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Approximated Outage Probability for ADF Relay Systems with Burst MPSK and MQAM Symbol Transmission

Kyunbyoung Ko
Dept. of IT Convergence & Dept. of Control and Instrumentation Engineering
Korea National University of Transportation, 50 Daehak-ro, Chungju-si, Chungbuk, 380-702 Korea

Sungmook Lim
Dept. of Electronics Engineering
Korea National University of Transportation, 50 Daehak-ro, Chungju-si, Chungbuk, 380-702 Korea

ABSTRACT

In this paper, we derive the outage probability for M-ary phase shifting keying (MPSK) and M-ary quadrature amplitude modulation (MQAM) burst transmission (BT) of adaptive decode-and-forward (ADF) cooperative relay systems over quasi-static Rayleigh fading channels. Within a burst, there are pilot symbols and data symbols. Pilot symbols are used for channel estimation schemes and each relay node's transmission mode selection schemes. At first, we focus on ADF relay systems in which the probability density function (PDF) is derived on the basis of error events at relay nodes corresponding to channel estimation errors. Next, the average outage probability is derived as an approximate expression for an arbitrary link signal-to-noise ratio (SNR) for different modulation orders. Its accuracy is demonstrated by comparison with simulation results. Further, it is confirmed that BT-ADF relay systems with pilot symbol based channel estimation schemes enables to select correctly decoded relay nodes without additional signaling between relay nodes and the destination node, and it is verified that the ideal performance is achieved with small SNR loss.

Key words*: Outage probability, MPSK, MQAM, ADF, Rayleigh Fading Channels.*

1. INTRODUCTION

Many researches have widely discussed cooperative relay schemes. In general, there are two main relay protocols for cooperative diversity schemes: amplify-and-forward (AF) and decode-and-forward (DF). AF amplifies the received signal and retransmits it to the destination, whereas DF detects the received signal and then retransmits a regenerated signal [1]-[3]. A third option is adaptive DF (ADF) scheme, in which relays forward only correctly decoded messages [4]-[6]. At ADF relay nodes, errors are assumed to be correctly detected by using a cyclic redundancy check (CRC) code from a higher layer (e.g., data link layer) [3], [7]-[9]. At the destination node, the receiver can enhance performance by employing one of various diversity combining techniques based on the multiple signal replicas from the relays and the source. The advantages of general cooperative diversity schemes come at the expense of the spectral efficiency since the source and all the relays must transmit on orthogonal channels (i.e., different time slots or frequency bands) in order to avoid interfering with each other as well [3]. Recent studies have examined relay-selection schemes in which only two channels are necessary (one for the direct link and the other one for the best relay link) [10]-[14]. However, they need additional process or feedback information for channel states.

In [5], the authors have derived an exact bit error rate (BER) applicable for both DF and ADF relaying as well-known tractable forms. It shows how an erroneous detection at each relay affects both the received signal-to-noise ratio (SNR) and the average BER. Even if it can give exact results [5], [15], it is noted that previous researches including relay-selection schemes have assumed that each relay can detect symbol-by-symbol error [5], [11], [15]. It means that at each relay, transmission mode ('Tx. mode') or no-transmission ('Sleep mode') can be determined per symbol-by-symbol. However, this is not practical and the performance based on this assumption implies only an achievable bound.

In [16]-[18], the authors showed the practical approach based on burst transmission for DF relay systems. Nevertheless, no one has expressed the approximated outage expression as well-known tractable forms, which can cover both M-ary phase shifting keying (MPSK) and M-ary quadrature amplitude modulation (MQAM) burst transmission. In [19], the authors provided a framework for analyzing the BER performance of AF relay-assisted cooperative transmission in the presence of

* Corresponding author, Email: smlim@ut.ac.kr
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imperfect channel estimation. However, the framework in [19] does not include pilot symbol assisted-channel estimation (PSA-CE) schemes which can be applied in practical systems, resulting in error-floor even at high SNR region. We extend the analytical approach in [19] to ADF burst transmission systems.

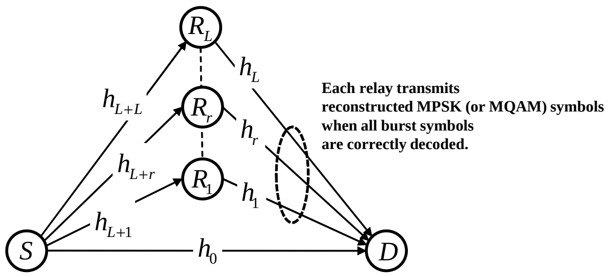

Fig. 1. Block diagram of BT-ADF Cooperative relay systems

In this paper, we consider burst-by-burst error detection for ADF relay systems, instead of symbol-by-symbol [16]-[18]. At first, we derive the probabilities for all possible error-events at relay nodes. By considering pilot and data symbol transmission within a burst, we derive error rate expressions over quasi-static independent and non-identical distributed (INID) Rayleigh fading channels, so that it can be an actual system performance. Furthermore, the average outage probability is approximated to a simplified expression for arbitrary link SNRs related to channel estimation errors and modulation order. In numerical and simulation results where the derived analytical solutions are compared with Monte-Carlo simulations, we verify that correctly decoded relay nodes can be selected from transmitted pilot symbols without additional signaling between relay nodes and the destination node. Furthermore, its performance well matches with our analytical results for all SNR regions and different modulation order.

The remainder of this paper is organized as follows: Section 2 describes the system model of BT-ADF cooperative relay systems. In section 3, the derived outage performance expression is presented. The numerical and simulation results are presented in Section 4 and also concluding remarks are given in Section 5.

2. BT-ADF COOPERATIVE RELAY SYSTEMS

[Fig. 1] shows the block diagram of BT-ADF relay systems with a source (S), a destination (D), and relays (R) where L is the number of relays. We assume that S and L relays transmit over orthogonal time slots so that we need $L+1$ time slots for single burst transmission [3]. At first, we explain fading channel model used in this paper.

2.1 BT-ADF COOPERATIVE RELAY CHANNEL MODEL

Let h_0, h_{L+r}, and h_r ($r=\{1,2,...,L\}$) be the channel gains of S-D, S-R, and R-D links, respectively, as shown in Fig. 1. In this paper, wireless channels between any pair of nodes are assumed to be quasi-static Rayleigh fading [20], [21]. It means that channel coefficients are considered to be constant during burst-transmissions and then, the magnitude and the phase of h_r are Rayleigh distributed and uniformly distributed over [0, 2π], respectively. From here, N_P and N_D are the number of pilot symbols and the number of modulated data symbols within a burst. N_B denotes the length of a burst (i.e., N_B=N_P+N_D). Also, each link channel is corrupted by complex additive white Gaussian noise (AWGN) term of $n_r[t]$. Without loss of generality, it is assumed that $E[|n_r[t]|]=0$, $E[|n_r[t]|^2]=\sigma^2$, and $\{n_r[t]\}$ are mutually independent for different r and t. The operator $E[\cdot]$ represents statistical expectation.

For simplicity, this paper considers the first burst transmission. Then, $s[t]|_{t=1}^{N_P}$ is the pilot symbol known to all nodes and $\left|s[t]|_{t=N_P+1}^{N_B}\right|=1$ is MPSK or MQAM data symbol. Also, $\{s[t]\}_{t=1}^{N_B}$ are mutually independent for different t with $E[s[t]]=0$ and $E\left[|s[t]|^2\right]=1$.

2.2 BT-ADF COOPERATIVE RELAY SYSTEM MODEL

As shown in [Fig. 1], BT-ADF cooperative relay systems have ($L+1$) steps for single burst transmission. The 0th step is related to the transmission from the source node to all the relays and the destination by using the 0th time slot. During the 0th step, the received signals can be presented for the S-D link and the rth S-R link as

$$\begin{aligned} y_0[t] &= h_0\sqrt{E_0}s[t]+n_0[t] \\ y_{L+r}[t] &= h_{L+r}\sqrt{E_{L+r}}s[t]+n_{L+r}[t] \end{aligned} \quad (1)$$

where $E_0= E_{L+r}= E_S$ is the average transmitted symbol energy of the source and $t=1,2,...,N_B$ is the time index of the first burst transmission. In (1), $y_0[t]$ is the received signal at the destination during the 0th time slot.

For the remaining L steps, each relay transmits the regenerated data symbols. Only when all N_D data symbols are correctly decoded, the rth relay transmits the regenerated symbol $\hat{s}_r[t]$ in the rth transmission step. For the rth time slot, the received signal at the destination node is written with $t=1,2,...,N_B$ as

$$\begin{aligned} y_0[t+rN_B] &= h_r\sqrt{E_r}\hat{s}_r[t]+n_0[t+rN_B] \\ y_r[t] = y_0[t+rN_B] &= h_r\sqrt{E_r}\hat{s}_r[t]+n_r[t] \end{aligned} \quad (2)$$

where $n_r[t]=n_0[t+rN_B]$ and E_r is the average transmitted symbol energy of the rth relay node.

2.3 PILOT-SYMBOL BASED CHANNEL-ESTIMATION

For $1\le t\le N_P$, $\hat{s}_r[t]=s[t]$ in (2) are pilots symbols to estimate R-D link channels so that, (1) and (2) can be expressed as single equation of

$$y_r[t]=h_r\sqrt{E_r}s_r[t]+n_r[t]$$

with $r\in\{0,1\cdots,2L\}$. Then, for pilot-symbol based channel-estimation schemes, the channel gains can be obtained as

$$\hat{h}_r = \frac{1}{N_P}\sum_{t=1}^{N_P} s^*[t]\, y_r[t] = h_r\sqrt{E_r} + e_r \tag{3}$$

where $e_r = 1/N_P\sum_{t=1}^{N_P} s^*[t]\, n_r[t]$ is the channel estimation error with $E\left[|e_r|^2\right] = \sigma^2/N_P$ and $E[e_r]=0$. From pilot symbols and the estimated channel gain $\hat{h}_r$, the noise variance for pilot symbols can be estimated as

$$\hat{\sigma}^2_{P,r} = 1/N_P\sum_{t=1}^{N_P}\left|y_r[t] - \hat{h}_r s[t]\right|^2. \tag{4}$$

Note that for large N_P, the estimated noise variance in (4) can be approximated as

$$\hat{\sigma}^2_{P,r} \approx \sigma^2_{P,r} = E\left[\left|y_r[t] - \hat{h}_r s[t]\right|^2\right]_{1\le t\le N_P} = \frac{N_P-1}{N_P}\sigma^2. \tag{5}$$

The statistical noise variance for data symbol transmission can be expressed as

$$\sigma^2_{D,r} = E\left[\left|y_r[t] - \hat{h}_r s[t]\right|^2\right]_{N_P<t\le N_B} = \frac{N_P+1}{N_P}\sigma^2. \tag{6}$$

From (5) and (6), the noise variance for data symbols can be estimated as

$$\hat{\sigma}^2_{D,r} = \frac{N_P+1}{N_P-1}\hat{\sigma}^2_{P,r}. \tag{7}$$

Note that in above equations from (3) to (7), $r=0$, $r=1,\ldots,L$, and $r=L+1,\ldots,2L$ mean S-D, R-D, and S-R links, respectively.

2.4 PILOT SYMBOL BASED-RELAYING MODE SELSECTION

Under pilot-symbol based channel estimation methods, it is assumed that each relaying node can always transmit pilot symbols to the destination node. Then, the destination node can simply detect each relay's data transmission mode and hereafter, it refers to pilot symbol based-relaying mode selection (PB-RMS). During the rth time slot, we can examine the average signal powers for pilot symbol part and data symbol part, respectively, as follows:

$$\begin{aligned}\hat{P}^r_{\text{pilot}} &= \frac{1}{N_P}\sum_{t=1}^{N_P}\left|y_0[t+rN_B]\right|^2 \\ \hat{P}^r_{\text{data}} &= \frac{1}{N_D}\sum_{t=N_P+1}^{N_B}\left|y_0[t+rN_B]\right|^2\end{aligned} \tag{8}$$

By comparing $\hat{P}^r_{\text{pilot}}$ with $\hat{P}^r_{\text{data}}$, the rth relay's data transmission mode $\hat{D}^r_{\text{Tx}}$ can be estimated as

$$\hat{D}^r_{\text{Tx}} = \begin{cases} 0 \text{ (Sleep mode)}, & \text{if } \dfrac{\hat{P}^r_{\text{pilot}}}{\hat{P}^r_{\text{data}}} > 1 + T_e \\ 1 \text{ (Tx. mode)}, & \text{else}\end{cases} \tag{9}$$

where T_e is a threshold. At the destination node, a maximal ratio combing (MRC) scheme can be applied in order to combine signals from S-D and R-D links. Then, by using $\hat{h}_r$, $\hat{\sigma}^2_{D,r}$, and $\hat{D}^r_{\text{Tx}}$, the decision variable can be combined as

$$\hat{z}_C[t]\,|_{t=N_P}^{N_B} = \frac{\hat{h}_0^*}{\hat{\sigma}^2_{D,0}} y_0[t] + \sum_{r=1}^{L}\frac{\hat{h}_r^*}{\hat{\sigma}^2_{D,r}}\hat{D}^r_{\text{Tx}} y_r[t]. \tag{10}$$

3. AVERAGE OUTAGE PERFORMANCE ANALYSIS FOR BT-ADF COOPERATIVE RELAY SYSTEMS

3.1 EACH RELAY'S ERROR PROBABILITY

From $\hat{h}_{L+r}$, the rth S-R link's decision variable is shown for data symbol transmission as

$$z_{L+r}[t]\,|_{N_P<t\le N_B} = \hat{h}^*_{L+r} y_{L+r}[t]. \tag{11}$$

and then, the received SNR can be obtained as

$$\gamma_{L+r} = \frac{\left|h_{L+r}\sqrt{E_{L+r}}\right|^2}{\sigma^2(\beta_{L+r}+1/N_P)} \tag{12}$$

with

$$\beta_{L+r} = E\left[|\hat{h}_{L+r}|^2\right] / E\left[\left|h_{L+r}\sqrt{E_{L+r}}\right|^2\right]$$

and $E\left[|\hat{h}_{L+r}|^2\right] = E\left[\left|h_{L+r}\sqrt{E_{L+r}}\right|^2\right] + \sigma^2/N_P$.

Then, the probability density function (PDF) of random variable γ_{L+r} can be presented for the Rayleigh fading channel as

$$f_{\gamma_{L+r}}(\gamma) = 1/\bar{\gamma}_{L+r} e^{-\gamma/\bar{\gamma}_{L+r}} \text{ for } \gamma \ge 0 \tag{13}$$

where $\bar{\gamma}_{L+r}$ is the average SNR of

$$\bar{\gamma}_{L+r} = E[\gamma_{L+r}] = \frac{E\left[\left|h_{L+r}\sqrt{E_{L+r}}\right|^2\right]}{\sigma^2(\beta_{L+r}+1/N_P)}. \tag{14}$$

When the number of pilots increases, the channel estimation error decreases and the average SNR merges to the case of ideal channel estimation. Furthermore, above derivations can be also applied to S-D and each R-D link by replacing $L+r$ with r, so we can obtain γ_r, $\bar{\gamma}_r$, and $f_{\gamma_r}(\gamma)$ for $r=0,1,\ldots,L$.

Consequently, the r th S-R link's conditional SER can be approximated for MPSK as

$$P_S(\gamma_{L+r}) \approx aQ\left(\sqrt{b\gamma_{L+r}}\right) \tag{15}$$

with

$$(a,b) = \begin{cases} (1,2), & M=2\,(\text{BPSK}) \\ \left(2, 2\sin^2(\pi/M)\right), & M>2\,(\text{MPSK}) \\ \left(4\dfrac{\sqrt{M}-1}{\sqrt{M}}, \dfrac{3}{M-1}\right), & M>8\,(\text{MQAM}) \end{cases}$$

and $Q\left(\sqrt{x}\right) = 1/\sqrt{2\pi}\int_{\sqrt{x}}^{\infty}\exp(-t^2/2)dt$ [20][21].

3.2 ERROR EVENET PROBABILITY

For error-events at relays, the pth error-event vector is defined as $E^p = \left[e_1^p \cdots e_r^p \cdots e_L^p\right]$ with $p=1,2,\ldots,2^L$ and the total number of error-events is 2^L. Generally, we can define that E^1 is all-zero vector, E^{2^L} is all-one vector, and so on [5], [22]. For the pth error-event, $e_r^p = 0$ means that the rth relay correctly decodes N_D symbols (i.e., $\hat{s}_r[t] = s[t]$ for $N_P < t \le N_B$) and its 'Tx. mode' probability is

$$\begin{aligned} P_{\text{TM}}(\gamma_{L+r}) &= \left[1-P_S(\gamma_{L+r})\right]^{N_D} \\ &= \sum_{k=0}^{N_D}\binom{N_D}{k}(-1)^k P_S^k(\gamma_{L+r}) \end{aligned} \tag{16}$$

with $P_S(\gamma_{L+r})$ of (15). In addition, the average 'Tx. mode' probability can be written as

$$\begin{aligned} P_{\text{TM}}(\bar{\gamma}_{L+r}) &= E\left[P_C^{N_D}(\gamma_{L+r})\right] \\ &= \sum_{k=0}^{N_D}\binom{N_D}{k}(-1)^k E\left[P_S^k(\gamma_{L+r})\right] \end{aligned} \tag{17}$$

with

$$\begin{aligned} E\left[P_S^k(\gamma_{L+r})\right] &= \int_0^\infty P_S^k(\gamma) f_{\gamma_{L+r}}(\gamma)d\gamma \\ &= \int_0^\infty a^k Q^k\left(\sqrt{b\gamma}\right) f_{\gamma_{L+r}}(\gamma)d\gamma \end{aligned} \tag{18}$$

On the other hand, $e_r^p = 1$ indicates that there is at least one symbol error among N_D data symbols with the 'Sleep mode' probability of $P_{\text{SM}}(\bar{\gamma}_{L+r}) = 1 - P_{\text{TM}}(\bar{\gamma}_{L+r})$.

Consequently, the probability of the pth error-event at BT-ADF relay systems is presented as

$$\Pr{}^p = \prod_{r=1}^{L}\left[P_{\text{TM}}(\bar{\gamma}_{L+r})\right]^{\overline{e_r^p}}\left[P_{\text{SM}}(\bar{\gamma}_{L+r})\right]^{e_r^p} \tag{19}$$

with $\overline{e_r^p} = (e_r^p+1)\text{mod}2$ [5], [22]. The evaluation of (18) can be carried out by using the 'integral( )' function of MATLAB. When we apply the approximation of the Q-function, shown in [23], as

$$P_S(\gamma_{L+r}) \approx aQ\left(\sqrt{b\gamma_{L+r}}\right) \approx a_1\exp\left(-b_1\gamma_{L+r}\right) \tag{20}$$

with $a_1/a = 0.2$ and $b_1/b = 3.2/3$ into (18), we can obtain the approximated bound as

$$\begin{aligned} E\left[P_S^k(\gamma_{L+r})\right] &\approx \int_0^\infty a_1^k e^{-b_1 k\gamma} f_{\gamma_{L+r}}(\gamma)d\gamma \\ &= \frac{a_1^k}{1+b_1 k\bar{\gamma}_{L+r}} = E\left[P_S^k(\gamma_{L+r})\right]_{\text{App}} \end{aligned} \tag{21}$$

and from $E\left[P_S^k(\gamma_{L+r})\right]_{\text{App}}$, the result of (19) can be simplified.

3.3 COMBINED RECEIVED SNR AND AVERAGE OUTAGE PROBABILITY

For BT-ADF relay systems, the rth relay transmits the regenerated data symbols of $\hat{s}_r[t]|_{t=N_P}^{N_B}$ only when N_D data symbols are correctly decoded. Therefore, $\hat{s}_r[t]$ can be two values: one is $\hat{s}_r[t] = s[t]$ with the probability of $P_{\text{TM}}(\bar{\gamma}_{L+r})$ and the other is $\hat{s}_r[t] = 0$ with the probability of $P_{\text{SM}}(\bar{\gamma}_{L+r}) = 1 - P_{\text{TM}}(\bar{\gamma}_{L+r})$. Under the assumption that the destination node knows correctly decoded relay nodes, the combined decision variable is written by using $\hat{h}_r$ and $\sigma_{D,r}^2$ as

$$z_C[t]|_{t=N_P}^{N_B} = \frac{\hat{h}_0^*}{\sigma_{D,0}^2}y_0[t] + \sum_{r=1}^{L}\frac{\hat{h}_r^*}{\sigma_{D,r}^2}\overline{e_r^p}\,y_r[t] \tag{22}$$

and then, the received SNR can be written as

$$\gamma_C^p = \gamma_0 + \sum_{r=1}^{L}\overline{e_r^p}\,\gamma_r = \sum_{r=0}^{L}\overline{e_r^p}\,\gamma_r \tag{23}$$

with $\overline{e_0^p} = 1$ and $\overline{e_0^p}\,\bar{\gamma}_0 = \bar{\gamma}_0$ for all p. It is worthwhile to mention that when there is a detection-error at the rth relay node for the pth event vector (i.e., $e_r^p = 1$), no-transmission gives $\overline{e_r^p}\,\gamma_r = 0$. The PDF of γ_C^p can be presented as

$$f_{\gamma_C^p}(\gamma) = \sum_{r=0}^{L}\frac{\pi_r^p}{\bar{\gamma}_r}\exp\left(-\frac{\gamma}{\bar{\gamma}_r}\right) \text{ for } \gamma \ge 0 \tag{24}$$

with $\pi_r^p = \prod_{i=0, i\neq r}^{L} \frac{\overline{e_r^p}\,\overline{\gamma}_r}{\overline{e_r^p}\,\overline{\gamma}_r - \overline{e_i^p}\,\overline{\gamma}_i}$ [5][20]. Then, the outage probability can be expressed with respect to γ_{th} as

$$\begin{aligned} P_{\text{OUT}}^p(\gamma_{th}) &= Pr[\gamma_C^p \le \gamma_{th}] \\ &= \sum_{r=0}^{L} \pi_r^p \left(1 - \exp\left(-\frac{\overline{e_r^p}\gamma_{th}}{\overline{\gamma}_r}\right)\right). \end{aligned} \quad (25)$$

By taking into account for all the possible error-events, the outage probability is presented as [5], [22]

$$P_{\text{OUT}} = \sum_{p=1}^{2^L} \Pr{}^p P_{\text{OUT}}^p(\gamma_{th}). \quad (26)$$

4. NUMERICAL AND SIMULATION RESULTS

In this section, we show numerical results of average outage probability and then, evaluate their accuracy by comparing simulation results. For simplicity, we assume that $E_r = E_s / L$ for $r = 1, \cdots, L$. To capture the effect of path-loss on average outage probability, $\alpha_r = r/(L+1)$ is defined as the relative distance between source and the rth relay when the distance between source and destination is 1. Then, we use $E\left[|h_{L+r}|^2\right] = \frac{E\left[|h_0|^2\right]}{\alpha_r^\mu}$ and $E\left[|h_r|^2\right] = \frac{E\left[|h_0|^2\right]}{(1-\alpha_r)^\mu}$ with the path-loss factor μ. From here, we use $\mu=3.76$ which is the parameter of outdoor hotzone model [Table A.2.1.1.2-3] in [24] and SNR is defined as

$$\text{SNR} = \lim_{N_P \to \infty} \overline{\gamma}_0 = \frac{E\left[|h_0|^2\right] E_s}{\sigma^2}.$$

'Analysis' indicates the numerical results obtained from (26) with $E\left[P_S^k(\gamma_{L+r})\right]_{\text{App}}$ in (21) and 'Simulation' denotes the simulation results obtained from the assumption that the destination node can perfectly know each relay node's transmission mode (i.e., 'Tx. mode' or 'Sleep mode'). On the contrary, 'Simulation w/ PB-RMS' indicates the simulation results which are obtained from each relay's 'Tx. mode' selection based on PB-RMS of (9) with $T_e=1.0$.

For BPSK ($M=2$), the average outage probabilities are shown in Figs. 2 and 3 when $N_P=\infty$ and $N_P=8$, respectively. As a performance reference, we also plot the S-D link's outage performance. Fig. 2 shows the results of $N_P=\infty$ which means the case of perfect channel estimation. It is shown that numerical results of 'Analysis' are well matched with simulation results for all SNR regions. On the other hand, in Fig. 3 where $N_P=8$ which means the case of practical channel estimation, some mismatches are shown at lower SNR. Note that for BPSK 'Analysis' with $M=2$, single approximation of (20) is used for the burst error rate simplification, whereas the approximation of (15) is not used for BPSK.

[Fig. 4] shows the performance comparison with respect to N_P. From three figures, it is verified that $N_P=8$ shows less than 0.5dB SNR loss when it is compared with the ideal channel estimation case. In addition, we can find that average outage probability increases in proportion to N_D (the number of data symbols within a burst). When N_D increases, each relay's 'Tx. mode' probability decreases. Consequently, it generates the performance degradation shown as SNR loss at high SNR regions. Also, it is worthwhile to mention that $N_D=1$ means the symbol-by-symbol detection of previous researches [5], [15]. The performance for $N_D=1$ is confirmed to be an achievable lower bound for ADF relaying schemes. It is noted that as a practical performance reference, we also plot the simulated performance obtained from using PB-RMS of (9) with $T_e=1.0$. When comparing our approximated analytical results with two simulation results, we can find that they are well matched and the accuracy of the derived analytical method is verified. Also, even if performance loss occurs according to the increase of N_D, we can still find the diversity gain caused by the increase of L.

[Fig. 5], [Fig. 6], and [Fig. 7] show the average outage probability versus SNR with respect to M for $L=1$, $L=2$, and $L=4$, respectively. We can see that the diversity order linearly increases as the number of relays, L. Moreover, it is worthwhile to mention that the approximated analytical bounds are tight enough for all SNR values and for the different modulation order M. It is seen from three figures that the performance loss caused by the increase of M is similar for the different L (the number of relays).

Consequently, we verify that even though our analytical approach is based on the perfect knowledge of correctly decoded relay nodes, it shows the achievable error rate performance of actual ADF relay systems having pilot symbol transmission schemes. In other words, ADF relay systems with PSA-CE methods can select correctly decoded relay nodes without additional signaling between relay nodes and the destination node and also, the achievable performance is guaranteed at a cost of negligible SNR loss.

5. CONCLUSIONS

The average outage probability is derived as the approximated closed-form for BT-ADF relay systems over quasi-static INID Rayleigh fading channels. Our proposed analytical approach includes channel estimation errors related to transmitted pilot symbols within a burst. Firstly, for the relay nodes' error event, its probability is approximated as the form which is related to the error probability of a burst MPSK or MQAM transmission. Then, the average outage probability is derived as the closed-form to be simply calculated by numerical operations. It is verified to be an outage performance bound by comparing with simulation results. Therefore, we can conclude that our analytical outage expression is very tractable form, and can be used as a tool to verify outage performance for the different modulation order, the numbers of pilots and data symbols within a burst.

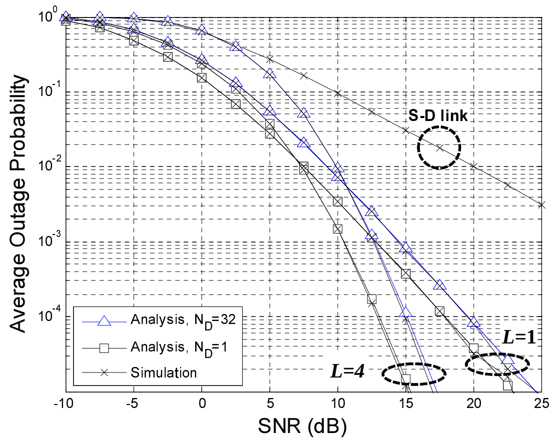

Fig. 2. Average Outage Probability versus SNR (dB) with respect to different N_D and L for the ideal channel estimation (L=1,4, N_P=∞, N_D=1,32, M=2, μ=3.76).

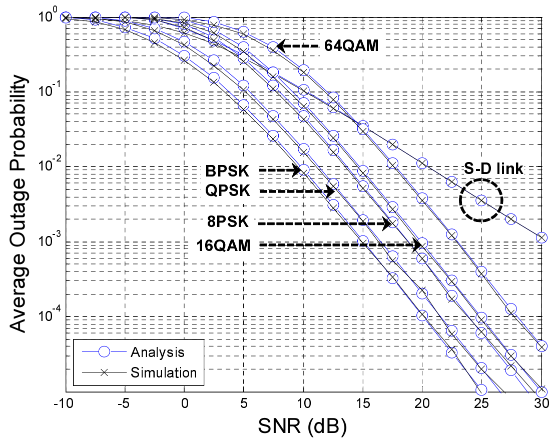

Fig. 5. Average Outage Probability versus SNR (dB) with respect to different M (L=1, N_P=8, N_D=32, M=2,4,8,16,64, μ=3.76).

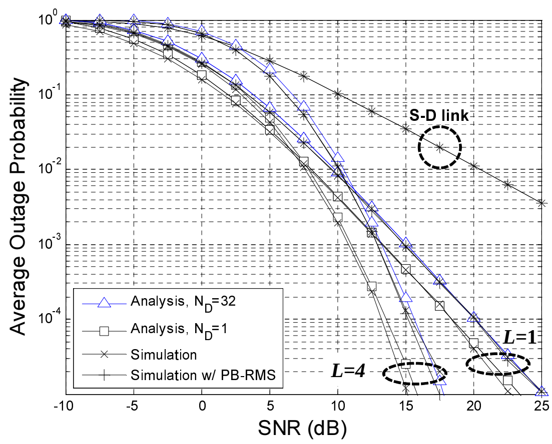

Fig. 3. Average Outage Probability versus SNR (dB) with respect to different N_D and L for the practical channel estimation (L=1,4, N_P=8, N_D=1,32, M=2, μ=3.76, T_e=1.0).

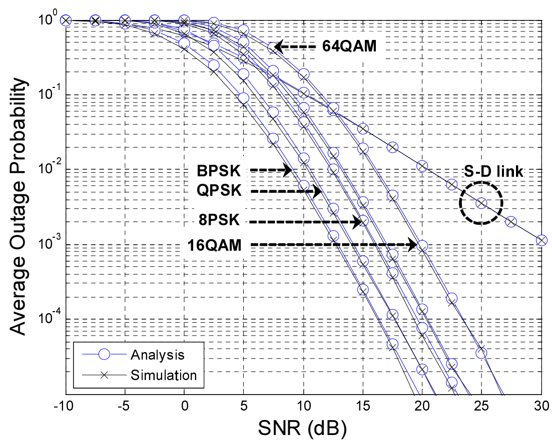

Fig. 6. Average Outage Probability versus SNR (dB) with respect to different M (L=2, N_P=8, N_D=32, M=2,4,8,16,64, μ=3.76).

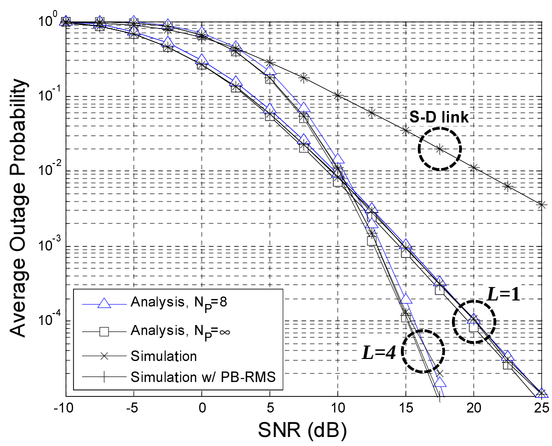

Fig. 4. Average Outage Probability versus SNR (dB) with respect to different N_P and L (L=1,4, N_P=8,∞, N_D=32, M=2, μ=3.76, T_e=1.0).

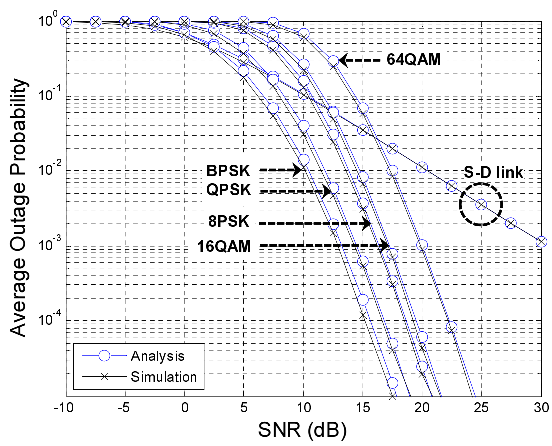

Fig. 7. Average Outage Probability versus SNR (dB) with respect to different M (L=4, N_P=8, N_D=32, M=2,4,8,16,64, μ=3.76).

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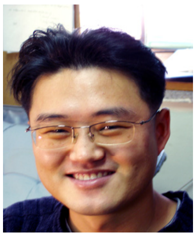
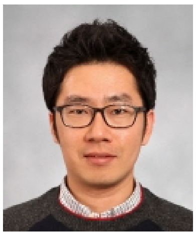


Kyunbyoung Ko
He received the B.S., M.S., and Ph.D. degrees in Electrical and Electronic Engineering at Yonsei University, Seoul, Korea in 1997, 1999, and 2004, respectively. From March 2004 to February 2007, he was a senior engineer in Samsung Electronics, Suwon, Korea where he developed Mobile WiMAX systems for broadband wireless services. Since March 2007, he joined the Department of Control and Instrumentation Engineering at Korea National University of Transportation as an Associate Professor. His current research interests include the field of wireless communications focusing on multicarrier and multi-antenna systems, cooperative relaying, and ITS.



Sungmook Lim
He (corresponding author) received the B.S. and Ph.D. degrees in Electrical and Electronic Engineering at Yonsei University, Seoul, Korea in 2005 and 2012, respectively. From September 2012 to March 2014, he was a Postdoctoral Fellow at Yonsei University where his research interents were in 5G wireless communications. Since March 2014, he joined the Department of Electronics Engineering at Korea National University of Transportation as an Assistant Professor. His current research interests include the field of 5G wireless communications focusing on multicarrier and multi-antenna systems, cooperative relaying, and ITS.