Impact of M-ary Data Symbol Burst Transmission on Averaged Channel Capacity for ADF Relay Systems

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Abstract

In this paper, we consider M-ary phase shifting keying (MPSK) and M-ary quadrature amplitude modulation (MQAM) data symbol burst transmission for adaptive decode-and-forward (ADF) relay systems over quasi-static Rayleigh fading channels. A burst has pilot symbols and data symbols. From pilot symbols, we can estimate the channel gain and detect each relay node’s transmission mode for ADF schemes. At first, we focus on the derivation of the received signal to noise ratio’s (SNR’s) probability density function (PDF) for ADF relay systems, in which error events at relay nodes and channel estimation errors are considered. Then, we derived the average channel capacity as an approximated closed-form for an arbitrary link signal-to-noise ratio (SNR) for different modulation orders. We verified its accuracy by comparison with simulation results.

Keywords: MPSK, MQAM, burst transmission, ADF, Rayleigh fading channels, channel capacity

1. Introduction

Many papers 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 schemes amplify the received signal and retransmit it to the destination, whereas DF schemes detect the received signal and then retransmit a regenerated signal [1-15]. A third option is adaptive DF (ADF) scheme, which relays forward only correctly decoded messages [⁵]. 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, ⁵-⁸]. 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 for the best relay link) [⁹-¹¹]. 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
In this paper, it is assumed that S and D link fading and error work in [1-4]. Performance of cooperative transmission in the presence of imperfect channel estimation. However, the framework in [15] does not include pilot symbol assisted-channel estimation (PSA-CE) schemes which can be applied in practical systems, resulting in error-floors even at high SNR region. We extend the analytical approach in [15] to ADF burst transmission systems [6, 12-14].

In this paper, we consider burst-by-burst error detection for ADF relay systems instead of symbol-by-symbol [6], [12]-[14]. 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 the averaged channel capacity expression over quasi-static independent and non-identical distributed (INID) Rayleigh fading channels, so that it can be an actual system performance. Note that the derived channel capacity expression is a simplified closed-form 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 M-ary data symbol burst transmission for ADF relay systems. In Section 3, the derived performance expressions are provided. The numerical and simulation results are presented in Section 4 and concluding remarks are given in Section 5.

2. M-ary Data Symbol Burst Transmission for ADF Relaying Systems

Figure 1 shows the block diagram of M-ary symbol burst transmission for ADF relaying systems with a source (S), a destination (D), and a relay (R). The number of relays is L. In this paper, it is assumed that S and L relay transmit over orthogonal time slots. First, let us describe the quasi-static Rayleigh fading channel model to derive the analytical approach of M-ary data symbol burst transmission for ADF relaying systems.

2.1. System Model for ADF Relay Scheme with Burst Transmission

For \( r \in \{1, 2, \ldots, L\} \), let \( h_s, h_r, \ldots, h_r \) be the channel gains of S-D, S-R, and R-D links respectively, as shown in Figure 1. In this paper, each wireless channel is assumed to be quasi-static independent and non-identical distributed (INID) Rayleigh fading [16, 17]. This means that the channel coefficient can be assumed to be a constant within a burst transmission time. For the channel gain, the magnitude and the phase of \( h_r \) are Rayleigh distributed and uniformly distributed over \([0, 2\pi]\) respectively. The number of pilot symbols and the number of modulated data symbols within a burst are \( N_p \) and \( N_d \). Then, the length of a burst is \( N_b = N_p + N_d \). In addition, each link channel is corrupted by complex additive
white Gaussian noise (AWGN) term of \( n_r[t] \) with \( \mathbb{E} [|n_r[t]|] = 0 \) and \( \mathbb{E} [|n_r[t]|^2] = \sigma^2 \). Note that \( \{n_r[t]\} \) are mutually independent for different \( r \) and \( t \). The operator \( \mathbb{E}[\cdot] \) means the statistical expectation. Without loss of generality, we consider the first burst transmission. Then, \( s[t]|_{t=1}^{N_D} \) is the pilot symbol known to all nodes and \( \{s[t]|_{t=1}^{N_D}\} = 1 \) is MPSK or MQAM data symbol. Then, \( \{s[t]|_{t=1}^{N_D}\} \) can be regarded as mutually independent for different \( t \) with \( \mathbb{E}[s[t]] = 0 \) and \( \mathbb{E}[k[t]] = 1 \).

As shown in Figure 1, ADF cooperative relaying systems have \('L+I'\) transmission steps for each burst transmission. The \( 0 \)th step is the transmission from the source node to all the relays and the destination by using the \( 0 \)th time slot. During the \( 0 \)th time slot, the received signals at the destination node and the \( r \)th relay node can be presented respectively, as

\[
y_o[t] = h_o \sqrt{E_o s[t]} + n_o[t]
\]

\[
y_{L-r}[t] = h_{L-r} \sqrt{E_{L-r} s[t]} + n_{L-r}[t]
\]

where \( E_o = E_{L-r} = E_s \) is the transmitted symbol energy of the source node and \( t \in \{1, 2, \ldots, N_p\} \) is the time index within a burst. For the remaining \( L \) steps, each relaying node can transmit the regenerated data symbol burst. Only when all \( N_D \) data symbols are correctly decoded, the \( r \)th relaying node transmits the regenerated data symbols \( \hat{s}_r[t] \) at the \( r \)th transmission step. It means that for the \( r \)th time slot, the destination node’s received signal can be written as

\[
y_o[t + rN_p] = h_r \sqrt{E_r \hat{s}_r[t]} + n_o[t + rN_p]
\]

\[
y_r[t] = y_o[t + rN_p] = h_r \sqrt{E_r \hat{s}_r[t]} + n_o[t]
\]

with \( t \in \{1, 2, \ldots, N_p\} \) and \( n_r[t] = n_o[t + rN_p] \). In (2), \( E_r \) is the transmission symbol energy of the \( r \)th relay node.

### 2.2. Channel Estimation by Pilot Symbols within a Burst

Note that for \( t \in \{1, 2, \ldots, N_p\} \) in (2), \( \hat{s}_r[t] = s[t] \) are pilots symbols which can be used to estimate R-D link channels and then, (1) and (2) are expressed as

\[
y_r[t] = h_r \sqrt{E_r s[t]} + n_o[t]
\]

with \( r \in \{0, 1, \ldots, 2L\} \). Then, pilot-symbol based channel-estimation schemes can give the estimated channel gains as [6, 12].

\[
h_r = \frac{1}{N_p} \sum_{r=1}^{N_p} s^*[t] y_r[t] = h_r \sqrt{E_r} + e_r
\]

with \( \mathbb{E} [e_r] = \sigma^2 / N_p \) and \( \mathbb{E} [e_r^2] = 0 \). Note that \( e_r = 1 / N_p \sum_{r=1}^{N_p} s^*[t] n_o[t] \) is the channel estimation error. By using known pilot symbols and the estimated channel gain \( h_r \), we can obtain the estimated noise variance as

\[
\hat{\sigma}^2_{r,t} = \frac{1}{N_p} \sum_{r=1}^{N_p} |y_r[t] - h_r \hat{s}_r[t]|^2.
\]
For \( N_p \geq 1 \), we can approximate the estimated noise variance of (4) as
\[
\hat{\sigma}_{p,r}^2 = \frac{N_p - 1}{N_p} \sigma^2.
\]  
(5)

The statistical noise variance for data symbol part can be obtained as
\[
\sigma_{D,r}^2 = \frac{N_p + 1}{N_p} \sigma^2.
\]  
(6)

From (5) and (6), we can obtain the estimated noise variance for data symbol part as
\[
\hat{\sigma}_{D,r}^2 = \frac{N_p + 1}{N_p - 1} \hat{\sigma}_{p,r}^2.
\]  
(7)

### 2.3. Relay Transmission Mode Detection at Destination Node

Note that in this paper, we use pilot-symbol based channel estimation methods. It means that each relaying node can always transmit pilot symbols to the destination node regardless of its correct data detection. Based on this, we can make the destination node to detect each relay’s data transmission mode without additional information [6].

During the \( r \)th time slot, we can obtain two signal powers for pilot symbol part and data symbol part, respectively, as follows:
\[
\hat{P}_{\text{pilot}} = \frac{1}{N_p} \sum_{t=1}^{N_p} \left| y_0[t + rN_b] \right|^2
\]  
(8)

\[
\hat{P}_{\text{data}} = \frac{1}{N_D} \sum_{r=n_N + 1}^{N_D} \left| y_0[t + rN_b] \right|^2
\]

From \( \hat{P}_{\text{pilot}} \) and \( \hat{P}_{\text{data}} \), we can detect the \( r \)th relay’s data transmission mode as [6]
\[
\hat{D}_{\text{tx}} = \begin{cases} 
0 \ (\text{No Tx mode}), & \text{if } \hat{P}_{\text{pilot}} / \hat{P}_{\text{data}} > 1 + T_e \\
1 \ (\text{Tx mode}), & \text{else}
\end{cases}
\]  
(9)

where \( T_e \) is a threshold value. Note that at the destination node, a maximal ratio combing (MRC) scheme can be assumed in order to combine signals from S-D and R-D links. By utilizing \( \hat{h}_r \), \( \sigma_{D,r}^2 \), and \( \hat{D}_{\text{tx}} \), we can express the decision variable as
\[
\hat{z}_x[r] = \frac{\hat{h}_r}{\hat{\sigma}_{D,r}^2} y_0[r] + \sum_{r=1}^{N_p} \frac{\hat{h}_r}{\hat{\sigma}_{D,r}^2} \hat{D}_{\text{tx}} y_r[r].
\]  
(10)

From here, we define the relay node transmission detection of (9) as the pilot based-relay mode selection (PB-RMS) [6].

### 3. Averaged Channel Capacity for M-ary Data Burst Transmission

In ADF relay systems, the \( r \)th relay can participate in transmitting the regenerated symbol of \( \hat{s}_r[r] \) only when all data symbols within a burst are correctly decoded. Then, \( \hat{s}_r[r] \) can be \( \hat{s}_r[r] = 0 \) or \( \hat{s}_r[r] = s[r] \) which are related with the given relay’s symbol error probability.
3.1. Each Relay Node’s Symbol Error Probability

By using $\hat{h}_{L_r}$, the $r$th S-R link’s decision variable can be written, for data symbol transmission part, as

$$z_{L_r}[t] = \hat{h}_{L_r}y_{L_r}[t].$$

(11)

Also, we can express the received SNR as

$$\gamma_{L_r} = \frac{\|h_{L_r}\sqrt{E_{L_r}}\|^2}{\sigma^2(\beta_{L_r} + 1/N_p)}$$

(12)

with

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

$$E\left[|\hat{h}_{L_r}|^2\right] = E\left[h_{L_r}\sqrt{E_{L_r}}\right] + \sigma^2/N_p.$$

For Rayleigh fading channels, the probability density function (PDF) of random variable $\gamma_{L_r}$ can be written as

$$f_{\gamma_{L_r}}(\gamma) = 1/\gamma_{L_r} e^{-\gamma/\gamma_{L_r}} \text{ for } \gamma \geq 0$$

(13)

where $\gamma_{L_r}$ is the $r$th S-R link’s averaged SNR of

$$\gamma_{L_r} = E[\gamma_{L_r}] = \frac{E\left[h_{L_r}\sqrt{E_{L_r}}\right]}{\sigma^2(\beta_{L_r} + 1/N_p)}.$$  

(14)

Notice that when the number of pilots increases, the averaged SNR approaches to the ideal channel estimation case. In addition, the derived method can be applied to S-D and each R-D link. The replacement of $L + r$ with $r$ can give $\gamma_r$, $\gamma_{L_r}$, and $f_{\gamma}(\gamma)$, for $r \in \{0, 1, \ldots, L\}$.

Consequently, the $r$th S-R link's conditional SER can be approximated, for MPSK and MQAM, as [6]

$$P_s(\gamma_{L_r}) \approx aQ\left(b\gamma_{L_r}\right)$$

(15)

with

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

and $Q(\sqrt{x}) = 1/\sqrt{2\pi} \int_x^\infty \exp(-t^2/2) \, dt$ [16, 17].

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3.2. Error-Events of Relay Nodes and their Probability

From the analytical method based on error-events at relays [5], we can define the \( p \)th error-event vector \( E^p \) as

\[
E^p = [e_1^p, \ldots, e_r^p, \ldots, e_L^p]
\]

with \( p \in \{1, 2, \cdots, 2^L\} \) and \( 2^L \) is the total number of error-events. Additionally, we can define that \( E^i \) is all-zero vector, \( E^x \) is all-one vector, and so on. Note that for the \( p \)th error-event, \( e_r^p = 0 \) means the correct burst detection at the \( r \)th relay and \( \hat{\delta}_r [t] \big|_{k \leq N_D} = s [t] \) with the probability of

\[
P_{\text{IN}}^N (\gamma_{L,r}) = \left[1 - P_\delta (\gamma_{L,r})\right]^{N_D} = \sum_{k=0}^{N_D} \left( \begin{array}{c} N_D \\ k \end{array} \right) (-1)^k P_\delta^k (\gamma_{L,r}).
\]

Also, the averaged transmission mode probability can be presented as

\[
P_{\text{IN}}^N (\overline{\gamma}_{L,r}) = E \left[ P_{\text{IN}}^N (\gamma_{L,r}) \right] = \sum_{k=0}^{N_D} \left( \begin{array}{c} N_D \\ k \end{array} \right) (-1)^k E \left[ P_\delta^k (\gamma_{L,r}) \right]
\]

with

\[
E \left[ P_\delta^k (\gamma_{L,r}) \right] = \int_0^\infty P_\delta^k (\gamma) f_{\overline{\gamma}_{L,r}} (\gamma) d\gamma = \int_0^\infty t^k Q^k \left( \sqrt{b\gamma} \right) f_{\overline{\gamma}_{L,r}} (\gamma) d\gamma.
\]

Also, \( e_r^p = 1 \) leads to \( \hat{\delta}_r [t] \big|_{k \leq N_D} = 0 \) with the probability of \( 1 - P_{\text{IN}}^N (\overline{\gamma}_{L,r}) \).

Furthermore, we can present the probability of the \( p \)th error-event as

\[
P_{\text{r}}^p = \prod_{r=1}^{L} \left[ P_{\text{IN}}^N (\overline{\gamma}_{L,r}) \right]^{\overline{e}_{r}^p} \left[1 - P_{\text{IN}}^N (\overline{\gamma}_{L,r})\right]_{\overline{e}_{r}^p}
\]

with \( \overline{e}_r^p = (e_r^p + 1) \mod 2 \) [5][6]. In this paper, we use the approximation of the Q-function shown in [18] as

\[
P_\delta (\gamma_{L,r}) \approx a Q \left( \sqrt{b\gamma_{L,r}} \right) \approx a_i \exp(-b_i\gamma_{L,r})
\]

with \( a_i \neq a \) and \( b_i \neq b = 3.2 / 3 \). From (19) and (21), we can obtain [6]

\[
E \left[ P_\delta^k (\gamma_{L,r}) \right] \approx \int_0^\infty a_i e^{-b_i \gamma_{L,r}} f_{\overline{\gamma}_{L,r}} (\gamma) d\gamma = \frac{a_i^k}{1 + b_i k \overline{\gamma}_{L,r}} = E \left[ P_\delta^k (\gamma_{L,r}) \right]_{\text{opp}}.
\]

From \( E \left[ P_\delta^k (\gamma_{L,r}) \right]_{\text{opp}} \), we can obtain the simplified results of (20).

3.3. Combined Received SNR and Its PDF

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. For MRC, the noise variance normalization process is necessary in order to obtain the full diversity. Note that in our analytical approach, we assume the perfect detection of each relay’s transmission mode. Then, the decision variable for the \( p \)th error-event can be presented as
\[ z_\ell^p [t]_{\ell=0}^{\infty} = \frac{\hat{h}_0^p}{\sigma^2_p} y_0^p [t] + \sum_{r=1}^{L} \frac{\hat{h}_r^p}{\sigma^2_r} e_r^p \gamma_r [t] \] (23)

and then, we can obtain the received SNR as

\[ \gamma_r^p = \gamma_0 + \sum_{r=1}^{L} e_r^p \gamma_r = \sum_{r=1}^{L} e_r^r \gamma_r, \] (24)

It means that when there is a burst error detection at the \( r \)-th relay node for the \( p \)-th event vector (i.e., \( e_r^p = 1 \)), no-transmission gives \( e_r^r \gamma_r = 0 \). Consequently, the PDF of \( \gamma_r^r \) can be obtained as

\[ f_{\gamma_r^r} (x) = \sum_{r=1}^{L} \frac{\pi_r^p}{\gamma_r} \exp \left( -\frac{e_r^p x}{\gamma_r} \right) \] (25)

with \( \pi_r^p = \prod_{r=0, r \neq r} e_r^p \gamma_r, \) \( e_r^p \gamma_r - e_r^p \gamma_r, \) and define \( e_0^p = 1 \) so as to \( e_0^p \gamma_0 = \gamma_0 \).

3.4. Closed-form Expression of Averaged Channel Capacity

In Shannon’s sense, the channel capacity is an important performance metric since it provides the maximum achievable transmission rate under which the errors are recoverable [7]-[9]. For the \( p \)-th error-event, we can approximate the averaged channel capacity as

\[ \overline{C}(\{e_r^p, \gamma_r\}) = \frac{B W}{L + 1} E \left[ \log_2 \left( 1 + \gamma_r^p \right) \right] = \frac{B W}{L + 1} \int_0^\infty \log_2 \left( 1 + \gamma \right) f_{\gamma_r^p} (\gamma) \, d\gamma \]

\[ = \frac{B W}{(L + 1) \ln(2)} \sum_{r=0}^{L} \pi_r^p e^{\ln(2)} E_1 \left( \frac{1}{\gamma_r} \right) \] (26)

where \( B W \) is the transmitted signal bandwidth and \( E_1(x) = \int_x^\infty \exp(-t) / t \, dt \) is the exponential integral [9]. Consequently, we can obtain the averaged channel capacity as a closed-form of

\[ \overline{C}(\{\gamma_r\}) = \sum_{p=1}^{L} P_r^p \overline{C}(\{e_r^p, \gamma_r\}) \overline{C}(\{e_r^p, \gamma_r\}). \] (27)

4. Numerical and Simulation Result

In this section, we show numerical results of averaged channel capacity and verify its accuracy by comparing simulation results. For simplicity, it is assumed that \( E_x = E_x / L \) for \( r \in \{1, 2, \cdots, L\} \). In order to capture the effect of path-loss, \( \alpha_r (= r / (L + 1)) \) is defined as the relative distance between source and the \( r \)-th relay when the distance between source and destination is one. Then, we introduce the channel model that \( E \left[ |h_{r, r}^1|^2 \right] = E \left[ |h_{r, r}^p|^2 \right] / \alpha_r^p \) and
\[ E \left[ | h_e |^2 \right] = E \left[ | h_0 |^2 \right] / (1 - \alpha_v)^\nu \] with the path-loss factor \( \mu = 3.76 \) [19]. We define SNR as
\[
\text{SNR} = \lim_{N_p \rightarrow \infty} \frac{E \left[ | h_0 |^2 \right] E_s}{\sigma^2}
\]
where \( N_p = \infty \) indicates the ideal channel estimation, which is the achievable performance bound without channel estimation error. In addition, the normalized channel capacity is defined from (27) as
\[
\text{Normalized Channel Capacity} = \frac{C \left( \{ e^{a} \}, \gamma_r \right)}{B W}.
\]

From here, 'Analysis' means the numerical results obtained from (27) with \( E \left[ P_s (\gamma_{L+r}) \right] \) in (22). For 'Simulation', the simulation results are obtained from the assumption that the destination node can perfectly know each relay node’s transmission mode. On the other hand, 'Simulation w/ PB-RMS' means the simulation results obtained from each relay’s 'Tx. mode' selection based on both (9) with \( T_e = 1.0 \) and (10).

For \( M = 4 \) (QPSK), Figures 2, 3, and 4 show the normalized channel capacity versus SNR with respect to different \( N_p \), \( N_o \), and \( L \). The derived numerical results are well matched with simulation results. Consequently, we can say that the derived analytical approach can be used as a general tool to verify effects of burst transmission on the averaged channel capacity over quasi-static Rayleigh fading channels.

From Figure 2 and 3, we can find that the normalized channel capacity performance decreases in proportion to \( N_o \) (number of data symbols within a frame). When \( N_o \) increases, the \( N_o \) symbols’ correct detection probability of (17) decreases, so that each relay’s participation probability into the transmission also decreases. Consequently, it leads to performance degradation, which is only shown as the average SNR loss for low SNR region. Note that for high SNR region, there is no SNR loss. It means that the channel capacity performance can be merged regardless of \( N_o \). Moreover, it is worthwhile to mention that the performance difference between \( N_o = 1 \) and \( N_o = 32 \) is in proportion to \( L \). Figure 4 shows averaged channel capacity versus SNR with respect to \( L \). We can find that the channel capacity linearly decreases as the number of relays. It means that the diversity gain can be achieved by the capacity loss in proportion to \( L \). By comparing Figure 2 and Figure 3, we can say that the practical case of \( N_p = 8 \) shows similar performance of the ideal channel estimation case. Furthermore, Figure 3 and Figure 4 show that 'Simulation' and 'Simulation w/ PB-RMS' give the same performance. It is confirmed that we can detect each relay’s transmission mode by only pilot symbols for ADF relay systems.

Figures 5, 6, and 7 show the normalized channel capacity for 16QAM with respect to different \( N_p \), \( N_o \), and \( L \). From those figures, we can find that the capacity loss caused by \( N_o \) is proportion to modulation order \( M \). Figures 8, 9, and 10 show the normalized channel capacity versus SNR with respect to different \( M \) for \( L = 1, 2, 3 \), respectively. As mentioned before, the channel capacity performance
can be merged regardless of $N_D$ for high SNR region. In addition, the capacity loss is proportion to modulation order $M$ regardless of the number of relay $L$.

![Block Diagram of M-ary Symbol Burst Transmission for ADF Relaying Systems](image)

**Figure 1.** Block Diagram of M-ary Symbol Burst Transmission for ADF Relaying Systems(source(S), Destination(D), relay(R))

![Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_D$ and $L$](image)

**Figure 2.** Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_D$ and $L$ ($L = 1, 4$, $N_P = \infty$, $N_D = 1, 32$, $M = 4$, $\mu = 3.76$)
Figure 3. Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_D$ and $L$ ($L = 1, 4$, $N_P = 8$, $N_D = 1, 32$, $M = 4$, $\mu = 3.76$)

Figure 4. Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_P$ and $L$ ($L = 1, 4$, $N_P = 8, \infty$, $N_D = 32$, $M = 4$, $\mu = 3.76$)
Figure 5. Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_D$ and $L$ ($L = 1, 4$, $N_p = \infty$, $N_D = 1, 3, 2$, $M = 16$, $\mu = 3.76$)

Figure 6. Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_D$ and $L$ ($L = 1, 4$, $N_p = 8$, $N_D = 1, 3, 2$, $M = 16$, $\mu = 3.76$)
Figure 7. Normalized Channel Capacity versus SNR (dB) with Respect to Different $N_p$ and $L$ ($L = 1, 4$, $N_p = 8, \infty$, $N_D = 32$, $M = 16$, $\mu = 3.76$)

Figure 8. Normalized Channel Capacity versus SNR (dB) with Respect to Different $M$ ($L = 1$, $N_p = 8$, $N_D = 32$, $M = 2, 4, 8, 16, 64$, $\mu = 3.76$)
5. Conclusions

In this paper, we derived the average channel capacity for M-ary symbol burst transmission for ADF relaying networks over quasi-static INID Rayleigh fading channels. Our analytical approach includes burst transmission with pilot symbols and MPSK or MQAM data symbols, which can be considered as a practical system...
environment. By comparing the derived numerical results and simulation results, the accuracy of analytical approach is verified. Consequently, we can find that our derived analytical expression is a very tractable form, and can be used as a tool to verify the effects of a burst transmission on the averaged channel capacity.

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References

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