it can be shown that the maximum value of K will monotonously increase with the increase of data transmission rate ($R_{s,r}$ and $R_{r,d}$). For examples, when $R_{s,r} = 54\,Mbps$ and $R_{r,d} = 54\,Mbps$, the maximum value of K can reach 37 with $L = 1000\,bits$, 25 with $f_D = 150\,Hz$ and 10 with $\text{SNR}_{\text{comm}}) = 25\,dB$. This is so because a larger data transmission rate can reduce the delay between the relay selection and the actual data transmission, so that the difference between the actual SNR and the outdated version will become small and the correlation coefficient $\rho_{i,j}$ will become larger. Therefore, we should select the relay with higher $R_{s,r}$ and $R_{r,d}$ among relay candidates as the best relay to support the successive packets transmission.

In addition, Figure 3 shows that the maximum value of K can be greatly affected by the packet length. We can see that the maximum value of K will be reduced with the increase of the packet



(a) L = 1000 bits *(b) L = 3000 bits*

(c) L = 6000 bits *(d) L = 9000 bits*

Figure 3. The maximum value of K as a function of the data transmission rate and packet length L with $\text{SNR}_{\text{comm}}) = 20\,dB, f_D = 100\,Hz$ and $P_{th} = 0.001$, where X, Y and Z axes denote the maximum value of $R_{s,r}$, $R_{r,d}$ and K, respectively.

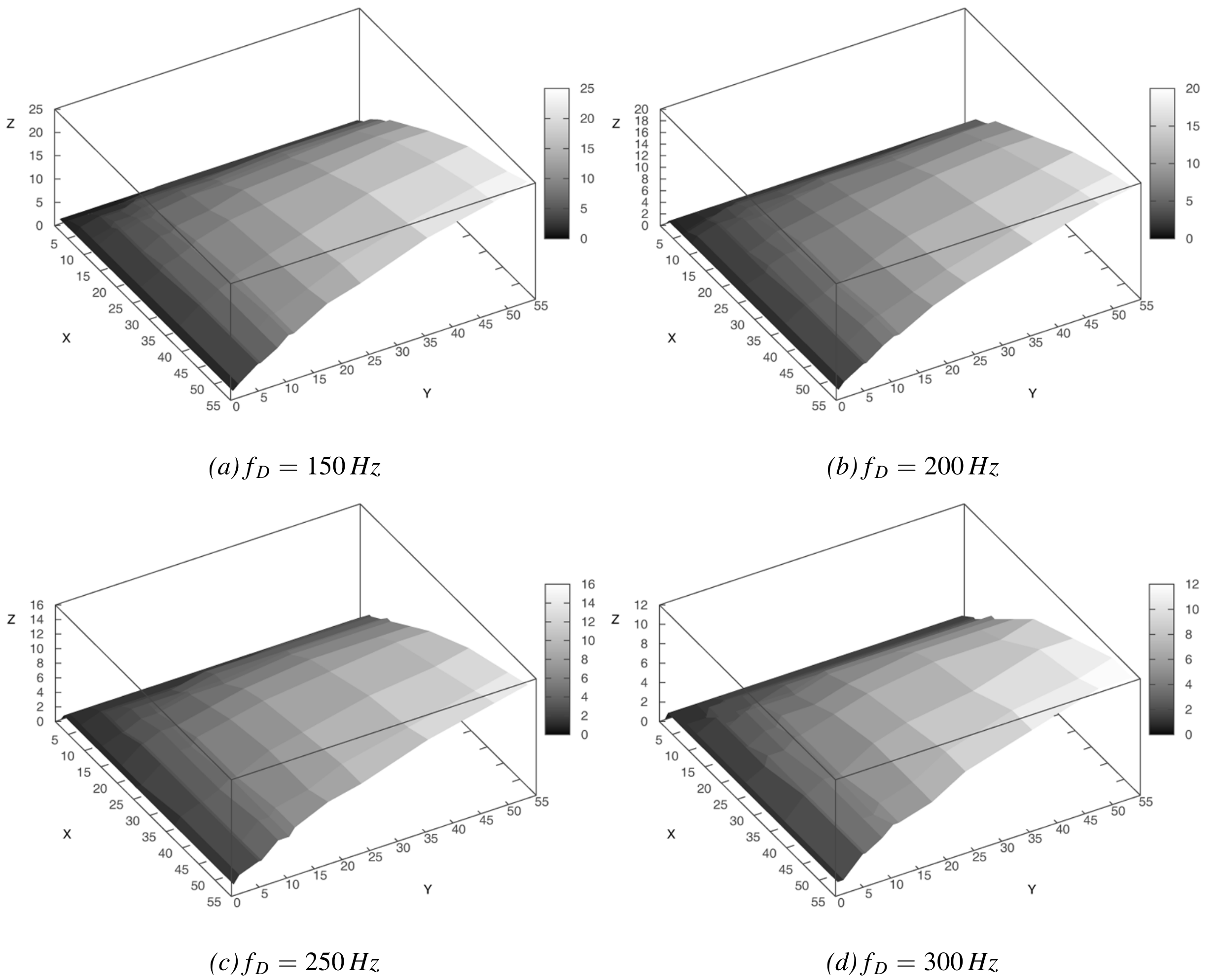
length. For instance, when $L = 9000\,bits$, the maximum value of K is only 4. Investigating the reason, the longer L will increase the delay between the relay selection and the actual data transmission and result in a smaller correlation coefficient.

In Figure 4, it is shown that the maximum value of K can be affected by the Doppler frequency f_D and reduced with the increase of f_D. This is because a larger value of f_D can reduce the correlation coefficient and lead to a larger SER. Figure 5 shows the effect of the SNR P/σ_n^2 on the maximum value of K. Unlike in the previous simulations, we can see that the maximum value of K is scarcely affected under a different SNR. This is because a higher SNR will require a smaller threshold P_{th} of SER, which can reduce the maximum value of K and counterweight the beneficial effect of a higher SNR on the maximum value of K.

Through the above simulations, we can see that the maximum value of K can be greatly influenced by certain network parameters, i.e., data transmission rate, packet length, Doppler frequency and the threshold P_{th} of SER. Therefore, when there are multiple relay candidates, the *k-th* relay can derive its own maximum value of K according to the optimization problem (21), and then the best relay $R_{k^*_{best}}$ can be selected through the OR scheme.

6. Conclusions and Future Work

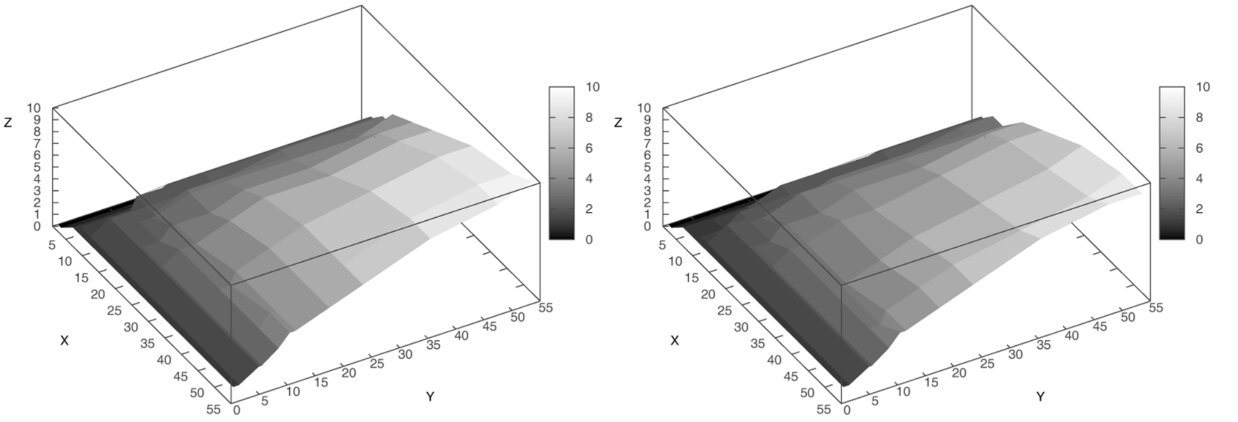
In this paper, we propose a best relay selection scheme for supporting successive packets transmission. First, we predict the actual instantaneous SNR through the outdated version. Then



(a) $f_D = 150\,Hz$ *(b)* $f_D = 200\,Hz$

(c) $f_D = 250\,Hz$ *(d)* $f_D = 300\,Hz$

Figure 4. The maximum value of K as a function of the data transmission rate and Doppler frequency f_D with $\text{SNR}_{\text{comm}}) = 20\,dB$, $L = 1000\,bits$ and $P_{th} = 0.001$, where X, Y and Z axes denote the maximum value of $R_{s,r}$, $R_{r,d}$ and K, respectively.



(a) $\mathrm{SNR}_{\mathrm{comm}} = 25dB$ and $P_{th} = 0.0001$ *(b)* $\mathrm{SNR}_{\mathrm{comm}} = 30dB$ and $P_{th} = 0.00001$

Figure 5. The maximum value of K as a function of the data transmission rate and SNR with $f_D = 100\,Hz$, $L = 4000\,bits$, where X, Y and Z axes denote the maximum value of $R_{s,r}$, $R_{r,d}$ and K respectively.

we derive the SER expression and the optimization problem to obtain the maximum number of successive packets transmissions. In addition, we also give an OR scheme to select the best relay. Simulation results illustrate that, in an cooperative network, the operation of successive packets transmission can be supported and the maximum number of successive packets transmissions is affected by selecting different network parameters, i.e., data transmission rate, packet length and Doppler frequency at one relay node under the constraint of SER performance, perhaps coming from the requirement of application layer.

As our future work, we will analyze effect of the proposed relay selection scheme on the system performance, i.e., throughput, delay and packet error rate.

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