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Outage Analysis of Multi-hop Parallel Relay Networks

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ABSTRACT

In this paper, we consider a multi-hop parallel relay network in which relays cooperate with its next relay in a series fashion, and the cooperation between two relays exists if they are not in outage. For this network, we derive the generalized expression of outage probability in terms of number of relays in a cluster. We also present the simulation results to find the relationship of outage probability with the number of hops and the relay nodes in a stage.

Keywords: Multi-hop Relaying, Decode-and-Forward (DF) Relaying, Outage Probability, Rayleigh Fading.

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1 INTRODUCTION

Cooperative relay communication is a powerful technique to improve the reliability and coverage of a wireless system [1]-[5]. Among various relaying techniques Amplify-and-Forward (AF) and Decode-and-Forward (DF) are the (two) most widely used protocols. In Amplify-and-Forward (protocol) the relay simply forwards a scaled version of the received signal. And in Decode-and-Forward relaying relay has to regenerate and then retransmit the signal towards the destination. So Decode-and-Forward relaying needs complex relay circuits. But in advantage, it can prevent the propagation of noise throughout the communication path. Usually the dual hop relaying is the simplified model of multi-hop relaying system [6]-[16]. In multi-hop communication, the signal has to pass through multiple relay nodes before reaching to the destination. Here we have considered a multi-hop relaying system with M-hop and each relay stage has K relays which communicate in parallel mode. i.e. relays of one parallel path cannot communicate to the other path relays.

Outage probability is a very important performance measure in quasi-static fading. In case of Decode-and-Forward (DF) relaying outage of a network is the main concern than Symbol Error Probability (SEP). Here, in this paper we assume outage occurs due to deep fades that cause the desired signal power to fall below a predetermined threshold and the link fails to establish to reliable communication between cooperating nodes.

Pioneer works on multi-hop relaying [6]-[10] has analyzed the performances of multi-hop systems in physical layer with series relay structure, where each hop consists of a single relay node. Especially [6]-[9] has derived the outage probability expressions of a series multi-hop relay network. The outage probability, SEP and diversity analysis with multi-antenna nodes (all nodes have multiple antennas including the source and the destination) have studied in [12]. However the models related to our work, with multiple relays per stage, have investigated in [13]-[15]. Among them a space-time block code scheme has used in [13] to develop a cooperative scheme for both DF and AF relaying and analyzed the frame error rate of the system. Furthermore a couple of relay selection or routing strategies were proposed in [15] and [16] assuming centralized CSI and ad-hoc environment (distributed system).

In this paper we have analyzed the outage probability of a series multi-hop relay communication structure where multiple relay paths are parallel to each other. To the best of author's knowledge, the field of performance analysis on the multi-hop parallel relaying has still ample scope of conducting further research. Besides a relay network with the cooperation between all relay nodes has kept as future work.

2 SYSTEM MODEL

We have considered a multi-hop relay network model, consisting of one source and one destination pair; communicate via *M-1* relay clusters in series, where all nodes are equipped with single antenna. Further each relay cluster has *K* number of DF relays with perfect Channel State Information (CSI) of the preceding links. All relay links are modeled for Rayleigh fading.

Additionally, we have assumed that the total power for the whole system is constrained to P_{tot} so that the source and the total relay power is given by, $P_S = (1-\zeta)P_{tot}$ and $P_R = \zeta P_{\text{tot}}$ respectively, where, $\zeta \in (0,1]$. The relay stages share equal power such that $P_{\text{stage}} = P_R/(M-1)$. The instantaneous SNR vector of the i^{th} relay path is given by, $\Gamma_i = [\gamma_{i,1}\ \gamma_{i,2}\ \gamma_{i,3}\ \cdots\cdots\ \gamma_{i,M}]^T$ where, $\gamma_{i,1}, \gamma_{i,2} \cdots \gamma_{i,M}$ are instantaneous SNR of 1$^{\text{st}}$, 2$^{\text{nd}}$..,M$^{\text{th}}$ hop respectively of i^{th} series path. Again the average SNR of *i*th path and *m*th hop link can be written as, $\bar{\gamma}_{i,m} = \Omega_{i,m} P/N_0$ where, $\Omega_{i,m} = E\{|h_{i,m}|^2\}$, P is the corresponding transmitted power and N_0 is the noise variance modeled as circularly symmetric complex Gaussian random variable.

3 OUTAGE ANALYSIS

In a typical multi-hop model as shown in **Fig.1**, the outage of a series path will occur if any one relay link SNR falls below the predefined threshold value γ_{th} and consequently if all relay paths are in outage the whole network will be in outage. We have considered all possible relays participate in cooperation if they are not in outage. However, due to lack of centralized CSI we cannot decide before *M*-1 hop which relay paths will contribute in the last hop. Then the outage of path *i* can be written as,

$$\begin{aligned} P_{\text{outage}}(i) &= \Pr\left\{\min\left\{\gamma_{i,1}, \gamma_{i,2}, \gamma_{i,3}, \cdots\cdots \gamma_{i,M-1}\right\} < \gamma_{\text{th}}\right\} \\ &= 1 - \prod_{m=1}^{M-1} \Pr\left\{\gamma_{i,m} > \gamma_{\text{th}}\right\} \end{aligned} \tag{1}$$

The last hop SNR is the sum of all possible decodable paths SNR. So to find that we have to define decodable path D_p,

$D_p = \{\text{The path that has all relays SNR up to M - 1 hop above the threshold}\}$

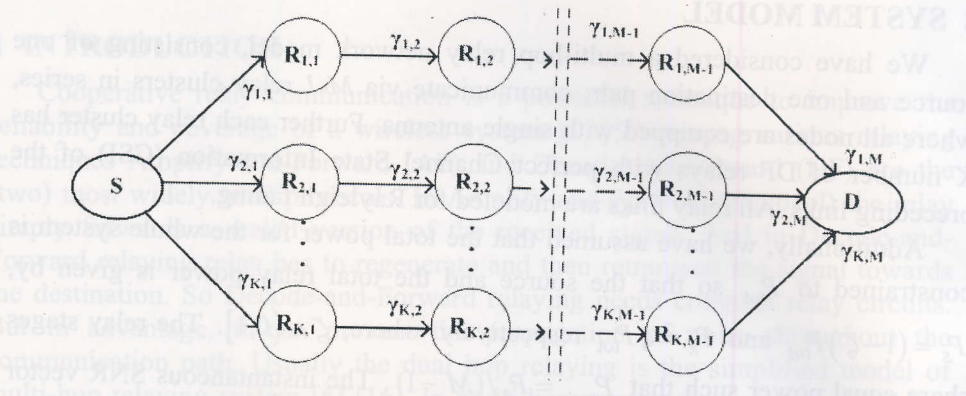

Figure 1: Multi-hop parallel relay network.

$$\Pr\{D_p\} = \prod_{i \in D_p} \Pr\left\{ \min_{m\in\{1,2,\dots,M-1\}} \{\gamma_{i,m}\} > \gamma_{\text{th}} \right\} \prod_{j \notin D_p} \Pr\left\{ \max_{m\in\{1,2,\dots,M-1\}} \{\gamma_{j,m}\} < \gamma_{\text{th}} \right\} \quad \dots \quad (2)$$

$\gamma_{i,m}$ is the link of relay hop m of path i . Total probability of outage can be expressed as,

$$\mathrm{P}\left(\text{outage} \middle| D_p\right) = \Pr\left\{ \sum \gamma_{n,M} < \gamma_{\text{th}} \middle| n \in D_p \right\} \quad \dots \quad (3)$$

Taking cardinality of D_p as p. i.e. $|D_p| = p$, we can write the outage probability equation, using the law of total probability as,

$$\mathrm{P}(\text{outage}) = \sum_{p=0}^{K} \sum_{D_p} \mathrm{P}\left(\text{outage} \middle| D_p\right) \Pr\{D_p\} \dots \quad \dots \quad (4)$$

Putting the **Eq.3** in **Eq.4** we have,

$$\begin{aligned} \mathrm{P}(\text{outage}) &= \sum_{p=0}^{K} \sum_{D_p} \Pr\left\{ \sum_{n \in D_p} \gamma_{n,M} < \gamma_{\text{th}} \right\} \Pr\{D_p\} \\ &= \sum_{p=0}^{K} \sum_{D_p} \left[\Pr\left\{ \sum_{n \in D_p} \gamma_{n,M} < \gamma_{\text{th}} \right\} \prod_{i \in D_p} \Pr\left\{ \min_{m\in\{1,2,\dots,M-1\}} \{\gamma_{i,m}\} > \gamma_{\text{th}} \right\} \right. \\ &\quad \left. \times \prod_{j \notin D_p} \Pr\left\{ \max_{m\in\{1,2,\dots,M-1\}} \{\gamma_{j,m}\} < \gamma_{\text{th}} \right\} \right] \end{aligned} \quad (5)$$

After some manipulation the outage probability **Eq.5** can be written as,

$$\mathrm{P}(\text{outage}) = \sum_{p=0}^{K} \sum_{D_p} \left[\Pr\left\{ \sum_{n \in D_p} \gamma_{n,M} < \gamma_{\text{th}} \right\} \cdots \right. \quad (6)$$

$$\left. \times \prod_{i \in D_p} \prod_{m=1}^{M-1} e^{-\gamma_{\text{th}}/\bar{\gamma}_{i,m}} \prod_{j \notin D_p} \prod_{m=1}^{M-1} \left(1 - e^{-\gamma_{\text{th}}/\bar{\gamma}_{j,m}} \right) \right]$$

And finally solving the sum probability problem by using equation in [17], the outage probability of the whole network can be expressed as,

$$\mathrm{P}(\text{outage}) = \sum_{p=0}^{K} \sum_{D_p} \left[\left(\prod_{i \in D_p} \prod_{m=1}^{M-1} e^{\frac{-\gamma_{\text{th}}}{\bar{\gamma}_{i,m}}} \right) \left(\prod_{j \notin D_p} \prod_{m=1}^{M-1} \left(1 - e^{\frac{-\gamma_{\text{th}}}{\bar{\gamma}_{j,m}}} \right) \right) \right.$$

$$\times \left\{ \left(\prod_{n \in D_p} \frac{1}{\bar{\gamma}_n^{m_n}} \right) \sum_{n \in D_p} \sum_{l=1}^{m_n} \frac{d^{l-1}}{ds^{l-1}} \left\{ \frac{\left(s + \frac{1}{\bar{\gamma}_n} \right)^{m_n}}{\prod_{n \in D_p} \left(s + \frac{1}{\bar{\gamma}_n} \right)^{m_n}} \right\} \Bigg|_{s=-1/\bar{\gamma}_n} \frac{\bar{\gamma}_n^{\, m_n - l + 1}}{(m_n - l)!(l-1)!} \cdots \right. \quad (7)$$

$$\left. \left. \left\{ \Gamma(m_n - l + 1) - \Gamma(m_n - l + 1,\ \gamma_{\text{th}}/\bar{\gamma}_n) \right\} \right\} \right]$$

where, $\bar{\gamma}_n$ is the average SNR of the corresponding link and $\Gamma(a,z)$ is the upper incomplete gamma function [18].

Proof: See in **Appendix-A.**

4 NUMERICAL RESULTS

The numerical results of the multi-hop network are plotted by taking $\zeta = 0.7$, SNR threshold $\gamma_{th} = 1$ and noise variance of each link as unity.

Fig.2 shows the outage probability as a function of SNR in dB for 4 and 6 relays per stage with a varying number of hops (*M*). It shows that performance over outage probability can be improved by increasing the number of parallel relaying lines. It also shows that as the number of hop in the network increases the probability of outage also increases. For example, a system with *K* = 6 as shown in **Fig.2** needs a SNR penalty of about 5dB due to the increase in number of hop from 4 to 6 to ensure sufficient low outage. The inherent idea of this

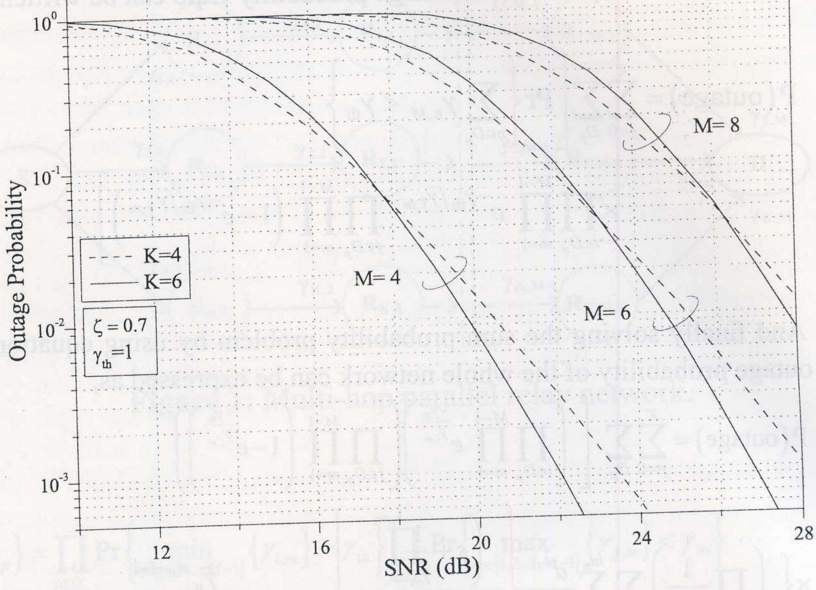

Figure 2: Outage probability of multi-hop relay network as a function of SNR for $K = 4$ and $K = 6$.

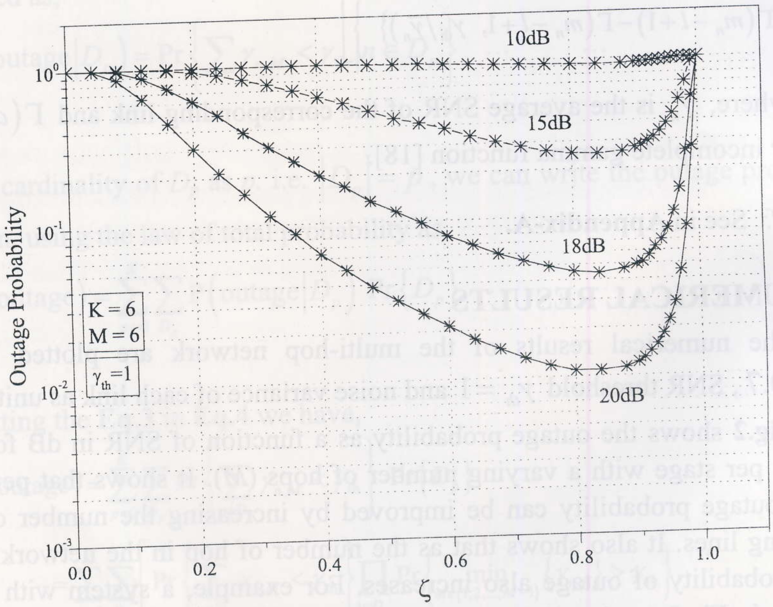

Figure 3: Outage probability of multi-hop relay network as a function of power sharing coefficient ς.

result can be described as, the increase in the number of hops in a parallel multi-hop relay network requires more aggregated power to transmit a signal with sufficient low outage. Another observation from **Fig.2** is, for specific number of relays in each stage the high SNR slop of the probability of outage shifts parallel way with the increasing the number of hops.

Fig.3 shows the outage probability of the system as a function of ζ for different values of SNR with the selected values of *K, M* and γ_{th}. It is observed that, the value of outage will be optimum if the total energy is equally divided into the source and the relay stages. Eventually, in a dual hop network, $\zeta \sim 0.5$ will give the better result [5].

5 CONCLUSIONS

In this work, we have presented the generalized expression of outage probability for a multi-hop parallel relay network. We also study the relationship of outage probability with the number of hop and the relay in a cluster. It is observed that, the outage probability increases with the number of hop and decreases with the number of relay used in a cluster. We also observe that equal energy sharing between the source and the relay stages can provide optimal performance. Therefore, we can conclude that, increase in the number of hops in a parallel multi-hop relay network requires more aggregated power to transmit a signal with low outage, and equal energy division between the source and the relay stages provides optimum outage.

APPENDIX-A

Proof of outage probability:

The sum of the received SNR in **Eq.5**, $\gamma_{k,M}$ is a random sum of independent random variables.

Let, $Y = \sum_{i \in D_p} X_i$, X is exponentially distributed with parameter $1/\lambda$, $\Phi_Y(s) = E\left\{e^{-sY} \middle\| D_p\right| = p\}$

$$E\left\{e^{-sY} \| D_p| = p\right\} = E\left\{e^{-sX_1 - sX_2 - sX_3 - \ldots - sX_{|D_p|}} \| D_p| = p\right\} \quad \ldots \quad (8)$$
$$= \prod_{n=1}^{p} \frac{1}{1 + s\lambda_n}$$

The inverse Laplace transform of **Eq.8** will give the PDF of Y, then taking integration we can find the CDF of Y.

Using equation in [17], we can derive the PDF and the CDF of Y as follows,

$$f_Y(y) = f_Y(y) = \left(\prod_{n=1}^{p} \lambda_n^{m_n}\right) \sum_{n=1}^{p} \sum_{l=1}^{m_n} \frac{A_{nl}(-\lambda_n) y^{m_n - l}}{(m_n - l)!(l-1)!} e^{-\lambda_n y}, \quad y \geq 0. \quad \cdots \quad (9)$$

where, $$A_{nl}(s) = \frac{d^{l-1}}{ds^{l-1}} \left\{ \frac{s+\lambda_n}{\prod_{n=1}^{p}(s+\lambda_n)} \right\}$$

and,

$$F_Y(y) = \left(\prod_{n=1}^{p} \lambda_n^{m_n}\right) \int_0^y \sum_{n=1}^{p} \sum_{l=1}^{m_n} \frac{d^{l-1}}{ds^{l-1}} \left\{ \frac{(s+\lambda_n)^{m_n}}{\prod_{n=1}^{p}(s+\lambda_n)^{m_n}} \right\}\Bigg|_{s=-\lambda_n} \frac{y^{m_n - l} e^{-\lambda_n y}}{(m_n - l)!(l-1)!} dy$$

$$= \left(\prod_{n=1}^{p} \lambda_n^{m_n}\right) \sum_{n=1}^{p} \sum_{l=1}^{m_n} \frac{d^{l-1}}{ds^{l-1}} \left\{ \frac{(s+\lambda_n)^{m_n}}{\prod_{n=1}^{p}(s+\lambda_n)^{m_n}} \right\}\Bigg|_{s=-\lambda_n} \frac{1}{(m_n - l)!(l-1)!} \frac{1}{\lambda_n^{m_n - l + 1}} \quad \cdots \quad (10)$$

$$\times \left\{ \Gamma(m_n - l + 1) - \Gamma(m_n - l + 1, \lambda_n y) \right\}$$

Putting this result of **Eq.10** in **Eq.6**, yields desired the outage probability **Eq.7**.

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Performance Enhancement in Media Access Control (MAC) layer protocol on Wireless Sensor Network

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ABSTRACT

The Media Access Control (MAC) layer is a part of the data link layer specified in the seven layer OSI model (layer 2). It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multipoint network. The MAC sub-layer acts as an interface between the Logical Link Control (LLC) sub-layer and the network's physical layer. It provides an addressing mechanism called physical address or MAC address that is described by MAC address protocol or MAC protocol. An efficient Medium Access Control (MAC) protocol is very important for the performance of a Wireless Sensor Network (WSN), especially in terms of energy consumption. There are different existing MAC protocols for the wireless sensor network. We have analyzed those protocols and found the issues on which performance varies. Then we have tried to eliminate some of the demerits and finally proposed a new MAC protocol that performs better considering some attributes.

Keywords: *Wireless Sensor Networks, MAC Protocol, Energy Consumption, Logical Link Control, OSI Model.*

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