AHP-based Relay Selection Protocol for Flexible Resource Management

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***Abstract*—In this paper, we deal with a relay selection issue to improve throughput performance under signaling overhead and delay constrained system. The proposed relay selection protocol, which is based on analytic hierarchy process (AHP), adopts signal-to-noise ratio (SNR), system delay, and switching weight as selection criteria. We examined target system performance under various weighting to the above attributes. Also, average throughput can be maximized adaptively in various system environments. The proposed protocol entirely realizes the feature of opportunistic relaying (OR) protocol by totally weighting the SNR criterion. The performance of our protocol is verified in terms of average throughput, average delay and average relay switching counts.**

I. Introduction

Relay has been introduced to enlarge cell edge coverage and enhance the data rate on a shadowing hole. As service providers establish intermediate nodes, which relay data between a source node (SN) and a destination node (DN), radio channel quality is improved by shortening the physical distance or utilizing spatial diversity gain. Therefore, the improvement in radio channel condition increases the achievable data rate. For such outstanding features, the relay technique is considered as a key scheme for data transmission in next generation systems such as 802.16j and LTE-Advanced [1],[2].

One of critical issues in relay technique is which relay node (RN) should be selected to improve target performance such as throughput, BER and outage probability [3],[4]. Here, important thing is that the performance is mainly affected by system environment, channel condition, traffic type and so on, we have to consider system parameters that reflect these attributes in relay selection protocol. By doing so, a the protocol can improve the target performance.

In relay selection techniques, opportunistic relaying (OR) protocol has been generally adopted to achieve selective diversity, where the SN opportunistically selects RN maximizing instantaneous SNR [5]. However, frequent relay switching is introduced, which results in the increase of signaling overhead in OR protocol. Most of the previous works are based on OR protocol. In [6], authors suggested threshold-based relay switching (TRS) protocol for reducing the signaling overhead based on OR protocol. In TRS protocol, relay switching occurs only when SNR at DN is greater than the threshold value. In [7] and [8], authors investigate the effect of link delay and queue delay in relay networks, respectively.

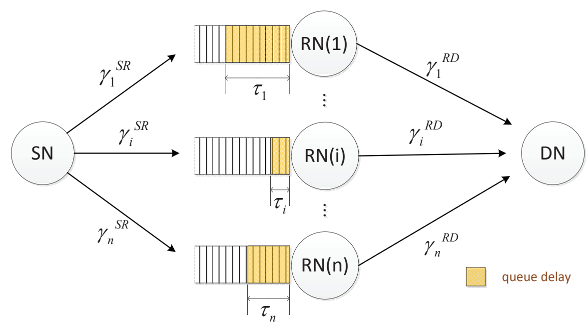

Fig. 1. Two-Hop Relay Network with M/M/∞ Queue

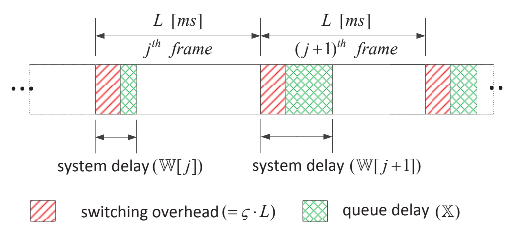

Fig. 2. TDMA-Based Frame Structure

However, previous studies based on OR protocol does not consider system delay caused by signaling overhead and queue delay. Since these kinds of system delay affect throughput performance, target performance is not maximized under delay constrained system. For reducing such system delay, we adopt analytic hierarchy process (AHP) algorithm in relay selection. AHP algorithm is a decision making process using the hierarchy of alternatives and criteria, which consists of two major steps: combination of qualitative and quantitative information and evaluation of priority from an eigenvector [9]. In order to apply AHP algorithm to relay selection, we consider not only 'instantaneous SNR' but also 'system delay' and 'switching weight' as selection criteria. From such consideration, achievable throughput is maximized under various system environments. Under delay constrained

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system, frequent relay switching increases system delay and the increased delay decreases throughput performance. From this relationship, such metrics as 'relay switching counts', 'system delay' and 'throughput' are correlated with the decision criteria. Therefore, we investigate these three metrics from our AHP-based relay selection protocol.

The rest of this paper is organized as follows. In Section II, a two-hop relay system model with M/M/∞ queue and simulation environment is introduced. The proposed protocol is introduced and relationship among three metrics is derived in Section III. Then, we analyze our proposed protocol compared with OR and TRS protocol by simulations and introduce further works in Section IV. Finally, we make conclusions in Section V.

II. System Model

A simple two-hop relay network with M/M/∞ queue is considered as in Fig. 1. We assume that the direct communication between SN and DN is not allowed, which means that SN communicates with DN only through selected RN$_i$. We assume that packet arrivals process at SN follows the Markov process [8]. Each channel of all possible link is assumed to follow flat Rayleigh fading model [8]. In this assumption, channel quality is constant for frame duration, which is reasonable if a frame duration is shorter than the coherence time of channel. Additive White Gaussian Noise (AWGN) with $\mathcal{CN}(0, N_0)$ is added to the received signal. For frame duration, the SNR of SN-RN$_i$(RN$_i$-DN) is described as $\gamma_i^{SR(RD)} = \frac{P_t |g_i{}^{SR(RD)}|^2}{N_0}$, where P_t, $g_i{}^{SR(RD)}$ and N_0 indicate transmitted power at SN, SN-RN$_i$(RN$_i$-DN) channel gain and noise variance, respectively. So, achievable SNR is obtained by $\gamma_i = \min(\gamma_i{}^{SR}, \gamma_i{}^{RD})$ for a given RN. In OR protocol, the RN is selected by

$$i^*[j] = \underset{i \in \mathbb{N}=\{1,\cdots,n\}}{\arg\max} \; \{\gamma_i[j]\} \tag{1}$$

for frame duration, where $i^*[j]$ indicates selected RN in j^{th} frame. We also assume that there is no interference from an adjacent relay network due to assigning orthogonal frequency band to each RN. TDMA-based decode-and-forward relay network is adopted and a symmetric system is chosen [6]. A ζ portion of a frame is occupied by signaling overhead [6]. In addition to signaling overhead, packet waiting time in a queue is considered for system delay. For analysis, a queue delay is modeled as an exponential random variable with mean of $1/\lambda$ and this is the same for a frame duration [8]. We assume that packets are not transmitted within delayed duration. For this purpose, throughput for the j^{th} frame is calculated by

$$R[j] = (L - \mathbb{W}[j]) \; B \, log_2(1 + \gamma_{i^*[j]}) \;\; [bps], \tag{2}$$

where $j \in \mathbb{K} = \{1, \cdots, k\}$, B, and L indicates frame index, bandwidth, and frame length, respectively. A random variable $\mathbb{W}$ represents system delay. We assume that the packets are dropped in j^{th} frame when $\mathbb{W}[j] \geq L$.

III. AHP-Based Relay Selection Protocol

A. Proposed model

Analytic Hierarchy Process (AHP) algorithm is decision making based on the weighting process [10]. In AHP algorithm, both qualitative and quantitative information are considered as two hierarchies of alternatives and criteria. After that, the relative ranking of alternatives is computed by merging both information. From the relative ranking, the final decision is made by taking maximum ranking [10],[11].

In order to utilize AHP algorithm for relay selection, we consider the factor of 'SNR', 'system delay', and 'switching weight' as criteria of AHP algorithm.

In our proposed model, for a frame duration, a pairwise matrix of SNR criterion $\mathbf{S}$ is described by

$$\mathbf{S} = \begin{bmatrix} 1 & \frac{\gamma_1}{\gamma_2} & \cdots & \frac{\gamma_1}{\gamma_n} \\ \frac{\gamma_2}{\gamma_1} & 1 & \cdots & \frac{\gamma_2}{\gamma_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\gamma_n}{\gamma_1} & \frac{\gamma_n}{\gamma_2} & \cdots & 1 \end{bmatrix}, \tag{3}$$

where γ_i indicates SNR of RN$_i$ and $i \in \mathbb{N} = \{1, \cdots, n\}$ indicates RN index. From this pairwise matrix $\mathbf{S}$, n eigenvalues θ are obtained by

$$\mathbf{det}\,(\theta\mathbf{I} - \mathbf{S}) = 0, \tag{4}$$

where $\mathbf{I}$ indicates identity matrix. From the eigenvalue, n corresponding eigenvectors $\mathbf{s}$ are calculated by

$$(\theta\mathbf{I} - \mathbf{S})\,\mathbf{s} = \mathbf{0}, \tag{5}$$

where $\mathbf{0}$ indicates null vector. Then, out of n eigenvectors $\mathbf{s}$, an eigenvector $\hat{\mathbf{s}}$ is chosen whose components are all positive.

For frame duration, the pairwise matrix of delay criterion $\mathbf{D}$ is also obtained by

$$\mathbf{D} = \begin{bmatrix} 1 & \frac{\tau_1}{\tau_2} & \cdots & \frac{\tau_1}{\tau_n} \\ \frac{\tau_2}{\tau_1} & 1 & \cdots & \frac{\tau_2}{\tau_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\tau_n}{\tau_1} & \frac{\tau_n}{\tau_2} & \cdots & 1 \end{bmatrix}^T, \tag{6}$$

where τ_i indicates system delay of RN$_i$. In perspective of delay criterion, the better delay performance means the less delay duration. Therefore, transpose operation is taken as shown in (6). Similarly, n eigenvectors $\mathbf{d}$ are obtained from (5) by replacing $\mathbf{S}$ by ($\mathbf{D}$). Then, out of n eigenvectors $\mathbf{d}$, an eigenvector $\hat{\mathbf{d}}$ is chosen whose components are all positive.

Finally, for frame duration, an indicator vector $\mathbf{w} = [\, w_1 \cdots w_i \cdots w_n \,]^T$ is taken which represents the selected RN in the previous frame. By weighting δ parameter, AHP protocol similarly realizes TRS protocol for preventing frequent relay switching. $\mathbf{w}$ is obtained by

$$w_i[j] = \begin{cases} 1, & \text{for } i = i^*[j-1] \\ 0, & \text{for } i \neq i^*[j-1], \end{cases} \tag{7}$$

where $j \in \mathbb{K} = \{1, \cdots, k\}$ indicates frame index and '*' means the index of 'selected' RN. Note that **w** is null vector in the first frame. ($j = 1$)

After obtaining $\hat{\mathbf{s}}$, $\hat{\mathbf{d}}$ and **w**, these vectors should be normalized for merging information of three criteria. (i.e., $\sum\limits_{i\in\mathbb{N}} s_i$=1, $\sum\limits_{i\in\mathbb{N}} d_i$=1 and $\sum\limits_{i\in\mathbb{N}} w_i$=1)

After all, the priority vector **p** for frame duration is calculated by

$$\mathbf{p} = \begin{bmatrix} p_1 \\ \vdots \\ p_i \\ \vdots \\ p_n \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{s}} & \hat{\mathbf{d}} & \mathbf{w} \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \\ \delta \end{bmatrix}, \tag{8}$$

where α, β, and δ are weighting parameters which correspond to 'SNR', 'system delay', and 'switching weight' criteria, respectively.

Once priority vector **p** is obtained, the proper RN is selected by

$$i^* = \underset{i\in\mathbb{N}=\{1,\cdots,n\}}{\arg\max} \ \{p_i\} \tag{9}$$

for frame duration. Since (9) is the same process to (1) in OR protocol, AHP-based relay selection protocol realizes OR protocol by substituting that α=1, β=0 and δ=0. In other words, our proposed protocol includes OR protocol.

B. Relationship among three metrics

Throughput, delay, and frequent relay switching metrics are inter-related with each other. For example, delay is increased as frequent relay switching occurs and this result decreases throughput. Therefore, for various environments, the optimal performance can be achieved by controlling weighting parameters, α, β and δ. The relationship among these metrics is derived in a mathematical way.

For a single relay selection, relay switching probability is derived as follows:

$$\Pr\{switching\} = \frac{n-1}{n}, \tag{10}$$

where n indicates the number of RN. Then, the mean of total relay switching counts χ is obtained by

$$\mathbb{E}[\chi] = \Pr\{switching\} \times k = \frac{n-1}{n} \times k, \tag{11}$$

where k indicates the total number of frame. From the average total relay switching counts, the mean of total signaling overhead duration ξ is calculated by

$$\mathbb{E}[\xi] = \mathbb{E}[\chi] \times (\zeta \times L) = \frac{n-1}{n} \times k \times (\zeta \times L), \tag{12}$$

where ζ indicates a portion of signaling overhead within a frame length L.

Therefore, the mean of total system delay $\mathbb{W}$ is calculated by

$$\begin{aligned} \mathbb{E}[\mathbb{W}] &= \mathbb{E}[\xi + \mathbb{X}] = \mathbb{E}[\xi] + \mathbb{E}[\mathbb{X}] \\ &= \left(\frac{n-1}{n} \times k \times \zeta \times L\right) + \left(\frac{k}{\lambda}\right), \end{aligned} \tag{13}$$

where $\frac{k}{\lambda}$ is derived by central limit theorem from exponential random variable $\mathbb{X}[j]$ with mean of $\frac{1}{\lambda}$. (i.e., $\mathbb{X} = \sum\limits_{j=1}^{k} \mathbb{X}[j]$,which indicates total queue delay)

Finally, the mean of total throughput R over k frames is obtained by

$$\mathbb{E}[R] = \mathbb{E}\left[\left(\frac{kL - \mathbb{W}}{kL}\right) B\log_2(1+\Gamma)\right], \tag{14}$$

where Γ denotes random variable of SNR. In (14), total throughput R is divided by total duration kL to match the unit of bps.

IV. Performance Analysis

A. Result and Discussion

TABLE I
SIMULATION PARAMETER

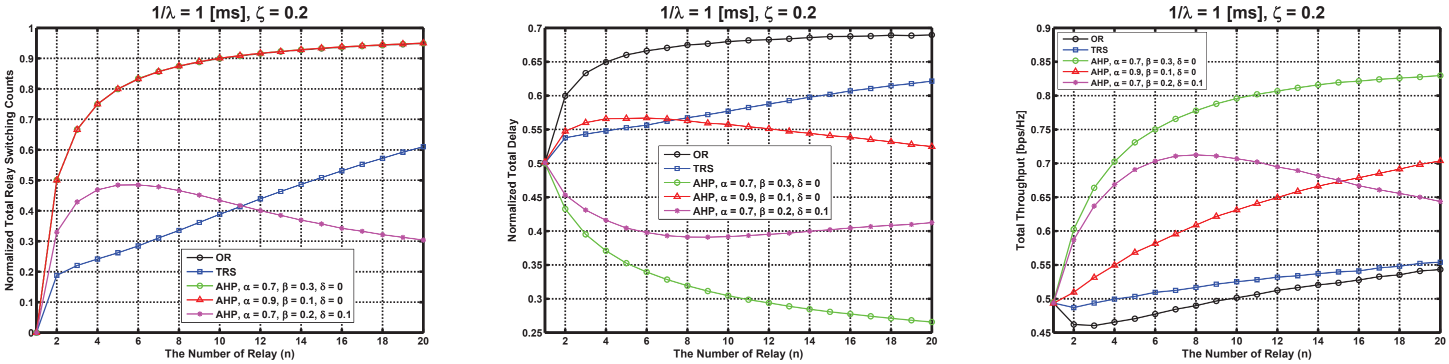
Parameter	Value	Unit
The number of total frame (k)	1000	-
Single frame length (L)	2	$[ms]$
The number of RN (n)	1 – 20	-
Transmitted power(P_t)	1	$[W]$
Bandwidth(B)	1	$[Hz]$
Noise variance(N_0)	1	$[W/Hz]$
Fraction of signaling overhead (ζ)	0.01, 0.2	-
Mean of random variable($1/\lambda$)	0.13, 1	$[ms]$
γ_t for TRS protocol	3	[dB]

In this subsection, we analyze the proposed AHP protocol compared with OR and TRS protocol in terms of 'average total relay switching counts', 'average total delay', and 'average total throughput' with respect to the number of RN. Here, throughput is calculated by unit bandwidth (i.e., unit of $[bps/Hz]$) as shown in Table I. Other important simulation parameters are summarized in Table I.

We firstly analyze relationship between three metrics as derived from (10) to (14).

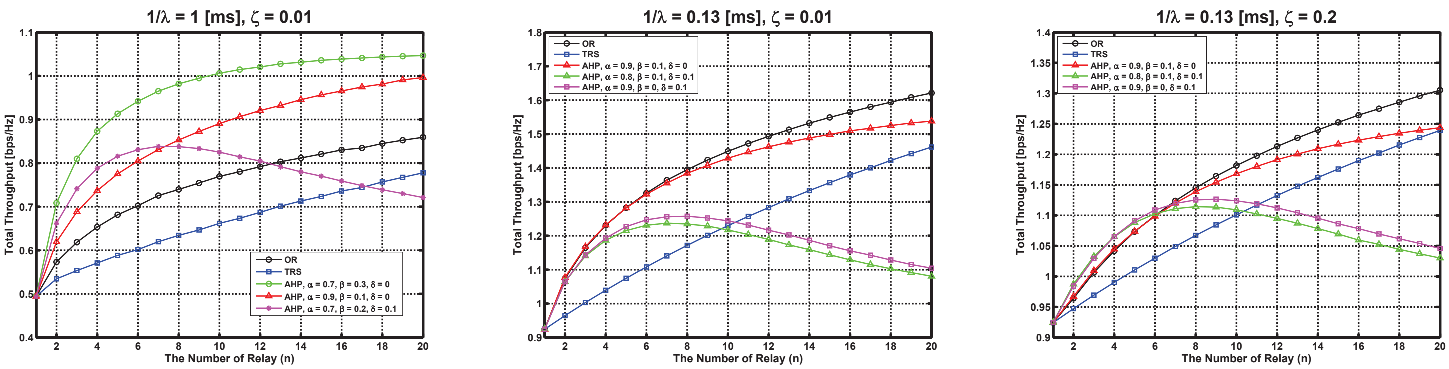
By using OR selection, total throughput is increased as the number of RN. The reason is that as the number of RN increases, the probability for the better channel gain is obtained. This result achieves selective diversity gain. We compare AHP protocol with OR and TRS protocol.

In the delay dominant environment such as heavy traffic environment, we investigate that queue delay occupies a half of frame duration with more signaling overhead. The results



(a) Average Total Relay Switching Counts ($\frac{1}{\lambda}$=1 $[ms]$, ζ=0.2) (b) Average Total Delay ($\frac{1}{\lambda}$=1 $[ms]$, ζ=0.2) (c) Average Total Throughput ($\frac{1}{\lambda}$=1 $[ms]$, ζ=0.2)

Fig. 3. Simulation results of delay-dominant network



(a) Average Total Throughput ($\frac{1}{\lambda}$=1 $[ms]$, ζ=0.01) (b) Average Total Throughput ($\frac{1}{\lambda}$=0.13 $[ms]$, ζ=0.01) (c) Average Total Throughput ($\frac{1}{\lambda}$=0.13 $[ms]$, ζ=0.2)

Fig. 4. Average total throughput of various system environment

TABLE II
AVERAGE TOTAL THROUGHPUT $[bps/Hz]$ ($\frac{1}{\lambda}$=1 $[ms]$, ζ=0.2)

Protocol		n = 4	n = 14	n = 20
OR [black]		0.4655	0.5204	0.5432
TRS [blue]		0.4995 (+7.30%)	0.5371 (+3.20%)	0.5540 (+1.99%)
AHP	α=0.7 β=0.3 δ=0 [green]	0.7026 (+50.93%)	0.8159 (+56.79%)	0.8296 (+52.72%)
	α=0.9 β=0.1 δ=0 [red]	0.5495 (+18.04%)	0.6663 (+28.03%)	0.7036 (+29.52%)
	α=0.7 β=0.2 δ=0.1 [pink]	0.6688 (+43.65%)	0.6816 (+30.98%)	0.6436 (+18.48%)

for delay dominant system are shown in Fig. 3. In Fig. 3(a), OR protocol and AHP protocol in the case that $\delta = 0$ show the same results to (10). However, others do not satisfy (10) any more due to a decrease of switching probability. This result indicates the effect of TRS protocol and δ-weighted AHP protocol on relay switching counts.

As can be seen in Fig. 3(b), the performance improvement in relay switching counts has an effect on the average total delay as described in (13). Although δ is not weighted to reduce signaling overhead, the green case shows the best result in perspective of total delay. This result implies that considered system is more affected by queue delay than signaling overhead.

In Fig. 3(c), throughput performance is affected by the improvement in total delay performance as described by (14). For example, the green case shows the best performance of throughput due to the shortest total delay.

In Fig. 3(c), the average throughput of AHP protocol generally improves the performance compared with OR and TRS protocols in delay-dominant system. Here, average throughput of red and green increase faster than that of black due to higher selective diversity gain. Also, throughput of OR protocol decreases when $n \leq 3$. It seems that OR protocol does not achieve diversity gain due to delay in this case.

In Table II, numerical results are shown for the given n. For example, AHP protocol with $\alpha = 0.7, \beta = 0.3, \delta = 0$ where $n = 14$ shows the best performance improvement compared with OR protocol by about 56%.

In Fig. 3(c), the important observation is that pink case partially achieves the better improvement than red case when $n \leq 15$. This observation means that the best performance is possibly achieved with different weighting parameters for the given number of RN.

In Fig. 3(c), red case achieve better throughput performance than blue case while delay performance of red case is worse than that of blue case in Fig. 3(b). According to (14), the throughput performance should be described in an opposite way when $n \leq 7$. However, throughput performance does not correspond to (14) any more due to the weighting process.

The other important observation is concerning the limitation of TRS protocol. As compared with AHP protocol, TRS protocol does not show remarkable improvement despite delay-dominant system. Two observations can be drawn for this result. Our system is more affected by queue delay than signaling overhead, while TRS protocol reducing only signaling overhead, not queue delay. The loss of SNR performance may be greater than the gain of delay performance when relay switching is prevented.

The last one is observed when δ is weighted. The throughput of pink case does not increase any more when $n \geq 8$. This observation also appears in the overall result in Fig. 4. The result gives an insight for the use of δ parameter. As δ gets larger, AHP protocol similarly realizes TRS protocol. Therefore, this result is also related to the lower gain of SNR performance compared with the gain of delay. However, the difference exists between TRS protocol and δ-weighted AHP protocol as shown in Fig. 3(c). From the figure, pink case shows favorable performance within the small number of RNs while TRS protocol does not in delay dominant system. Such difference results from the additional consideration of α and β parameters due to the relationship among three metrics.

As seen in Fig. 4(b), OR protocol is optimal when delay is not dominant. However, our proposed protocol with weighting can realize OR protocol as mentioned in Section III.

B. Further works

We introduce a potential way to operate relay network system with our protocol. For example, service providers operate system with feedback information of channel condition and total delay. After receiving feedback information, service providers decide the corresponding parameters of α, β and δ. Although this process requires high system complexity, it maximizes transmission performance as shown in simulation results. For this purpose, the optimum values of α, β and δ should be investigated for the given number of RNs.

The multiple relay selection scheme in AHP protocol is another future work of interest. For this work, the number of RN must be additionally considered as a criterion in AHP algorithm.

V. Conclusion

In this paper, we propose an analytic hierarchy process (AHP) based relay selection protocol. For the feasibility in real systems, system delay (i.e., signaling overhead and queue delay) is taken into consideration. We consider 'instantaneous SNR', 'system delay', and 'switching weight' as criteria of AHP algorithm to relay selection protocol. We show that the performance is flexible and adaptive to the four cases by controlling the weighting parameters of α, β and δ. In delay dominant environment, AHP protocol can generally achieve the maximum performance by choosing proper α, β and δ parameters for the given number of RN. On the contrary, OR protocol maximizes the performance in case of a poor delay system. However, AHP protocol realizes OR protocol by substituting that $\alpha = 1$, $\beta = 0$, and $\delta = 0$. This property shows that AHP protocol entirely realizes the feature of OR protocol. From this, the relay network is operated flexibly with the feedback information by AHP protocol.

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