Performance Modeling and Analysis for Minimum Energy Consumption in A Two-hop Relay Network

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ABSTRACT

In this paper we consider a two-hop relay network consisting of a source, a destination and multiple relay nodes which operate with Decode-and-Forward (DF) protocol. For a given quality of service (QoS) requirement such as transmission rate between the source and the destination, one relay node is selected and the selected relay node adapts its power to meet the QoS requirement. The relay selection and the adaptive power control scheme are based on the channel condition between relay nodes and the destination. By considering the details on the operations of the relay node selection protocol and the length of the source transmission time, we first develop a mathematical model for the relay network and analyze total average energy consumption. Based on our analytic results, we formulate an optimization problem of finding the optimal length of source transmission time that minimizes total average energy consumption. We provide some numerical examples to investigate the behavior of total average energy consumption of the relay network and show that our proposed scheme outperforms previously proposed schemes where the source and the relay node transmission times are the same.

INTRODUCTION

To alleviate detrimental fading effect occurred from signal fluctuation in wireless networks, various diversity techniques have been developed [1]. Especially, cooperative diversity systems, which exploit broadcast nature of wireless channels and are beneficial from multiple relay nodes forming virtual and distributed antennas, have recently become one of important research issues in the study of wireless networks because it can significantly improve spectral efficiency of wireless networks. The concept of cooperative diversity and relaying in wireless networks was first introduced by Van der Meulen [2], and then developed by many other researchers, e.g., [3–5].

In this paper, we consider a two-hop relay network consisting of a source, a destination and multiple relay nodes. We assume that there are no direct communication paths between the source and the destination due to obstacles, e.g., buildings, and accordingly the source communicates with the destination only through one of relay nodes. To forward information between the source and the destination, the decode-and-forward (DF) protocol is used in the relay network where the relay node first decodes the information from the source and then encodes and forwards the information to the destination. The relay node selection is performed by the destination based on the best signal-to-noise ratio (SNR) in relay-destination (RD) channels. To this
aim, the destination uses training signals transmitted from relay nodes to estimate the SNR values of RD channels and selects the relay node that has the best SNR value. We assume that all channels, source-relay (SR) channels and RD channels are independent and follow the Rayleigh block fading model with respective parameters. Accordingly, the SNR of each channel remains invariant during the coherent time [6], called a slot time \( T_s \) in this paper. Since the selected relay node with best SNR value forwards the information in the relay network, the transmission between the selected relay node and the destination should be completed within a slot time.

Since the selected relay node receives the information from the source and forwards the information to the destination, one slot time is in fact divided into three subperiods - the transmission period by the source \( T_{sr} \), the SNR estimation and relay node selection period called the training period \( T_0 \), and the transmission period by the selected relay node \( T_{rd} \). We assume that a certain level of quality of service (QoS) requirement such as transmission rate in the relay network, e.g., \( C \) bits/sec, is given. To meet such QoS requirement, there is an adaptive power control scheme in the selected relay node which adaptively changes the transmission power to forward the information to the destination based on its channel condition.

Under our assumptions so far, we analyze total average energy consumption per slot of the relay network. For \( N \) relay nodes, the power gain between the source and relay node \( i \), \( 1 \leq i \leq N \) is according to an exponential distribution with parameter \( \lambda \). Also, the power gain between relay node \( i \) and the destination follows an exponential distribution with parameter \( \mu \). Let \( \delta \) be a threshold value such that each relay node decides to participate in forwarding information with guaranteeing required outage probability. If the source and selected relay node transmit the information with coding rate \( C_s \) (bits/symbol) and \( C_r \) (bits/symbol), respectively, total average energy consumption per symbol time \( E[P] \) is computed as follows:

\[
E[P] = \mu N (2^{C_r} - 1) \sum_{m=0}^{N-1} \frac{N - 1}{m} (-1)^m e^{-(m+1)\lambda(2^{C_s} - 1)} \\
\times E_1((m+1)\mu \delta) \sum_{l=0}^{N-(m+1)} \frac{N - (m + 1)}{l} \\
\times e^{-l\lambda(2^{C_s} - 1)}[1 - e^{\lambda(2^{C_s} - 1)}]^{N-(m+1)-l} \\
= \mu N (2^{C_r} - 1) \sum_{m=0}^{N-1} \frac{N - 1}{m} (-1)^m e^{-(m+1)\lambda(2^{C_s} - 1)} E_1((m+1)\mu \delta),
\]

where \( E_1(x) := \int_x^{\infty} \frac{1}{y} e^{-y} dy \). Since total average energy consumption per slot time is given by \( E[P] \cdot T_{rd} \), our optimization problem is formulated as follows.

\[
\min_{T_{sr}} E[P] \cdot (T_f - T_0 - T_{sr}) \\
\text{s.t. } 0 < T_{sr} < T_f - T_0.
\]

Throughout numerical studies we show that selecting the optimal length of source transmission time within a slot time reduces total average energy consumption per slot time. For this, we change the value of \( \mu \) form 1 to 2.5 and compute total average energy consumption when we use the optimal value of \( T_{sr} \). From Fig. 1 we see that the use of the optimal value of \( T_{sr} \) saves more energy than \( T_{sr} = T_{rd} \). In addition, we investigate the effect of the RD channel condition on total average energy consumption. For this, the value of \( \mu \) is changed from 1 to 2 while the value of \( \lambda \) is set to 2. From Fig. 2 we see that the amount of total average energy consumption per slot time significantly increases when the RD channels gets worse.
The value of $\mu$

Total Average Energy Consumption per slot time

the case of $T_{sr} = T_{rd}$
the case of the optimal $T_{sr}$

Figure 1. Total Average Energy Consumption in a slot vs. $\mu$

$\mu = 1$
$\mu = 1.5$
$\mu = 2$

Figure 2. Total Average Energy Consumption vs. $\mu$ ($\lambda = 2$)

REFERENCES