Journal of Theoretical and Applied Information Technology
10th July 2014. Vol. 65 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

EFFICIENT POWER ALLOCATION FOR HYBRID-ARQ RELAY NETWORKS

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ABSTRACT

Spatial diversity is an inherent nature of wireless communications. This nature can be exploited to make communications more reliable by Multiple-Input-Multiple-Output (MIMO). However the use of multiple co-located antennas is constrained by the dimensions of modern devices. To overcome this drawback cooperative relaying shares antennas between different network nodes thus realizing a Virtual antenna arrays (VAA). In this paper we study a single user relay network aided Hybrid-ARQ (H-ARQ) type I consisting of a source, a relay and a destination. We provide the closed form expressions for the outage probability and delay. We use a numerical method based on relative distance between nodes to estimate the optimum amount of power to be allocated to source and relay. The numerical results show the accuracy of our analytical expressions. In addition proposed allocation strategy outperforms the equal power allocation.

Keywords: *Spatial Diversity, Relaying Networks (RN), Virtual Antenna Arrays (VAA), Multiple-Input-Multiple-Output (MIMO), H-ARQ Optimal Power Allocation.*

1. INTRODUCTION

Since the standardization of the first generation of mobile communication systems the transceiver bit rate has increased from 9.6kbit/s in GSM to rates above 100Mbit/s in 4th generation. This development was due especially to the effort done by researchers in field of applied signal processing algorithms which leads to a tremendous improvement in the performances of transceivers approaching the attainable systems capacities.

The use of multiple antennas in both transmitter and receiver, known as MIMO, has been recognized as an important solution to increase capacities of emerging broadband wireless communication systems. Unfortunately this solution is challenging due to the small size of devices. Cooperative diversity is a promising alternative since it permits the realization of virtual antenna arrays (VAA) where antennas are distributed among a certain number of nodes [1].

In cooperative networks a source is transmitting a message to the destination with assistance from a number of relays. The transmission is divided into two phases. During the first phase the source decides on the "best" relay or "better" relays to use and transmits the message to those relays. In the second phase the source and the selected relays cooperate to transmit the message to the destination.

The design of cooperative networks comprises two issues: cooperation protocol and resources allocation. The first issue has received much interest leading to the design of more and more efficient cooperating protocols. The most popular cooperating protocols are: amplify and forward (AF), decode and forward (DF), selective or opportunistic relaying (SR) and incremental relaying (IR). In the AF protocol the relays scale the received message broadcasted during the first phase and send it in the second phase. The destination combines the received signals from source and relays to decode the message [2], [3], [4]. In DF protocol [5], [6], the relays will make use, in the first phase, of some detection or decoding techniques to recover the initial sent message. In the second phase the set of relays that successfully decoded the message during the first phase will cooperate with source to transmit the message to the destination. In opportunistic

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

relaying forwarding relay is chosen among the set of relays depending on some criterion like distance to destination or channel quality [7], [8], [9]. Although this protocol achieves full diversity gain and higher throughput than fixed AF and DF protocols, it does not take into account the fact that in some circumstances, where the direct channel quality is "good" the direct transmission will be sufficient to transmit the message. In the IR protocol the cooperation will take place only if the destination failed to decode the message in the first phase [2]. IR protocol, assisted by H-ARQ, is proven to improve throughput and energy while still achieving full diversity gain.

The second issue to consider when designing a relay network is resources allocation. This point didn't receive much effort compared to the protocol design [10], [11]. In [11], [12] optimal power allocation that maximizes received SNR at the receiver has been developed for AF and DF protocol. Most work found in literature provides some techniques to optimize power allocation in a two-phase system without H-ARQ assistance.

In this paper a relay aided H-ARQ system with direct link is considered. We provide the analytical expressions for exact and asymptotic outage probability and average delay. We use a numerical method to estimate the optimum power allocation that minimizes outage probability and delay at high SNR regime depending on the relative distance of three cooperating nodes. The rest of the paper is organized as follows: In section 2 we discuss the related work in literature. System model and relaying strategy are described in section 3. In section 4 we derive the exact and asymptotic outage probability, diversity gain and average delay. We then present a numerical method to obtain the optimum power scheme. In section 5 the accuracy of such analysis is corroborated using Monte Carlo simulations. Finally, in section 6 we draw conclusions and propose lines for future research work.

2. LITTERATURE REVIEW

Relaying systems have been extensively studied in previous years. Many techniques were studied and characterized for different channel models. In [13] authors proposed an approach to networks comprising multiple relays operating over orthogonal time slots based on Hybrid-Automatic Repeat Request (H-ARQ). In [14] authors derived the expressions of the outage probability for a wireless network that integrates incremental redundancy hybrid automatic repeat request (IR HARQ) and coded cooperation among nodes. The authors in [15] proposed a throughput-efficient relay selection HARQ system over Rayleigh fading. The throughput and delay performance of a half-duplex multi-branch relay system with HARQ has been analyzed. The authors in [16] introduced a new strategy for cooperative transmit diversity based on superposition modulation and multiuser detection.

Few papers in literature have studied the impact of the power allocation on the performances of a relaying system. In [3] an AF system where all relays participate in the second phase is considered. The authors showed that the optimal power allocation can be obtained by an extended water-filling process. The authors in [6] studied the performances of three protocols based on DF relaying. The asymptotic optimum power allocation to minimize the outage probability is also derived. In [17] outage probability for selective relaying aided incremental redundancy H-ARQ was derived for Nakagami-m channel. The authors also showed that for the considered relaying strategy the optimum power to allocate to the source is approximately between [0.7, 0.8]. Authors in [18] investigated the performances of a two phases AF and DF relaying system without H-ARQ. The authors concluded that optimum power allocation does not depend on the channel link between source and destination and that it depends only on the channel link between source and relay and the channel link between relay and destination. Authors provided approximate values for the optimum power allocation depending on the channels quality. In [19] optimum power allocation scheme minimizing the average symbol error rate is studied, and simple analytical solutions are obtained of multiuser multiple antennas amplify-and-forward relaying networks without H-ARQ employing opportunistic scheduling with feedback delay and co-channel interference over Rayleigh fading channels. Authors in [16] proposed to perform power allocation after selection of the best relay. The authors in this paper used the results in [18] and concluded that better improvement is obtained when the ratio of variances of the modeled Rayleigh direct and relay channels is about 15. The allocation scheme used in this paper doesn't take into account the affect of H-ARQ and direct link. The direct link is considered by authors in [21] and an algorithm is provided to optimize source and relay power allocations in a multicarrier relay system with direct link, where the source is allowed to transmit in a two-phase relay scheme without H-ARQ.

Journal of Theoretical and Applied Information Technology
10th July 2014. Vol. 65 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3. SYSTEM MODEL DESCRIPTION

Figure 1 illustrates the system model. We consider a wireless network consisting of a source (S), a Decode and Forward (DF) relay (R) and a destination (D).

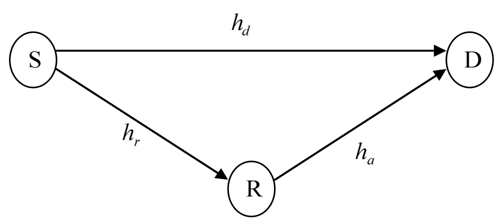

Figure 1 : System model

Three links are considered: direct link from source to destination, relay link from source to relay and access link from relay to destination. The distance between relay and destination is d_a and destination is located at distance d from the source. We assume an indoor environment with path loss exponent $\nu = 4$. We denote by h_d, h_r and h_a the independent channel gains for the direct, relay and access links respectively. We assume that the three links have a Rayleigh block fading channels independent from each other. Therefore h_d, h_r and h_a are i.i.d. complex Gaussian random variables with zero-mean and variances σ_d^2, σ_r^2 and σ_a^2 respectively. For any link $\sigma_x^2 = \frac{C}{d_x^{\nu}}$ where C is a constant depending on the operating frequency and d_x is the distance of the link. The power gains $|h_d|^2$, $|h_r|^2$ and $|h_a|^2$ follow then the exponential distribution with parameters $\lambda_d = \frac{1}{\sigma_d^2}$, $\lambda_r = \frac{1}{\sigma_r^2}$ and $\lambda_a = \frac{1}{\sigma_a^2}$ respectively.

Data is assumed to be split into multiple packets, and the transmission of a packet is split into two phases. During the first phase the source S broadcasts data through the relay and direct link until reception of an acknowledgement from destination (D) or relay (R), or consumption of total credit assigned to that packet. If the relay successfully decodes the sent packet the system enters in the second phase. During the second phase the relay forwards the decoded packet to the destination through the access link until reception of a positive acknowledgement or consumption of the remaining credit from the first phase. An outage event will occur if destination cannot decode the packet after consumption of the total credit assigned to the packet. To isolate the effect of the power allocation we don't consider any combining at both relay and destination. We assume that a positive or a negative acknowledgement (ACK and NACK) is zero delay error free. The source and relay transmit with powers P_1 and P_2 respectively satisfying the power budget constraint $P = P_1 + P_2$. We define α as the portion of the power allocated to the source such that $P_1 = \alpha P$, $P_2 = (1-\alpha)P$ and $0 \leq \alpha \leq 1$. We define signal-to-noise ratio as $\gamma = \frac{P}{N_0}$, where N_0 is the variance of additive white Gaussian noise in the channel. Each packet is assigned a total credit of $N + 1$ transmission.

4. SYSTEM'S PERFORMANCE ANLYSIS

In this section, we will be deriving respectively the exact and asymptotic outage probability, the diversity gain and average delay, and then we will present a numerical method for obtaining the optimum power scheme.

4.1 Exact Outage Probability

Let us denote P_O^d, P_O^r and P_O^a the probability of a failed transmission through direct, relay and access links respectively.

During the j^{th} transmission, $(1 \leq j \leq N + 1)$ the mutual information exchanged between the source and destination can be expressed respectively as:

$$I_d(j) = \log_2\left(1 + \frac{\alpha P}{N_0}|h_d(j)|^2\right) \quad (1).$$

The multiplicative noise is considered constant during one block transmission. Therefore the transmission of one block can be seen as if we transmit the signal through a channel which is subject to the AWGN noise. Applying Shannon–Hartley theorem we can write:

$P_O^d = P(I_d(j) < R)$ where R is the spectral efficiency of the system. Hence:

$$P_O^d = P\left(|h_d(j)|^2 < \frac{N_0(2^R - 1)}{\alpha P}\right)$$

$$= \int_0^{\frac{N_0(2^R-1)}{\alpha P}} \lambda_d \exp(-\lambda_d x) dx$$

$$= 1 - exp\left(-\frac{\lambda_d N_0(2^R-1)}{\alpha P}\right) \quad (2)$$

Similarly

$$P_O^r = 1 - exp\left(-\frac{\lambda_r N_0(2^R - 1)}{\alpha P}\right) \quad (3)$$

$$P_O^a = 1 - exp\left(-\frac{\lambda_a N_0(2^R - 1)}{(1-\alpha) P}\right) \quad (4)$$

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The Relay will forward the sent packet if it can decode it before consumption of total credit. Let us consider the mutually exclusive events as β_k={the relay is forwarding the packet starting from the k^{th} round} where $1 \leq k \leq N$, and define the event $\beta = \cup_{k=1}^{N} \beta_k$.
The global outage probability after N+1 H-ARQ round can be therefore expressed as:

$$P_{out}(N) = \sum_{k=1}^{N} P[out|\beta_k]\, P[\beta_k] + P[out|\bar{\beta}]P[\bar{\beta}] \quad (5)$$

Where $\bar{X}$ is the complementary event of X and $P[X|Y]$ is the probability of X given Y.

$$P[out|\beta_k] = (P_O^a)^{N-k+1} \quad (6)$$

$$P[\beta_k] = (P_O^d)^k (P_O^r)^{k-1}(1 - P_O^r) \quad (7)$$

$$P[\bar{\beta}] = 1 - \sum_{k=1}^{N} P[\beta_k] \quad (8)$$

$$P[out|\bar{\beta}] = (P_O^d)^{N+1} \quad (9)$$

Using (6), (7), (8) and (9) the equation (5) can be written as

$$P_{out}(N) = \sum_{k=1}^{N} (P_O^a)^{N-k+1} (P_O^d)^k (P_O^r)^{k-1}(1 - P_O^r) + (P_O^d)^{N+1}\left(1 - \sum_{k=1}^{N} (P_O^d)^k (P_O^r)^{k-1}(1 - P_O^r)\right) \quad (10)$$

The terms under summation in (10) are geometric sequence terms. Hence, using the formula for the sum of first N terms of a geometric sequence, the global outage probability of the system is:

$$P_{out}(N)=(P_O^d)^{N+1}\left(1\text{-}P_O^d(1\text{-}P_O^r)\left(\frac{1\text{-}(P_O^d P_O^r)^N}{1\text{-}P_O^d P_O^r}\right)\right) + (1 - P_O^r)P_O^a P_O^d \left(\frac{(P_O^a)^N - (P_O^d P_O^r)^N}{P_O^a - (P_O^d P_O^r)}\right) \quad (11)$$

4.2 Asymptotic Behavior at High SNR and Diversity Gain

Using the Taylor approximation near to zero $e^x \approx 1 + x$, we can write the individual links outage probabilities P_O^d, P_O^r and P_O^a at high SNR as :

$$P_O^d = \frac{\lambda_d N_0 (2^R - 1)}{\alpha P} \quad (12)$$

$$P_O^r = \frac{\lambda_r N_0 (2^R - 1)}{\alpha P} \quad (13)$$

$$P_O^a = \frac{\lambda_a N_0 (2^R - 1)}{(1-\alpha) P} \quad (14)$$

After some algebraic manipulations the asymptotic outage probability at high SNR can be written as:

$$P_{out}^{Asy}(N) = A_d\left(\frac{A_d^N + A_a^N}{\gamma^{N+1}}\right) \quad (15)$$

Where $A_d = \frac{\lambda_d(2^R-1)}{\alpha}$ and $A_a = \frac{\lambda_a(2^R-1)}{(1-\alpha)}$.

The outage probability at high SNR will depend essentially on the direct and access link. This is predictable because in such situation the probability for both relay and direct link to fade at the same time is very small. And the bottleneck of the system in this case is the direct and access link.

The diversity gain of the system is defined as [22]

$$G = -\lim_{\gamma \to +\infty} \frac{\log(P_{out}(N))}{\log \gamma}$$

Using (15) we obtain the diversity gain $G = N + 1$. In other words the diversity gain achieved by the studied system is exactly the total credit assigned to a packet. This can be seen as if the transmitted signal is passed through different N+ 1 paths or in a $(N + 1) \times 1$ MIMO channel.

4.3 Average Delay

The delay is the number of H-ARQ rounds spent to send a packet. Hence the average delay can be estimated as:

$$\delta(N)=(1\text{-}P_{out}(N))\sum_{k=1}^{N+1} kp(k) + (N+1)P_{out}(N) \quad (16)$$

Where $p(k)$ is the probability for a packet to be received in exactly k transmissions and can be expressed as:

$$p(k) = (1 - P_{out}(k-1)) \prod_{i=0}^{k-2} P_{out}(i) \ (17).$$

From (11), (16) and (17) the average delay closed form expression is obtained.

4.4 Asymptotic Optimum Power Allocation

In this subsection we provide a numerical method to optimize the power allocation based on relative distance between the three nodes. The optimization target function is the outage probability at high SNR regime. We minimize the asymptotic outage probability under the constraint of total power budget. The optimization problem is then:

$$\min P_{out}^{Asy}$$
$$\text{Subject to } 0 \leq \alpha \leq 1$$

By differentiating P_{out}^{Asy} with respect to α, and equating to zero we find that the optimum power allocation that minimizes the asymptotic

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

outage probability should satisfy the following equation:

$$N\alpha^{N+1}\text{-}\alpha^{N}(1\text{-}\alpha)=(N+1)(1\text{-}\alpha)^{N+1}\left(\frac{\sigma_a^2}{\sigma_d^2}\right)^{N} \quad (18)$$

As mentioned in section III, the variances σ_a^2 and σ_d^2 are related with following equation:

$$\sigma_a^2 = \sigma_d^2\left(\frac{d}{d_a}\right)^{\nu} \quad (19)$$

From (18) and (19), the optimum power allocation is the solution of the equation:

$$N\left(\frac{\alpha}{1\text{-}\alpha}\right)^{N+1}\text{-}\left(\frac{\alpha}{1\text{-}\alpha}\right)^{N}=(N+1)\left(\frac{d}{d_a}\right)^{\nu N} \quad (20)$$

Each node in the network can accurately estimate its own position using an embedded global positioning system (GPS) receiver, and distance information are exchanged between nodes using the header of the transmitted message. Given the distance information the source and relay can compute the optimum power allocation to minimize the outage probability by solving the equation (20).

Using this numerical method optimal power allocation for different positions of the relay is obtained in Table 1.

Table 1: Optimum Power Allocation for Different Position of the Relay, N=3.

d/da	8/7	4/3	8/5	2	8/3
α_{opt}	0.63	0.72	0.82	0.89	0.95

From table 1 we can conclude that equal power allocation is inefficient even when the relay is close to the source. When the relay is close to the destination the optimum is obtained if almost all the power is assigned to the source.

5. NUMERICAL RESULTS AND DISCUSSION

In this section we show the accuracy of the expressions derived in (11) and (16). We then discuss the improvement when optimum allocation is used instead of equal power allocation. The simulator is designed using MATLAB built-in functions. We assume perfect knowledge of the channel state at transmitter and receiver.

4.5 Closed Form Expressions Accuracy

In Fig. 2 and 3 the closed form expressions proposed here is compared with Monte Carlo simulation results when transmitting 10^7 data blocks of length 40 bits each modulated in BPSK. The variances of the three links are normalized to 1, R=1b/s/Hz and a total power budget P=5w is equally allocated to source and relay. From the figures we can conclude that there is a tradeoff between outage probability and delay to take into account in the design of relaying systems depending on application requirements. In Fig. 4 the outage probability and delay are plotted against maximum number of retransmission.

At low SNR regime, the retransmission of the same message doesn't improve much the outage probability. This is due to the fact that no combining technique is implemented in both relay and destination. In the other hand an additional delay is caused by multiple retransmissions. In the opposite, at medium and high SNR regime the retransmission of the same message is efficient. The gain in this case can reach 2.5 dB and no extra delay is generated from multiple retransmissions.

4.6 Impact of unequal Power Allocation

In Fig. 5 and 6 the performances of equal and optimized power allocation are compared for $d/d_a = 2$, $\sigma_d^2 = 1$, $\sigma_r^2 = \sigma_a^2 = 16$, total power budget P=5w, power allocation $\alpha = 0.89$ and maximum number of retransmission N=3. For the outage probability (Fig. 5) the gain of optimum power allocation is more visible at high SNR where it can reach a maximum of 2dB. At low SNR the gain is not significant. This is due to the fact that in such circumstances the three links exhibits very bad performances. For the delay (Fig. 6), optimum power allocation impact is more visible at medium SNR regime and gain rises to 2dB. This is due to the fact that at high SNR the first transmission is always sufficient to transmit the message.

6. CONCLUSION

This paper investigates the performance of relay network consisting of three nodes. Closed form and asymptotic expressions for the outage probability and delay are obtained through analytical analysis and confirmed by Monte Carlo simulations. In addition a numerical method is used to obtain the optimum power scheme based on relative distance between the three nodes.

Simulation results confirm the presented mathematical analysis and show that the proposed optimum power allocation clearly outperforms the equal power allocation in terms of outage probability and average delay performances.

The obtained results also showed that relaying aided H-ARQ type I is inefficient at low SNR. An open point is to investigate the impact of

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Chase combining on the optimum power allocation. Another question to be treated in future work is the optimum power allocation scheme in presence of multiple relays cooperating with the source using space time coding.

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

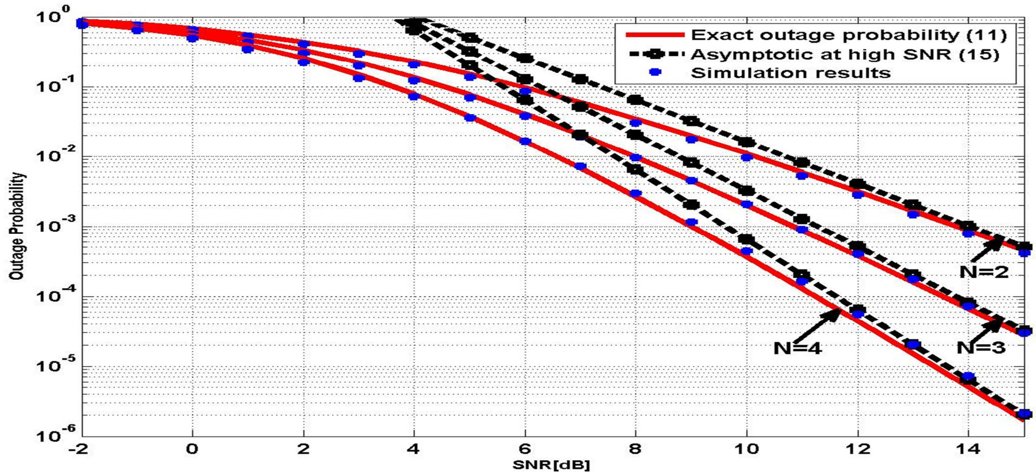

Figure 2: Exact and Asymptotic Outage Probability for Different Values of Packet Credit, $\sigma_d^2 = \sigma_r^2 = \sigma_a^2 = 1$, $R = 1\ bit/s/Hz\ and\ P = 5w$

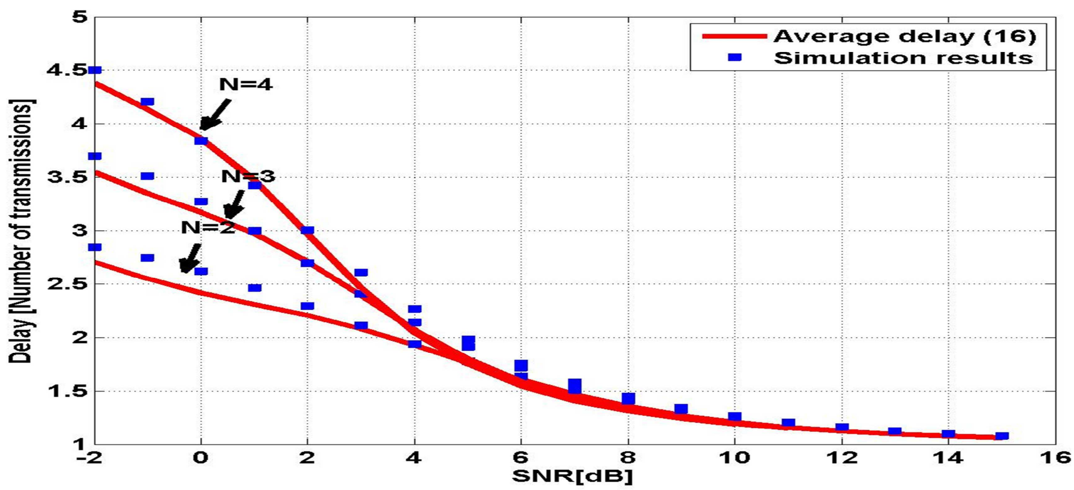

Figure 3: Average Delay Different Values of Packet Credit, $\sigma_d^2 = \sigma_r^2 = \sigma_a^2 = 1$, $R = 1\ bit/s/Hz\ and\ P = 5w$

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

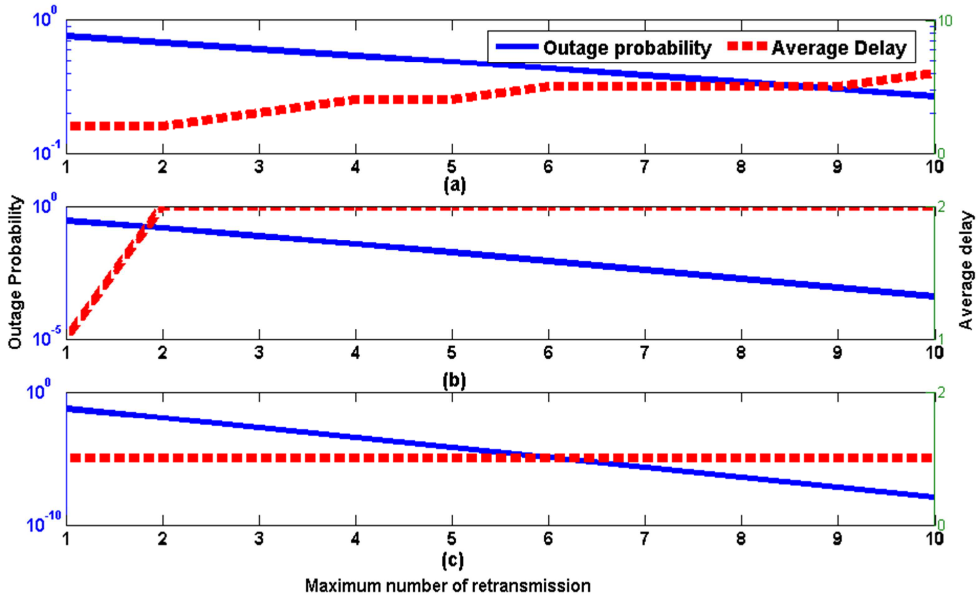

Figure 4: Outage Probability and Average Delay Against Maximum Number of Retransmissions for SNR= 0 (a), 5 (b) and 10 dB (c)

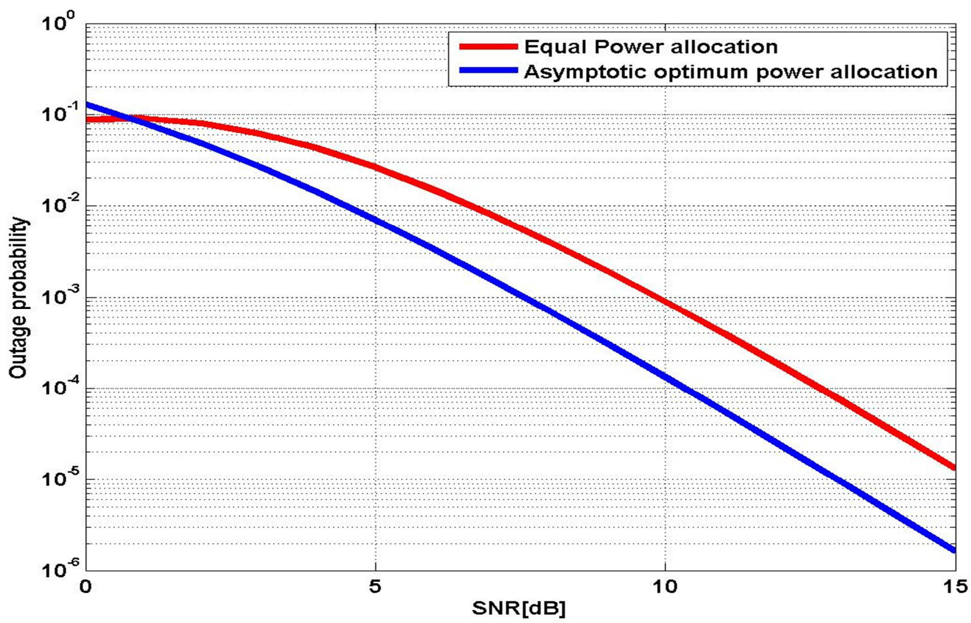

Figure 5: Outage Probability for Equal (α=0.5) and Asymptotic Optimum (α=0.89) Power Allocation, $\sigma_d^2 = 1, \sigma_r^2 = \sigma_a^2 = 16$.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

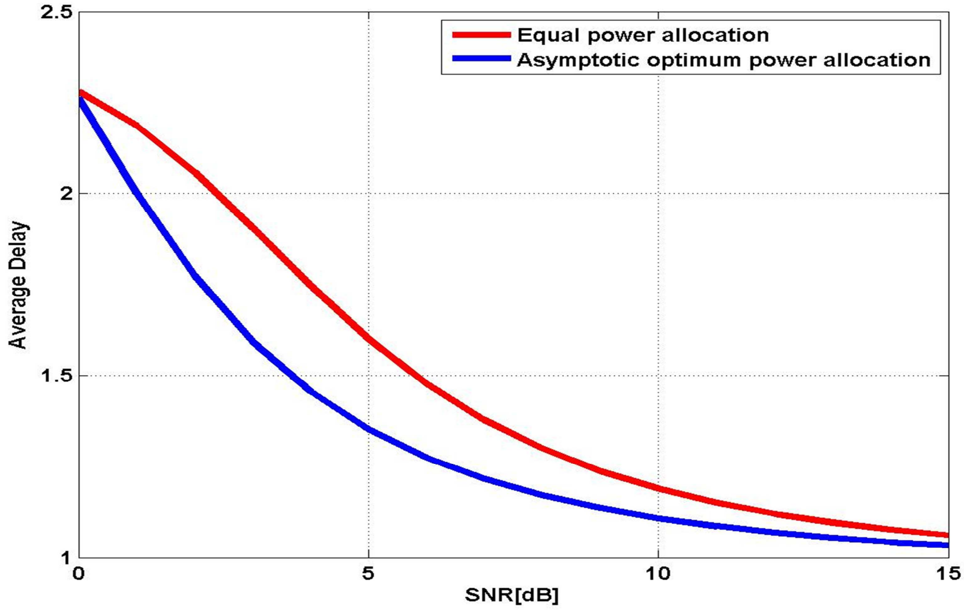

Figure 6: Average Delay Against SNR for Equal (α=0.5) and Asymptotic Optimum (α=0.89) Power Allocation, $\sigma_d^2 = 1, \sigma_r^2 = \sigma_a^2 = 16$.