# Performance Analysis of Outage Probability of Clipped OFDM Cooperative Communication System Based on Best Two Relay Selection

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***Abstract*—The end-to-end performance analysis of outage probability of clipped orthogonal frequency division multiplexing (OFDM) of amplify-and-forward (AF) relaying cooperative communication system with two pair relay selection is addressed. The simplest approach to overcome the high peak-to-average power ratio (PAPR) of OFDM transmitted signals is the clipping technique. However, it may give rise to in-band distortion and out-of-band interference. In this paper, the modeling of nonlinear distortions which is introduced by the clipping process at the source is presented as the aggregate of an attenuation factor and clipping noise. The probability density function (PDF) of the signal scaled by the clipping factor can be modeled by an exponential distribution. The multipath of two hop wireless transmission channels are modeled in the time domain as an Erlang distribution function. As a result of this model, the outage probability with the clipped OFDM signal transmitted over multipath fading channel of length *L* and an arbitrary number of relay nodes *M* with best two relay selection is calculated. Moreover, the analytical expression for CDF of the end-to-end signal-to-noise ratio (SNR) is obtained. In addition, this analysis shows how the clipping process affects the outage probability for different clipping ratio levels (μ). Finally, the theoretical results are compared with simulated results to confirm the validity of the analysis.**

***Keywords—Outage analysis; two hop cooperative system; best two relay selection; clipped OFDM source***

## I. INTRODUCTION

Cooperative multi-node communication system with selection relaying has gained increasing attention recently due to not only its improved the bandwidth utilization but also, its exploited spatial diversity. Spatial and temporal cooperative diversity are one of the most effective techniques to mitigate fading in the multi-path wireless channel environment [1], [2]. The spatial cooperative diversity can be naturally exploited in a multi-relay environment as a virtual multi-input multi-output (VMIMO). Moreover, exploiting the OFDM technique is to transform a frequency selective fading channel to parallel flat fading channels. An OFDM signal is a superposition of $N$ usually statistically independent sinusoidal subchannels modulated by possibly coded data symbols. It can constructively sum up to high peaks which theoretically can be up to the number of OFDM subcarriers in magnitude. As a result of this drawback, a large linear range for the radio frequency (RF) power amplifier is required which is expensive. Also, the system may require more bits to cover a potentially broad dynamic range. Moreover, commercial RF power amplifiers can lead to unwanted out-of-band (OOB) interference and in-band distortion due to operating in the saturation region. PAPR becomes even more important in MIMO-OFDM systems because there are multiple transmit antennas each of which would require its own DAC and RF power amplifier. According to [3], the efficiency and gain of the PA stage are a tradeoff. Therefore, clipping an OFDM signal at the source not only allows the use of an efficient PA, but also, acts as input back-off (IBO) to avoid the nonlinear effect of the PA by decreasing the average power of the input signal. This implies the OFDM signal to be transmitted is in the linear region of the PA [4]. In [5] there are several solutions to the PAPR problem of OFDM. The clipping method is the simplest solution, which is the focus of this paper, but it increases the BER and adds out-of-band interference.

### *A. Contributions and related work of this paper*

Outage probability is a common measure of performance for cooperative communication systems but most previous works have not considered the evaluation of networks with PAPR reduction [6] [7] [8]. However, in [9], the end-to-end outage probability analysis of AF for one relay and direct link between source and destination node and power amplifier (PA) nonlinear distortions at the relay nodes was presented. In our work, a theoretical analysis of the outage probability of a clipped OFDM signal transmitted over a multipath fading channel of length $L$ and an arbitrary number of relay nodes $M$ with best two relay selection is calculated. The clipping process is modeled as an aggregate of an attenuated signal component and clipping noise. The signal before clipping can be assumed to be Gaussian distributed because $N$ is large enough. Thus, the magnitude squared of the signal scaled by the clipping factor can be modeled by an exponential distribution. The clipping noise can be assumed to play the same role as channel noise. The PDF of the multipath two-hop wireless transmission is modeled in the time domain as an Erlang distribution function.

### *B. Common notations*

Common notations that have been used in this paper are $\Gamma(L)$ denotes the complete Gamma function. $C_A(.)$ denotes the clipping operation with the clipping amplitude A. E{·} is the statistical expectation function. The operator denotes the Euclidean squared norm of a complex vector and Re{·} its real part, and $\|.\|^2_F$ denotes the Frobenius squared norm.

## II. SYSTEM MODEL OF A COOPERATIVE SYSTEM WITH CLIPPING AT THE SOURCE

The cooperative multi-node communication system includes one clipped OFDM source node *S*, one destination node *D* and *M* relay nodes $R_m$ , where $m = 1, 2, \ldots, M$. The assumptions are the terminals operate in a half-duplex mode and the received signals at the destination are only from the relays. The cooperative transmission technique is implemented with three wireless links as described and represented in part (II) of Fig.1. The effect of the clipping process at the transmitter is modeled as one transmission link. The other two links are presented by two AF type communication phases as in part (I) of Fig 1. In the first transmission phase, the source node *S* broadcasts the clipped signals to the *M* relay nodes. Then, during the second phase, the relay nodes retransmit the data to the destination node. In addition, the channel impulse response (CIR) from the *S* to $R_m$ and from $R_m$ to *D* as below in (1). These channel coefficients are assumed to represent quasi-static frequency selective Rayleigh fading models as

$$h_{m,i,L} = \sum_{l=1}^{L} h_{m,i,l}\,\delta(t - \tau_{m,i,l}), \qquad (1)$$

where *L* is the number of multi-paths and $h_{m,i,L}$ and $\tau_{m,i,l}$ are the complex fading amplitude and time delay of the *L* path, respectively. The continuous time *t* is sampled in our work so that we have a discrete time channel [10].

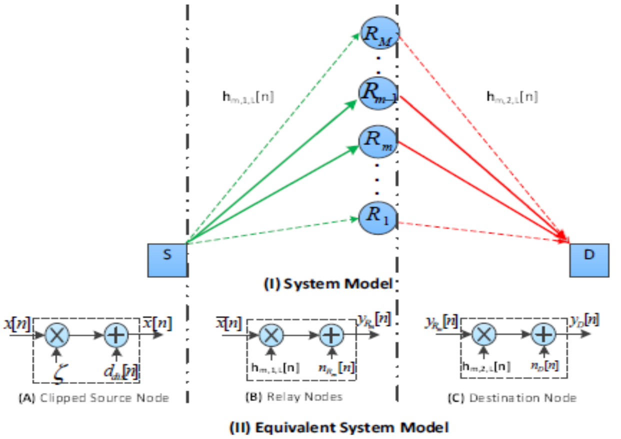

Fig.1 (I) System model and (II) Equivalent system model of clipped source multi-path and two-hop wireless transmission with the best pair relay selection (solid lines).

It is assumed that all channel coefficients within $h_{m,i,L}$ are uncorrelated with each others. Equation (2) represents the PDF of the strength of the constructive sum of *L* independent paths of each channel, which has an Erlang distribution, which is given by

$$f_{\gamma_{m,i,L}}(\gamma) = \frac{\gamma^{L_{m,i}-1} e^{-\frac{\gamma}{\bar{\gamma}}}}{\Gamma(L_{m,i})\bar{\gamma}^{L_{m,i}}}, \qquad i = 1,2, \qquad (2)$$

where

$$\Gamma(L) = \int_0^\infty s^{L-1} e^{-s} ds = (L-1)!\,, \qquad (3)$$

$\Gamma(L)$ is the complete Gamma function, where *L* is called the shape parameter which represents the number of paths in each channel, $\gamma$ is called the scale parameter and $\bar{\gamma}$ is denoted as the average SNR [11]. The CDF of (2) can be obtained by taking the integral with respect to $\gamma$ , yielding (4)

$$F_{\gamma_{m,i,L}}(\gamma) = 1 - \frac{\Gamma(L_{m,i}, \frac{\gamma}{\bar{\gamma}})}{\Gamma(L_{m,i})}, \qquad i = 1,2, \qquad (4)$$

where $\Gamma(L, x) = \int_0^x s^{L-1} e^{-s} ds$ is the incomplete Gamma function.

### *A. Modelling of the clipped OFDM source node*

The simplest approach to reduce the PAPR in an OFDM waveform is applying clipping process at source node. The clipping process can be implemented by using a simple envelope limiter. The mathematical can be modelled as (5). However, clipping process induces in-band distortion and out-of-band interference

$$\begin{aligned} \bar{x}[n] &= C_A(x[n]) \\ &= \begin{cases} x[n] & |x[n]| \le A \\ Ae^{\arg\{x[n]\}} & |x[n]| > A \end{cases} \quad n = 0,1,\ldots, N-1, \end{aligned} \qquad (5)$$

where $x[n]$ and *n=0, 1, ..., N-1* denotes $n^{th}$ sample of the OFDM symbol duration and *N* is the number of OFDM subcarriers. According to the Bussgang theorem [12] [13] [11], the output memoryless nonlinear can be modeled as in (6) which is an aggregate of the original signal which is scaled by factor ξ and clipping noise $d_{dis}[n]$ as

$$\bar{x}[n] = \sqrt{\xi}\; x[n] + d_{dis}[n]. \qquad (6)$$

The scale factor ξ can be calculated by (7), dropping the time index $[n]$ for convenience

$$\xi = 1 - e^{-\mu^2} + \frac{\sqrt{\pi}\mu}{2} erfc(\mu), \qquad (7)$$

where $\mu$ is a clipping ratio and defined as $\mu = A/\sqrt{P_x}$ , where *A* is a clipped amplitude and $p_x$ is the average input power of the nonclipped OFDM signal.

According to the central limit theorem, the time domain OFDM signal can be approximated as a complex Gaussian distributed process with zero main and variance ${\sigma_x}^2$, when the number of subcarriers is large. Therefore, the OFDM envelope converges to a Rayleigh envelope distribution [14] [15]. As a result, the probability density function (PDF) of OFDM signal can be approximated as (8)

$$f_X(x) = \frac{2x}{p_x} e^{-\frac{x^2}{P_x}} \tag{8}$$

According to (6) the total output power $P_{out}$ contains of output clipped signal power $P_{CS}$ and a power of distortion noise $P_{dis}$ ( $P_{out} = P_{\bar{x}} = P_{CS} + P_{dis}$ ). Then, with the assumption $p_x$ is close to unity the output-to-input average power ratio η can be obtained as

$$\begin{aligned}\eta &\cong \frac{P_{\bar{x}}}{P_x} = \frac{\int_0^\infty \left|\bar{x}[n]\right|^2 f_X(x)\,dx}{P_x} \\ &= \frac{\int_0^A x^2 \frac{2x}{P_x} e^{-\frac{x}{P_x}} dx + \int_A^\infty A^2 \frac{2x}{P_x} e^{-\frac{x^2}{P_x}} dx}{P_x} \\ &= 1 - e^{-\mu^2}.\end{aligned} \tag{9}$$

Next, the representation of received clipped signal at the relay nodes and destination node will be addressed.

### B. Received signal at the relays and destination nodes

The source node broadcasts the clipped signal to the relay nodes, in the first stage and then the relay nodes resend the data to the destination, during the second stage. Then, the received signals at relay nodes can be written as

$$\begin{aligned}y_{SRm}[n] &= \sqrt{P_s} H_{m,1,L}[n]\ \bar{x}[n] + w_{Rm}[n] \\ &= G_1 \xi \sqrt{P_s} H_{m,1,L}[n]\ x[n] + G_1 H_{m,1,L}[n] d_{dis}[n] + w_{Rm}[n]\end{aligned} \tag{10}$$

Then, the signal received by the destination during the second transmission stage is given by:

$$\begin{aligned}y_{RmD}[n] &= H_{m,2,L}[n]\ y_{SRm}[n] + w_D[n] \\ &= G_1 G_2 \xi \sqrt{P_s} H_{m,1,L}[n]\ H_{m,2,L}[n]\ x[n] \\ &\quad + G_1 G_2 H_{m,1,L}[n] H_{m,2,L}[n] d_{dis}[n] \\ &\quad + G_2 H_{m,2,L}[n] w_{Rm}[n] + w_D[n]\end{aligned} \tag{11}$$

where $H_{m,1,L}[n]$ and $H_{m,2,L}[n]$ represent convolution matrices formed from the coefficients of the source to relays channel and relays to destination channel, respectively. The elements of $w_{Rm}[n] \sim CN(0, {\sigma_n}^2)$ and $w_D[n] \sim CN(0, {\sigma_n}^2)$ are additive white Gaussian noise (AWGN) at the mth relay and the destination D, respectively, and the clipping noise $d_{dis}$ has a variance $\sigma^2{}_{dis} = P_s(1 - e^{-\mu^2} - \xi^2)$.

### C. End-to-end SNR of clipped source AF Network

From (11), the end-to-end SNR terms are calculated by summing the SNRs of the different multi-path links. Thus, the received end-to-end SNR can be written as in (12)

$$\gamma_{Dm} = \frac{P_s G_1^2 G_2^2 \left\|H_{m,1,L}[n]\right\|_F^2 \left\|H_{m,2,L}[n]\right\|_F^2}{G_1^2 G_2^2 \left\|H_{m,1,L}[n]\right\|_F^2 \left\|H_{m,2,L}[n]\right\|_F^2 \sigma_{dis}^2 + G_2^2 \left\|H_{m,2,L}[n]\right\|_F^2 \sigma_n^2 + \sigma_n^2}, \tag{12}$$

where $P_s$ is the average energy per symbol, $\left\|H_{m,1,L}[n]\right\|_F^2$ and $\left\|H_{m,2,L}[n]\right\|_F^2$ are the channel gain between source and mth relay nodes and destination node, respectively. $\sigma_n^2$ and $\sigma_{dis}^2$ are the noise variance of the nonclipped and clipped signal, respectively. $G_1$ is the clipped source normalization gain and $G_2$ is the amplification gain at the mth relay nodes which used to normalize the received signal $y_{RmD}[n]$, given by

$$G_1 = \frac{\sqrt{P_s}}{\sqrt{\xi^2 P_s + \sigma_{dis}^2}}, \tag{13}$$

$$G_2 = \frac{\sqrt{P_r}}{\sqrt{\xi^2 G_1^2 P_s \left\|H_{m,1,L}[n]\right\|_F^2 + G_2^2 \left\|H_{m,2,L}[n]\right\|_F^2 \sigma_{dis}^2 + \sigma_n^2}}. \tag{14}$$

The instantaneous SNR of the clipped signal at source ( $\gamma_{Clip}$ ), the instantaneous SNR ( $\gamma_{m,1,L}$ ) of the first hop (*S* to *R*$_m$) and SNR ( $\gamma_{m,2,L}$ ) of the second hop (*R*$_m$ to *D*) can be calculated as follows

$$\gamma_{Clip} = \frac{\xi^2 P_s}{\sigma_{dis}^2}, \tag{15}$$

$$\gamma_{m,1,L} = \frac{P_s \left\|H_{m,1,L}[n]\right\|_F^2}{\sigma_n^2}, \tag{16}$$

$$\gamma_{m,2,L} = \frac{P_s \left\|H_{m,2,L}[n]\right\|_F^2}{\sigma_n^2}. \tag{17}$$

The effect of the clipping process $\gamma_{Clip}$ is modelled as exponential wireless link. By substituting (13), (14), (15), (16) and (17) into (12), instantaneous received end-to-end SNR ( $\gamma_D$ ) will be obtained as (18)

$$\gamma_D = \frac{\gamma_{Clip} \gamma_{m,1,L} \gamma_{m,2,L}}{\gamma_{m,1,L} \gamma_{m,2,L} + \gamma_{Clip} \gamma_{m,1,L} + \gamma_{Clip} \gamma_{m,2,L} + \gamma_{Clip} + \gamma_{m,1,L} + \gamma_{m,1,L} + 1} \tag{18}$$

In the next section, the outage probability analysis will be explained.

## III. OUTAGE PROBABILITY ANALYSIS

The definition of the outage probability is that when the average received end-to-end SNR falls below a certain predefined threshold value and cannot support the target transmission rate. The threshold value is $\gamma = 2^{2R} - 1$, where $R$ is the target transmission rate [16]. The outage probability can be expressed as

$$P_{out} = \int_0^{\gamma} f_\gamma(\gamma) d\gamma = F_\gamma(\gamma), \tag{19}$$

where $f_\gamma(\gamma)$ is the probability density function (PDF) and $F_\gamma(\gamma)$ is the cumulative distribution function (CDF) of the SNR. Next, we consider upper bound analysis.

### *A. CDF analysis of upper bound*

Lower and upper bounds for the equivalent SNR can be given as

$$\gamma_{LB} \le \gamma_{Dm} \le \gamma_{UB}, \tag{20}$$

where $\gamma_{LB} = \frac{1}{2}\sum_{m=1}^{M} \gamma_m$ and $\gamma_{UB} = \sum_{m=1}^{M} \gamma_m$ .To find $\gamma_{UB}$, we adopt the following relay selection criterion:

$$\gamma_{UB} = \min\{\gamma_{Clip}, \gamma_{m,1,L}, \gamma_{m,2,L}\} \ge \gamma_{Dm}. \tag{21}$$

In order to calculate the theoretical analysis of upper bound outage probability through the CDF of the end-to-end SNR for an arbitrary multi-path channel length $L$, we need to find the CDF of $\gamma_{UBm} = \min\{\gamma_{Clip}, \gamma_{m,1,L}, \gamma_{m,2,L}\}$ which can be expressed as (22)

$$\begin{aligned} F_{\gamma_{UBm}} &= 1 - P_r(\gamma_{Clip} > \gamma) P_r(\gamma_{m,1,L} > \gamma) P_r(\gamma_{m,2,L} > \gamma) \\ &= 1 - \left[1 - P_r(\gamma_{Clip} \le \gamma)\right]\left[1 - P_r(\gamma_{m,1,L} \le \gamma)\right]\left[1 - P_r(\gamma_{m,2,L} \le \gamma)\right] \\ &= 1 - \left[1 - F_{\gamma_{Clip}}(\gamma)\right]\left[1 - F_{\gamma_{m,1,L}}(\gamma)\right]\left[1 - F_{\gamma_{m,2,L}}(\gamma)\right], \end{aligned} \tag{22}$$

where $F_{Clip}(\gamma) = 1 - e^{-\gamma/\bar{\gamma}_{Clip}}$ is the CDF of clipped signal which is modeled as exponential distribution and $\bar{\gamma}_{Clip}$ represents the average SNR of the clipped signal at source. $F_{\gamma_{m,1,L}}(\gamma) = [1 - \Gamma(L_{m,1}, \gamma/\bar{\gamma})/\Gamma(L_{m,1})$ and $F_{\gamma_{m,2,L}}(\gamma) = [1 - \Gamma(L_{m,2}, \gamma/\bar{\gamma})/\Gamma(L_{m,2})$ are the CDFs of the multi-path channels with length $L$, which are represent the first and second hops, respectively. By simple manipulation of (22), we get upper bound end-to-end CDF in (23)

$$F_{\gamma_{UBm}}(\gamma) = 1 - e^{-\gamma/\bar{\gamma}_{Clip}} \times \frac{\Gamma(L_{m,1}, \gamma/\bar{\gamma})}{\Gamma(L_{m,1})} \times \frac{\Gamma(L_{m,2}, \gamma/\bar{\gamma})}{\Gamma(L_{m,2})}. \tag{23}$$

The full outage probability analysis of selecting two relay from M relays will be considered in the next section.

## IV. OUTAGE PROBABILITY ANALYSIS OF SELECTING TWO RELAY FROM M RELAYS

We select the best pair relay a node from M available relays, namely, selecting the first and second largest instantaneous SNR $\gamma_{UB_{opt}}$ and $\gamma_{UB_{opt}-1}$ from the *M* relays. The selection of the best couple of relays is performed in two steps [1]. The first step is to obtain the weaker link between the first and second hop of each relay node. Secondly, these weak links are ordered and the two links with the first and second maximum SNR are selected as the candidates to relay the data to the destination, which are expressed in (24)

$$\begin{aligned} \gamma_{UB_{opt}} &= \max_{m}\{\min\{\gamma_{Clip}, \gamma_{m,1,L}, \gamma_{m,2,L}\}\}, \\ \gamma_{UB_{opt}-1} &= \max_{m-1}\{\min\{\gamma_{Clip}, \gamma_{m,1,L}, \gamma_{m,2,L}\}\}, \quad m = 2, 3, \ldots, M. \end{aligned} \tag{24}$$

Building upon (23) and its derivative to provide the joint PDF of $\gamma_{UB_{opt}}$ and $\gamma_{UB_{opt}-1}$ can be expressed

$$f_{X,Y}^{L}(x,y) = M(M-1) f_X^L(x) f_Y^L(y) [F_Y^L(y)]^{M-2}, \tag{25}$$

where $M$ is the number of relay nodes in the system, $\gamma_{UB_{opt}} = X$ and $\gamma_{UB_{opt}-1} = Y$ which are the first and second largest maximum values, respectively. Based upon the fact that the OFDM technique has the ability to transform a frequency selective fading channel, which is multipath in the time domain, to parallel flat fading channels, which can be represented as one path in the time domain ($L$ = 1), therefore, equation (22) can be written as (26)

$$\begin{aligned} F_{\gamma_{UBm}}(\gamma) &= 1 - e^{-\gamma/\bar{\gamma}_{Clip}} \times \frac{1}{\bar{\gamma}_{m,1}} e^{-\frac{\gamma}{\bar{\gamma}_{m,1}}} \times \frac{1}{\bar{\gamma}_{m,2}} e^{-\frac{\gamma}{\bar{\gamma}_{m,2}}} \\ &= 1 - \frac{1}{\bar{\gamma}_{m,i,Clip}} e^{-\frac{\gamma}{\bar{\gamma}_{m,i,Clip}}}, \end{aligned} \tag{26}$$

where $\bar{\gamma}_{m,i} = \bar{\gamma}_{m,1} = \bar{\gamma}_{m,2}$ and $\bar{\gamma}_{m,i,Clip} = \frac{\bar{\gamma}_{m,i}}{2 + \bar{\gamma}_{m,i}/\bar{\gamma}_{Clip}}$. By substituting (26) into (25), so, the PDF form can be expressed as (27)

$$f_{X,Y}^{1}(x,y) = M(M-1)\left[\frac{1}{\bar{\gamma}_{m,i,Clip}} e^{-\frac{x}{\bar{\gamma}_{m,i,Clip}}}\right]\left[\frac{1}{\bar{\gamma}_{m,i,Clip}} e^{-\frac{y}{\bar{\gamma}_{m,i,Clip}}}\right] \left[1 - \frac{1}{\bar{\gamma}_{m,i,Clip}} e^{-\frac{y}{\bar{\gamma}_{m,i,Clip}}}\right]^{M-2}. \tag{27}$$

The CDF equation can be found by substituting (27) in (28).

$$F_{\gamma_{opt}}^{1}(\gamma) = \int_0^{\gamma/2} \int_y^{\gamma-y} f_{X,Y}^{1}(x,y)\, dx\, dy. \tag{28}$$

Then, by integrating (28), the full CDF closed form expression as

$$F^{1}_{\gamma_{opt}}(\gamma)=M(M-1)\left\{\frac{1}{2}\frac{(\bar{\gamma}_{m,i,Clip}e^{-\frac{\gamma}{\bar{\gamma}_{m,i,Clip}}}-\bar{\gamma}_{m,i,Clip}-\gamma)e^{-\frac{\gamma}{\bar{\gamma}_{m,i,Clip}}}}{\bar{\gamma}_{m,i,Clip}}+\right.$$

$$\left.\sum_{k=1}^{N-2}\binom{N-2}{k}(-1)^{k}\frac{(e^{-\frac{\gamma}{\bar{\gamma}_{m,i,Clip}}}k-2-k+2e^{-\frac{\gamma k}{2\bar{\gamma}_{m,i,Clip}}})e^{-\frac{\gamma}{\bar{\gamma}_{m,i,Clip}}}}{(2+k)k}\right\}. \quad (29)$$

Next, the simulation results of comparison the outage probability analysis, without and with relay selection.

## V. SIMULATION RESULTS

### *A. Simulation results of outage probability analysis of clipped OFDM transmission*

To verify the result which is obtained from (29), we assumed that the links between $S$ to $R_m$ nodes and from $R_m$ to $D$ node have the same average SNR. It is assumed that, no direct link between the transmitter and the receiver due to shadowing, or distance, and all nodes are equipped with a single antenna. In this section, we show outage probability performance of different number of relays and different number of clipping ratio ($\mu$). Also, we assume the average SNR, $\bar{\gamma}$ = 5 dB. The simulated values, as in Fig. 2 is found by generating random channels and applying the max{min(., .)} operation

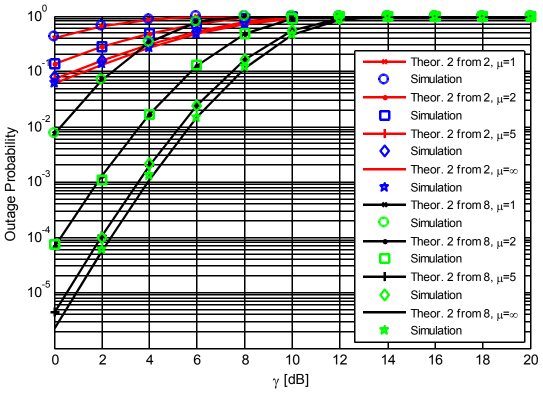

Fig. 2 *Comparison of outage probability of clipped OFDM at source with and without best two relay selection with various clipping ratio $\mu$ = 1, 2, 5 and ∞ (nonclipped) which represented by dash line).*

Fig. 2 illustrates the comparison of the outage probability without relay selecting ($M$ = 2) and with best pair relay selection from *8*available relay nodes. Both cases have been investigated when the clipping process is implemented at source node and with various clipping ratio levels ($\mu$). Generally, selecting best two relay pairs from 8 available relay nodes implies best performance compared with the system without relay selection. For example, when $\mu$ = 1 and the threshold value is $\bar{\gamma}$ = 5 dB which is equal to $R$ = 1.16 bps/Hz of transmission rate, the outage performance of the system which has just 2 relay nodes is approximately 90%, whereas, the outage performance of the system which selecting the best two relay from 8 available relay nodes is approximately 30% which approximately equal the nonclipped performance of former system. In addition, selection system provides significant improvement of outage when clipping level $\mu$ increased to 2, which is 0.02% at the threshold value is = 5 dB. Finally, the performance of the system with relay selection clipped by 5 is closed to nonclipped performance, which represented by dash line in Fig. 2

### *B. Simulation results of outage probability vs SNR of clipped*

By using also equation (20) to plot the theoretical outage probability versus the SNR by fixing the threshold value $\gamma = 2^{2R} - 1$ = 5 *dB* and varying the average SNR values $\bar{\gamma}$ in dB. In another hand, simulation results generated by using random channels and applying the max*{*min(. , . , .)*}* operation as in (24).

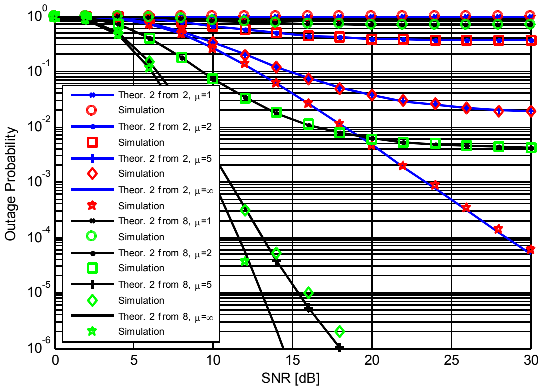

Fig. 3 *Comparison of outage probability vs SNR of clipped OFDM at source with and without relay selection with various clipping ratio $\mu$ = 1, 2, 5 and ∞ (nonclipped) which represented by dash line).*

From Fig.3, it is clearly seen that the scheme without relay selection has the worst performance when the clipping ratio $\mu$ = 1, the outage is 0%. However, slightly improvement is achieved of the selection system. Additionally, when the clipping ratio greater than one, the performance of the selection scheme is significantly improved compared with nonselection system. For example, at SNR = 15 dB, the outage probability of the system has just 2 relay nodes is approximately 100%, 50%, 10% and 4%, for $\mu$ = 1, 2, 5 and ∞ (nonclipped), respectively. Whereas, the outage probability of the system which selecting the best two relays from 8 available relay nodes is approximately 70%, 1%, 0:001% and 0:0001%, for $\mu$ = 1, 2, 5 and ∞ (nonclipped), respectively.

These results confirm that the selection of the best two relay pairs from large number available relay nodes provide more robust transmission compared with the system has two relay nodes. Moreover, the analytical and simulation results are very close to each other for all curves.

## VI. C ONCLUSION

We have derived outage probabilities of OFDM source for a cooperative amplify-and-forward system with the best two relay pairs selection from $M$ available relay nodes. The derived formulas are simple, applicable to an arbitrary number of relay nodes $M$. The two-hop wireless transmission was modelled in the time domain as a flat fading distribution function. Whereas, the nonlinear distortions introduced by the clipping process was modelled as an aggregate of attenuation factor and clipping noise, which the magnitude squared of the signal scaled by the clipping factor was modelled as an exponential distribution. The clipping noise has assumed to play the same role as channel noise. The clipping process caused a degradation of the system performance and the degradation depends upon the clipping ratio. However, to some extend, selecting the best two relay pairs from large number of relay nodes benefited to overcome this degradation. The results indicate that, the theoretical calculation and simulation were closed at different number of available relay nodes. Large improvement of outage probability of this system can be expected by selecting four relays from $M$ available relays, which is a subject of our ongoing research.

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