Neuro-Fuzzy based Joint Relay-Selection and Resource-Allocation for Cooperative Networks

M. Shamim Kaiser[1], **Raza Ali Shah**[2], and **Kazi M. Ahmed**[3], Non-members

ABSTRACT

This paper focuses on a joint relay-selection and resource-allocation algorithm for an Amplify-and-Forward (AF) cooperative network. In a multiuser scenario, joint relay selection and power allocation is a combinational problem for heterogeneous, i.e., real time (RT) and non-real time (NRT), users. In single relay AF (S-AF) scheme, a source-destination pair selects best relay. Thus only two channels are needed (i.e., one for source-destination direct link and other one for the source-relay-destination indirect link) between a source-destination pair. We propose a Neuro-Fuzzy (NF) based optimal relay selection algorithm for selecting best relay based on link's signal-to-noise ratio (SNR), link's delay and degree of mobility between a source-destination pair. The available radio resources are then allocated sub-optimally to the RT and NRT users on priority basis. The priority parameter depends on Quality-of-service (QoS) requirement of the RT and NRT users. We deduce a close form expression of the moment-generating-function (MGF) for independent and non identical Rayleigh fading channels. Performance evaluations reveal that the proposed joint scheme has lower complexity and better outage behavior as compared to the conventional schemes.

Keywords: Relay Selection, Resource Allocation, Outage Probability, OFDMA, Mamdani-Adaptive Neuro-Fuzzy Inference System (M-ANFIS) Architecture

1. INTRODUCTION

Next Generation (xG) wireless system demands higher data transmission rate. This has imposed serious challenges for the wireless system designer. Due to the frequency selective multipath fading, the high rate coverage cannot be achieved by the direct transmission. Multiple-input and multiple-output (MIMO) is a wireless networking technology that exploits the availability of multiple independent radio terminals to improve both the range and capacity of a connection between source and destination. Cooperative relaying techniques have been proposed as an alternative to the MIMO systems because of the technical constraints of MIMO. Relays provide spatial diversity and mitigate slow fading [1]. Recent studies show that the performance of a single relay cooperative network is better than that of multi-relay cooperative network[1, 2].

Orthogonal frequency division multiplexing (OFDM) is another widely accepted technology for next generation (xG) wireless systems. It can mitigate the channel fading and offer high spectral efficiency. The 2-hop transmission with one relay node helps to attain the wider coverage. Thus the performance of a 2-hop system can be improved by OFDM based transmission technique.

Many cooperative relaying schemes have been studied by the researchers. Multi-relay AF (M-AF) is proposed in [2] where M potential relaying nodes, i.e., $r_i (i = 1, 2, ..., M)$, relay source information using orthogonal channels. The source, denoted by s, has achieved the diversity order of $(M+1)$. Authors have used the optimal power allocation (OPA) algorithm assuming that the perfect knowledge of all channel gains are known to transmitters and receivers. A selection scheme based on delay at the relay is proposed in [3]. Single relay AF (S-AF) has been discussed in [1, 4]. The performance of the time dependent relay channels has been studied for the fast fading and log-normal fading [5]. The outage probability of an AF relay channel is calculated from the frequency and probability of outages. A simple relay search algorithms has proposed that only utilize the knowledge of average received SNRs at the destination [6]. To the best of our knowledge joint relay selection and resource allocation algorithms for the RT and NRT users based on user priority have not been studied.

This paper focuses on an AF based joint relay selection and resource allocation algorithm for cooperative network to study outage performance of RT and NRT users. It is assumed that all the wireless nodes use orthogonal-frequency-division-multiplexing (OFDM) based transmission. We propose a Neuro-Fuzzy (NF) based single relay selection algorithm considering non-identical and independent channel conditions, queuing delay at the relay and energy saving efficiency due to the cooperative diversity. The suboptimal power allocation optimization problem is formed for both RT and NRT users. It maximizes

[1] The author is with Applied Physics & Electronics, Brac University, Dhaka-1212, Bangladesh, E-mail:kaiser@bracu.ac.bd

[2,3] The authors are with Telecommunications, School of Engineering and Technology, Asian Institute of Technology, Thailand, E-mail:Raza.Ali.Shah@ait.ac.th and kahmed@ait.ac.th

the overall data rate of the system subject to the total power, Quality of Service (QoS) requirement and data buffer information. We schedule RT and NRT users based on a priority parameter. This parameter depends on the channel condition, buffer length information and the QoS constraint.

The remaining section is organized as follows: section II introduces the system model. Section III and IV discuss a NF based S-AF relaying and suboptimal power allocation algorithms respectively. Section V presents the simulation results. Finally, we conclude our work in section VI.

2. SYSTEM MODEL

As shown in Fig. 1, a base station (BS) communicates with k_a number of RT and k_b number of NRT users through Relays r_i and $\psi = k_a + k_b$. N_a and N_b are the number of subcarriers of RT and NRT users respectively and $N = N_a + N_b$. The NF based relay selection algorithm selects the best relay that allows the destination (d) to receive two copies of source (s) information in two time slots. In the first time slot, s transmits information to r_i and d. In the second time slot, r_i forwards s transmission. It is assumed that fading channels between the $s - r_i$ and $s - d$ are Rician and the fading channel between $r_i - d$ follows Nakagami-m distribution. It is also assumed that all channel gains are perfectly known to the transmitters and receivers and the source uses OFDMA based downlink transmission. The instantaneous signal-to-noise (SNR) of the k-th user using n-th subcarrier is $\gamma_{kn}^{xy} = P_{kn}^x h_{kn}^{xy\,2}/\sigma^2$, where $(x,y) \in \{(s,r_i),(s,d),(r_i,d)\}$. Let h_{kn}^{xy} denotes the channel coefficient between x and y, P_{kn}^x denotes the transmit powers of x node and σ^2 is variance of the additive white Gaussian noise (AWGN). Thus the average SNR is written as $\bar{\gamma}_{kn}^{xy} = E[\gamma_{kn}^{xy}]$. The data rate of the k-th user through r_i using n-th subcarrier, denoted by $b_{k,n}^{r_i}$, is given as [7,8]

$$b_{kn}^{r_i} = \frac{1}{2}\log_2(1 + \gamma_{kn}^{sd} + \gamma_{kn}^{sr_id}) \qquad (1)$$

$$= \frac{1}{2}\log_2\left(1 + \Gamma_k\gamma_{kn}^{sd} + \Gamma_k\frac{\gamma_{kn}^{sr_i}\gamma_{kn}^{r_id}}{1 + \gamma_{kn}^{sr_i} + \gamma_{kn}^{r_id}}\right) \qquad (2)$$

$$\approx \frac{1}{2}\log_2\left[1 + \frac{\Gamma_kP_{k,n}^s|h_{k,n}^{sd}|^2}{\sigma^2} + \frac{\Gamma_k}{\sigma^2}\frac{P_{k,n}^s|h_{k,n}^{sr_i}|^2P_{k,n}^{r_i}|h_{k,n}^{r_id}|^2}{P_{k,n}^s|h_{k,n}^{sr_i}|^2 + P_{k,n}^{r_i}|h_{k,n}^{r_id}|^2}\right], \qquad (3)$$

where, Γ_k is the SNR gap which can be expressed as $\Gamma_k = 1.5/[-\ln 5(BER)_k]$. $P_{k,n}^s$ and $P_{k,n}^{r_i}$ are the source and i-th relay transmit powers. Thus, the total power is $P_{k,n} = P_{k,n}^s + P_{k,n}^{r_i}$. Let $P_{k,n}^s = \varepsilon P_{k,n}$ then $P_{k,n}^{r_i} = (1 - \varepsilon)P_{k,n}$. The equivalent channel response of the k-th user using n-th subcarrier

$$h_{k,n}^2 = \varepsilon|h_{k,n}^{sd}|^2 + \frac{\varepsilon|h_{k,n}^{sr_i}|^2(1-\varepsilon)|h_{k,n}^{r_id}|^2}{\varepsilon|h_{k,n}^{sr_i}|^2 + (1-\varepsilon)|h_{k,n}^{r_id}|^2}, \qquad (4)$$

where ε is the OPA factor defined in [2]. Equ. (3) can be written as
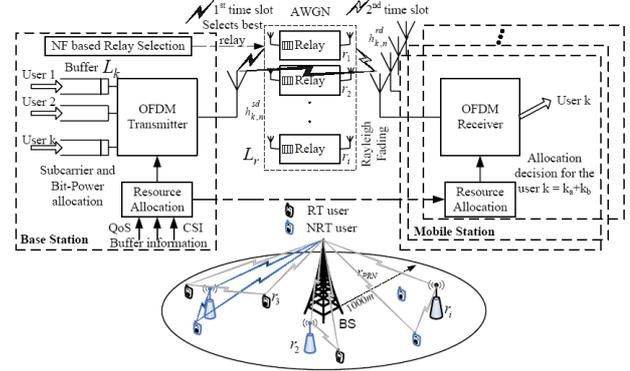
Fig.1: *A Multi-relay network with the best relay selection scheme. NF based relay selection controller selects best relay.*

$$b_{k,n}^{r_i} = \frac{1}{2}\log_2\left(1 + \frac{\Gamma_kP_{k,n}h_{k,n}^2}{\sigma^2}\right). \qquad (5)$$

The achievable data rate of the k-th user, i.e., b_k, can be expressed as

$$b_k = \sum_{n=0}^{N_a}\rho_{k,n}b_{k,n}^{r_i}, \qquad (6)$$

where $\rho_{k,n}$ is the subcarrier allocation indicator. $\rho_{k,n} = 1$, if n-th subcarrier is allocated to k-th user; else $\rho_{k,n} = 0$. The data rate of each RT/NRT user is limited by its buffer occupancy, that is, $b_k \leq \Im[\min(L_k, L_{r_i})]$, where L_k and L_{r_i} are the buffer length of the k-th user and i-th relay respectively. $\Im(.)$ is a function of buffer length.

3. NF BASED S-AF SCHEME

Optimal relay selection is a complex evaluation process. It depends on the attributes of all the relays and the utilities of an individual relay are weighted subjectively. The fuzzy logic and approximate reasoning can simplified this complex decision making process. Artificial Neural Network is a parallel distributed information processing technique that can learn the behavior of system [9]. A rule-based fuzzy system is developed which represents a preliminary model. It is then trained by Gradient Descent learning algorithm. After the training procedure, the modified membership functions of the proposed system are retrieved.
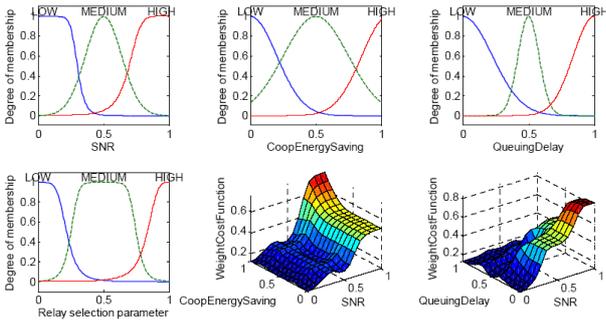
3.1 Relay Selection Parameters
3.1.1 SNR

The link SNR, denoted by $\gamma_{kn}^{r_i}$, can be written as

$$\gamma_{kn}^{r_i} = \gamma_{k,n}^{sd} + min(\gamma_{k,n}^{sr_i}, \gamma_{k,n}^{r_id}). \qquad (7)$$
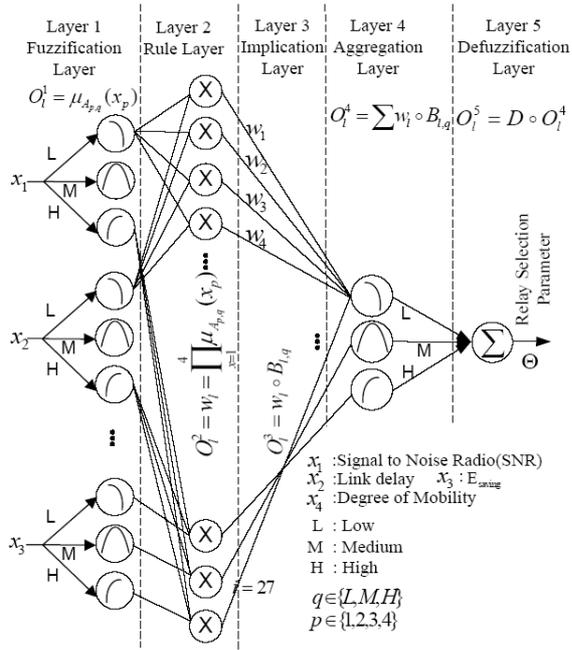
Fig.2: *M-ANFIS Architecture for optimal relay selection*

Fig.3: *inputs and output membership functions after training.*

3.1.2 Mean Delay Estimation

A practical communication system has limited data buffer length. The packet arrival (λ) and service processes (μ) follow the Poisson distribution. The queue size is fixed and can hold only V packets. When, $\mu > \lambda, \Rightarrow D_q = 0$ where, D_q is the mean queuing delay. When $\mu < \lambda$, the probability to have v packets in the queue $(v \leq V)$, denoted by $p(v)$, is written as [10]

$$p(v) = \begin{cases} \left(\frac{\lambda}{\mu}\right)^v \frac{1 - \left(\frac{\lambda}{\mu}\right)}{1 - \left(\frac{\lambda}{\mu}\right)^{V+1}} & \text{if } \mu \neq \lambda \\ \frac{1}{1+V} & \text{if } \mu = \lambda. \end{cases} \quad (8)$$

The mean number of packets in the queue is $Q = \sum_{v=0}^{V} v \times p(v)$. Since the queue length of r_i is fixed, the queuing delay at r_i, i.e., $D_q^{r_i}$, is bounded by some maximum value D_{max}. It can be calculated as [11]

$$D_q^{r_i} \leq D_{max}^{r_i} \approx V^{r_i}/\mu^{r_i}. \quad (9)$$

3.1.3 Energy Saving

Cooperative diversity reduces node energy consumption. In case of non-cooperative communication (NC), the total energy consumption per information bit, i.e., E_{kn}^{NC}, can be expressed in [4] as

$$E_{kn}^{NC} = a^{sd} + (P_{cck_{tx}} + P_{cck_{rx}})/b_k, \quad (10)$$

where $a^{xy} = \frac{\zeta^{xy}}{\eta^{xy}} h_{kn}^{xy} E_b$ is the total power consumption of the RF power amplifier, and P_{cck} is total power consumption of all other transceiver circuit block, E_b is the required energy/bit at the receiver for target BER (BER_T), b_k is the bit rate, ζ^{xy} is the peak-to-average power ratio and η^{xy} is the drain efficiency. In case cooperative communication, the total energy consumption per information bit at the i-th link, i.e., $E_{kn}^{C^i}$, can be written as

$$E_{kn}^{C^i} = a^{sr_i} + a^{r_i d} + (2P_{cck_{tx}} + 3P_{cck_{rx}})/b_k. \quad (11)$$

The energy efficiency of cooperation is defined as the percentage of energy saving, i.e., $E_{kn}^{sav^i}$, achieved by cooperation at the i-th link. Mathematically,

$$E_{kn}^{sav^{r_i}} = \left(E_{kn}^{NC} - E_{kn}^{C^{r_i}}\right)/E_{kn}^{NC}. \quad (12)$$

3.2 M-ANFIS

Fig. 2 shows a Mamdani-Adaptive Neuro-Fuzzy Inference System (M-ANFIS) architecture. It consists of five layers. The nodes in the Layer 1 (L1) generates the membership grades using Fuzzification process. The nodes in the Layer 2 (L2) produces the firing strengths or the rule weight coefficient. Layer 3 (L3) calculates the qualified consequent membership functions (MFs) based on the firing strengths. The qualified consequent MFs are aggregated to generate overall output MF in the layer 4 (L4). Finally the output MFs are converted into crisp output value in the layer 5 (L5). This process is called Defuzzification. In this paper, all the membership functions(MFs) are bell-shaped functions. Fig. 3 shows MFs of inputs and output after training. The layer relations of M-ANFIS model are depicted as below:

$$L1: O_l^1 = \mu_{A_{pq}}(x_p) = \frac{1}{1 + (x_p - c_{pq}/a_{pq})^{2b_{pq}}}, \quad (13)$$

$$L2: O_l^2 = \omega_l = \prod_{p=1}^{4} \mu_{A_{pq}}(x_p), \quad (14)$$

$$L3: O_l^3 = \omega_l \circ B_{lq}, \quad (15)$$

$$L4: O_l^4 = \sum \omega_l \circ B_{lq}, \quad (16)$$

$$L5: \Theta_l = f_l(O_l^4). \quad (17)$$

where, A_{pq} is the linguistic value of the input parameters x_p, $l = 1, 2, ... p \times q$ and $\{a_{pq}, b_{pq}, c_{pq}\}$ is the parameters set. Let, I_p is the input to node, $(p = 1, 2, 3)$. $I_1 : \gamma_{tot}$, $I_2 : D$ and $I_3 : Esav$. A_{pq} is the

linguistic label, $q \in \{1, 2, 3\} \equiv (Low, Medium, High)$ of the node functions. $O_{1,l}$ is the membership function of A_{pq}. The firing strength of the rules are w_{p^q}. B_{lq} is the linguistic value of the relay selection factor, $l = 1, 2, ..., q^p$. The COA (center of area) defuzzification method is considered. The MFs of input and output of the NF controller after training are shown in Fig. 3.

3.3 Weight Updating

The aim of the weight update is to adjust the shaping parameters of the membership function and thereby minimizing the overall error, defined by ϵ_l. Mathematically,

$$\epsilon_l = \sum_k (d_k - o_k)^2. \tag{18}$$

where, d_k and o_k are the k-th component of the l-th desired and the predicted output vectors respectively. The weight updating formula in M-ANFIS can be derived as

$$\Delta w_l = -\eta \frac{\delta \epsilon_l}{\delta w_l} = -\eta \frac{\delta \epsilon_l}{\delta B_{lq}} \frac{\delta f_l}{\delta w_l}, \tag{19}$$

$$w_l^{new} = w_l^{old} - \eta \frac{\delta \epsilon_l}{\delta w_l}, \tag{20}$$

where $\Theta_l = f_l(\sum \omega_l \circ B_{lq} + \phi)$ f_l and Θ_l are the activation function and output of q-l link. η is the learning rate, ϕ is the bias and Δw_l is the difference between the l-th new and old weight. The error signal $\frac{\delta \epsilon_l}{\delta B_{lq}}$ starts from the output layer and goes backward until the input layer is attained. The error signal of the present node can be derived by error signals in previous layer nodes. The shape parameters are tuned as follows

$$X_i(t+1) = X_i(t) - \eta \frac{\partial \epsilon_l}{\partial B_{lq}}; \tag{21}$$

where $X_i \to a_{pq}, b_{pq}$, and c_{pq} are shaping parameters.

3.4 Selection Criterion

We have constructed a mapping model between the relay selection parameters and relay selection factor, denoted by Θ_i, using M-ANFIS. The NF based algorithm selects r_i for user k using n-th subcarrier that has the maximum value of Θ_{r_i}. Mathematically,

$$\Theta_{r_i} = \arg \max_{r_i} \Im(\gamma_{kn}^{r_i}, D_q^{r_i}, E_{kn}^{sav^{r_i}}). \tag{22}$$

4. POWER ALLOCATION

We consider the problem of resource allocation in order to guarantee the QoS of both the RT and NRT services. The throughput of the RT service users are constant, this is due to the minimum data rate requirements of the RT users, i.e.,

$b_k = R_{k,min}$; for all k, where, $R_{k,min}$ is the minimum data rate requirement of the k-th user. The overall system throughput, denoted by T, will increase if the throughput of the RT service users increases. The resource allocation problem of the system can be formed as

$$\arg \max_{(\rho_{k,n}, P_{k,n})} [T] = \arg \max_{(\rho_{k,n}, P_{k,n})} \left[\underbrace{\sum_{k=0}^{k_a} b_k}_{\text{RT}} + \underbrace{\sum_{k=0}^{k_b} b_k}_{\text{NRT}} \right]. \tag{23}$$

This is a non-linear optimization problem. It is difficult to solve directly and the complexity of this problem is very high. Thus the optimization problem in Equ. (23) can be transformed into two suboptimal problems as

Problem I: RT users

minimize $\sum_{k=0}^{k_a} \sum_{n=0}^{N_a} P_{k,n}$
subject to $b_k = R_{k,min}$ $\qquad (24)$
$\qquad P_{k,n} > 0; b_k \leq \Im(min[L_k, L_r]),$

Problem II NRT users

maximize $\sum_{k=0}^{k_b} b_k$
subject to $P_a + P_b = P$ $\qquad (25)$
$\qquad P_{k,n} > 0; b_k \leq \Im(min[L_k, L_r]),$

where $P_a = \sum_{k=0}^{k_a} P_k = \sum_{k=0}^{k_a} \sum_{n=0}^{N_a} P_{k,n}$ and $P_b = \sum_{k=0}^{k_b} P_k = \sum_{k=0}^{k_b} \sum_{n=0}^{N_b} P_{k,n}$. P_k is the power of the k-th user, and P is the total power.

We allocate less number of subcarriers with high SNR to the user at cell edge to achieve the minimum data rate. Because the user at the cell edge suffers high path loss. In order to ensure the minimum QoS to all RT and NRT service users at the cell edge, a scheduling parameter must be set. The QoS requirements of the different users are different. The priority parameter, i.e., $W_k(q)$, is given as [7]

$$W_k(q) = \left[R_{k,min} \times \frac{R_k(q)}{R_k(q-1)} \right]^{1-\alpha} \times h_{k,n}{}^{\alpha}. \tag{26}$$

where $R_{k,min}$ is the minimum rate constraint of k-th user, $R_k(q-1)$ is the average rate at the end of $(q-1)$th frame of k-th user, and $R_k(q) = \Im[min(Q_k(q), L_k(q), L_r(q))]$ where $Q_k(q)$ is the number of bits which should be sent out at the q-th frame to satisfy the users demand, $L_k(q)$ and $L_r(q)$ are the data buffer length of the k-th user and r-th relay at the q-th frame respectively, and α is the priority selection factor, $\alpha = 0$ if $b_k < R_{k,min}$ else $\alpha = 1$. We follow the bit allocation algorithm in [7]. Subcarriers are first allocated to the RT users to achieve the minimum data rate requirement then the remaining

subcarriers are allocated to NRT user to maximize the overall throughput.

Using the Lagrange multiplier and Karush-Kuhn-Tucker conditions [7], we get the solutions of the above optimization problems. By taking the derivatives of L and after some algebraic manipulation, we can get the following solution for RT users

$$P_{k,n} = \frac{\sigma^2}{\Gamma_k} \left[\left(\frac{2^{2R_{k,min}}}{\prod_{n=1}^{m_k} |h_{k,n}|^2} \right)^{\frac{1}{m_k}} - \frac{1}{|h_{k,n}|^2} \right]^+. \quad (27)$$

where, m_k is the number of predetermined best subcarrier set [7] allocated to the k-th user to achieve $b_k = R_{k_{min}}$ The supported rate of the k-th RT user can be written as

$$b_k = \sum_{n=1}^{m_k} \rho_{k,n} \frac{1}{2} \log_2 \left(\frac{2^{2R_{k,min}} |h_{k,n}|^{2m_k}}{\prod_{n=1}^{m_k} |h_{k,n}|^2} \right)^{\frac{1}{m_k}}. \quad (28)$$

Similarly, We can write the solution of the Problem II:NRT users as

$$P_{k,n} = \left[\frac{1}{n_k} \left(P_k + \sum_{n=0}^{n_k} \frac{\sigma^2}{\Gamma_k |h_{k,n}|^2} \right) - \frac{\sigma^2}{\Gamma_k |h_{k,n}|^2} \right]^+. \quad (29)$$

The supported rate of the k-th NRT user can be written as

$$b_k = \sum_{n=0}^{n_k} \rho_{k,n} \frac{1}{2} \log_2 \left[\frac{1}{n_k} \left(P_k \right. \right. \\ \left. \left. + \sum_{n=0}^{n_k} \frac{\sigma^2}{\Gamma_k |h_{k,n}|^2} \right) \frac{\Gamma_k |h_{k,n}|^2}{\sigma^2} \right]. \quad (30)$$

5. OUTAGE PROBABILITY ANALYSIS

The outage probability is an important performance measure in fading scenarios. An outage event occurs when the SNR, denoted by γ_{MRC}, falls below the threshold SNR, denoted by γ_{th}. Mathematically, the outage probability, denoted by P_{out}, is given by [15, 16]

$$P_{out} = \Pr[\gamma_{kn}^{r_i} < \gamma_{th}], \quad (31)$$

where $\gamma_{th} = 2^{2R_{k,min}-1}$, and the transmitted data rate is $R_{k,min}$.

The joint probability density function (PDF) of two independent non identical Rician and Nankagami-m fading channels can be calculated by

using [17]. After few steps, it can be written as

$$f_{\gamma_{kn}^{r_i}}(\gamma) = \frac{1+K}{\bar{\gamma}_{kn}^{sr_i}} 2 \exp \left(-K - \frac{(1+K)\gamma}{\bar{\gamma}_{kn}^{sr_i}} - \frac{m\gamma}{\bar{\gamma}_{kn}^{r_id}} \right) \\ \times \frac{1}{\Gamma(m)} \left(\frac{m}{\bar{\gamma}_{kn}^{r_id}} \right)^m \sum_{x=0}^{\infty} \frac{1}{(x!)^2} \left(\frac{K(1+K)}{\bar{\gamma}_{kn}^{r_id}} \right)^x \\ \times \sum_{y=0}^{m+x+1} \binom{m+x+1}{y} \left(\frac{m}{\bar{\gamma}_{kn}^{r_id}} \right)^m \sum_{x=0}^{\infty} \frac{1}{(x!)^2} \\ \times \left(\frac{K(1+K)}{\bar{\gamma}_{kn}^{sr_i}} \right)^x \gamma^{m+x} \left(\frac{(1+K)\bar{\gamma}_{kn}^{r_id}}{m\,\bar{\gamma}_{kn}^{sr_i}} \right)^{\frac{(m-y)}{2}} \\ \times K_{m-y} \left(2\gamma \sqrt{\frac{m(1+K)}{\bar{\gamma}_{a,c}\bar{\gamma}_{kn}^{r_id}}} \right), \quad (32)$$

where $K_q(\cdot)$ is the q-th order modified Bessel function of the second kind, which is define by [17, eq.(8.432)]. $\bar{\gamma}_{u,v} = P_u \sigma_{u,v}^2 / N_0$ is the average SNR between the $u - v$ link with variance $\sigma_{u,v}^2$. Substituting $K = 0$ and $m = 1$ in Equ. (32), we have

$$f_{\gamma_{kn}^{r_i}}(\gamma) = \frac{2\gamma}{\bar{\gamma}_{kn}^{sr_i}\bar{\gamma}_{kn}^{r_id}} \exp \left[-\left(\frac{1}{\bar{\gamma}_{k,n}^{sr_i}} + \frac{1}{\bar{\gamma}_{k,n}^{r_id}} \right)\gamma \right] \\ \left[2K_0 \left(\frac{2\gamma}{\sqrt{\bar{\gamma}_{kn}^{sr_i}\bar{\gamma}_{kn}^{r_id}}} \right) + \left(\sqrt{\frac{\bar{\gamma}_{kn}^{sr_i}}{\bar{\gamma}_{kn}^{r_id}}} + \sqrt{\frac{\bar{\gamma}_{kn}^{r_id}}{\bar{\gamma}_{kn}^{sr_i}}} \right) \right. \\ \left. K_1 \left(\frac{2\gamma}{\sqrt{\bar{\gamma}_{kn}^{sr_i}\bar{\gamma}_{kn}^{r_id}}} \right) \right]. \quad (33)$$

This is the joint PDF of independent and non identical Rayleigh fading channels. Equ. (33) is same that of [18]. The moment-generating-function (MGF) is given by the expression

$$\mathcal{M}_\gamma(s) = E\left[e^{-s\gamma_{sd}} \right]. \quad (34)$$

Now the close-form MGF can be obtained by using the joint PDF given in 33. After some mathematical manipulation and using [17, eq.(6.621.3)], the MGF of $\gamma_{a \to b}$ can be expressed as

$$\mathcal{M}_{\gamma_{kn}^{r_i}}(s) = \frac{1+K}{\bar{\gamma}_{kn}^{sr_i}} 2 \exp(-K) \frac{1}{\Gamma(m)} \left(\frac{m}{\bar{\gamma}_{kn}^{r_id}} \right)^m \sum_{x=0}^{\infty} \frac{1}{(x!)^2} \\ \times \left(\frac{K(1+K)}{\bar{\gamma}_{kn}^{sr_i}} \right)^x \sum_{y=0}^{m+x+1} \binom{m+x+1}{y} \\ \times \left(\sqrt{\frac{(1+K)\bar{\gamma}_{kn}^{r_id}}{m\,\bar{\gamma}_{kn}^{sr_i}}} \right)^{(m-y)} \frac{\sqrt{\pi}(2\beta)^{m-y}}{(\alpha+\beta)^v} \\ \times \frac{\Gamma(v)\Gamma(x+y+1)}{\Gamma(\varpi)} {}_2F_1 \left(v, \psi, \varpi, \frac{\alpha-\beta}{\alpha+\beta} \right), \quad (35)$$

where $\alpha = \left[\frac{(1+K)}{\bar{\gamma}_{k,n}^{sr_i}} + \frac{m}{\bar{\gamma}_{k,n}^{r_id}} + s \right]$, $\beta = 2\sqrt{\frac{m(1+K)}{\bar{\gamma}_{k,n}^{sr_i}\bar{\gamma}_{k,n}^{r_id}}}$, $v = x + 2m - y + 1$, $\psi = m - y + \frac{1}{2}$, $\varpi = x + m + \frac{3}{2}$

and $_2F_1(\cdot,\cdot,\cdot;\cdot)$ is the gauss hypergeometric function which is defined in [17, eq.(9.100)]. Now the MGF of $\gamma_{a,b}$ can be shown as

$$\mathcal{M}_{\gamma_{sd}}(s) = \left(1 - \frac{s\,\bar\gamma_{sd}}{m}\right)^{-m}. \qquad (36)$$

Under the assumption of non identical fading channels, a close form expression of the moment generating function of γ_{r_i} can be obtained by multiplying the MGF of the γ_{sd} and γ_{sr_id}, i.e

$$\mathcal{M}_{\gamma_{kn}^{r_i}}(s) = \mathcal{M}_{\gamma_{kn}^{sd}}(s)\mathcal{M}_{\gamma_{kn}^{sr_id}}(s). \qquad (37)$$

The close form expression of $\mathcal{M}_{\gamma_{kn}^{r_i}}(s)$ can be used to calculate the outage probability as [19]

$$P_{\text{out}} = \mathcal{L}^{-1}\left(\frac{\mathcal{M}_{\gamma_{kn}^{r_i}}(s)}{s}\right)\bigg|_{\gamma_{th}}, \qquad (38)$$

where $\mathcal{L}^{-1}$ is the inverse Laplace transform. Using MGF-based approach, the end-to-end outage probability can be calculated by using any numerical techniques [12]-[20].

6. SIMULATION RESULTS

We consider a single cell cellular system . The cell-radius of the cell is 1000 m. A BS is placed at the center of the cell whereas the fixed infrastructure relays are placed 500 m away from BS. The total number of subcarriers is 64 and path loss exponent is 3.5. We generate N_a=3 and N_b=5 randomly in the cell. The total transmit power of each link is 30 dBm. Depending on the value of ε, the source and relay powers are distributed. Each subcarrier experiences a Rice-Nakagami-m fading with rms delay spread of 300 ns [11, 21]. We assume the path loss model of IEEE 802.11 with relay [11] and define the average SNR as $1/\sigma^2$. We allocate 20 and 10 subcarriers in the Fixed A and Fixed B schemes respectively.

The outage probability of the best selected relay (for $\bar\gamma^{sd} = \bar\gamma^{sr_i} = \bar\gamma^{r_id}$) is shown in Fig. 4. Solid curve shows the analytical result. The dash-symbol curve gives the outage performance of NF based selected relay. A close match is observed between the two curves.

Fig. 5 shows the throughput analysis of NRT users. Our algorithm maintains almost the same data rate as the algorithm in [8]. However, it outperforms the fixed allocation. The slight difference in performance is due to allocation of best carriers to the worst users in our case while algorithm in [8] allocates best carriers to the best users. It is also observed from Fig. 5 that dynamic resource allocation is better than the fixed allocation. For low value of SNR, the throughput of the Fixed A performs better then Fixed B. However, Fixed B performs better than Fixed A for high SNR values. It is due to the allocation of more
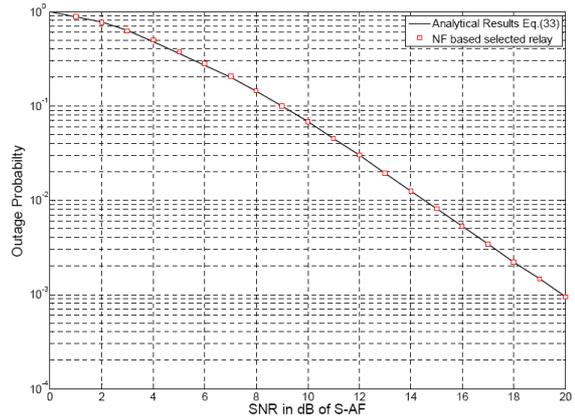

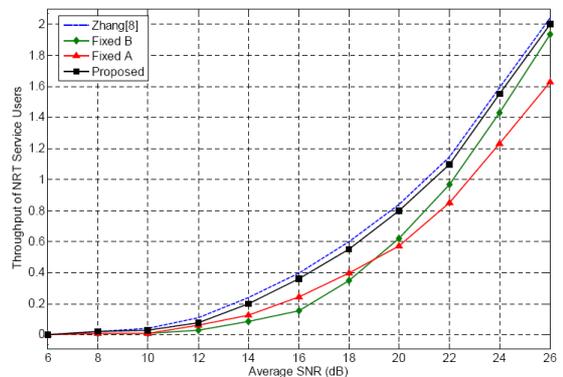**Fig.4:** *Outage probability of NF based relaying for $m = 1$ and $k = 3$.*

**Fig.5:** *Throughput of the NRT users.*

subcarriers in low SNR region and allocation of more power in high SNR region.

Fig. 6 presents the outage probability analysis of the RT users. We compare our proposed algorithm with adaptive resource allocation proposed in [8] and fixed allocation schemes. The proposed algorithm outperforms in algorithm [8] and fixed allocations. It is observed that the outage probability is reduced if more subcarriers are allocated to the users.

The computational complexity of the joint optimal relay selection-OPA is $O(\lceil N^R + N^K\rceil)$ whereas the complexity of proposed joint NF based optimal relay selection-suboptimal power allocation algorithm algorithm is $O(\lceil NKl\rceil)$ in worst case, where l is the $length(Fuzzy attributes)$.

7. CONCLUSION

We proposed an intelligent relay selection and sub-optimal power allocation algorithms for an OFDMA based cooperative communication network. The relay selection and power allocation have been done based on a priority parameter. Simulation results reveal that the outage probability of NF based relaying in non-identical and independent Rice-Nakagami-m fading channels is almost the same as that of analytical result. The data transmission rate of NRT users is
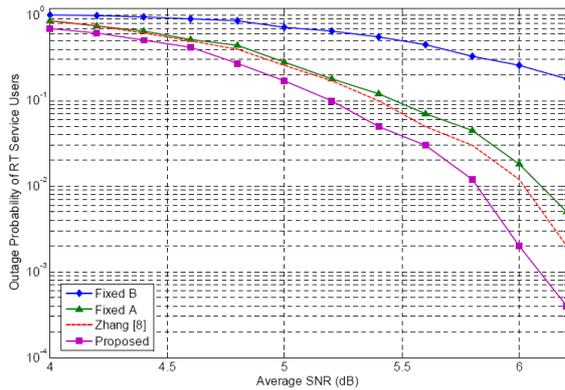
Fig.6: *Outage Probability of the RT users. The proposed algorithm outperforms Zhang algorithm*

lower than the algorithm proposed in [8]. The outage performance of RT users is better then the algorithm in [8]. The complexity of the joint relay selection and power allocation algorithm is lower than that of the Zhang algorithm and optimal algorithm. We will extend our work considering the partial CSI instead of full CSI and SVD-BP (singular value decomposition-back propagation) to reduce the number of rules in rule based system.

References

[1] A. Bletsas, H. Shin and M. Z. Win, "Outage Optimality of Opportunistic Amplify and Forward Relaying," *IEEE Communications Letters*, vol. 11, no. 3, pp. 261–263, March 2007.

[2] Y. Zhao, R. Adve and T. J. Lim, "Improving Amplify-and-Forward Relay Networks: Optimal Power Allocation versus Selection ," *Proceeding of ISIT 2006*, USA, July 9-14 2006.

[3] A. Bletsas, A. Lippman and D. Reed, "A Simple Distributed Method for Relay Selection in Cooperative Diversity Wireless Network Based on Reciprocity and Channel Measurements," *IEEE VTC 2005*, May 2005.

[4] Y. Yao, X. Chi and G. B. Giannakis, "On Energy Efficiency and Optimal Resource Allocation of Relay Transmission," *IEEE Trans. on Information Theory*, vol. 4, pp. 2917–2927, November 2005.

[5] D. B. Cheikh, and A. Saadani, "On the Outage Probability in Amplify-and-Forward Relay Channels," *IEEE WCNC 2009*, Hungary, April 2009.

[6] L. Zinan, and E. Erkip, "Relay Search Algorithms For Coded Cooperative Systems," *Global Telecommunications Conference, 2005. GLOBECOM '05. IEEE*, vol. 3, 28 Nov.-2 Dec. 2005 pp.6-10.

[7] M. Kaiser and K. M. Ahmed, "Resource Allocation for Heterogeneous Services in Relay Enhanced OFDMA System," *Journal of Communications*, Vol 5 (4), 2010.

[8] X. Zhang, S. Chen and W. Wang, "Multiuser Radio Resource Allocation for Multiservice Transmission in OFDMA Based Cooperative Relay Networks ," *EURASIP Journal on Wireless Communications and Networking*, 2009

[9] T. M. Hagan et. al.,"Neural Network Design",*PWS publishing company*,1996, pp- 215-496.

[10] S. Cheikh, G. Lassous, and Isabelle, "Estimating Average End-to-End Delays in IEEE 802.11 Multihop Wireless Networks," *INRIA a CCSD electronic archive server based on P.A.O.L (France)*, HAL CCSD Publisher, 2007.

[11] M. Kaiser, I. Khan and K. M. Ahmed, *NF Selection Algorithm for Optimal Relaying in OFDM Systems*, IEICE, 2010.

[12] J. Abate, "Numerical Inversion of Laplace Transforms of Probability Distributions", *ORSA J. Computing*, vol.7, no.1, pp.36–43, 1995.

[13] D. S. Michalopoulos, G. K. Karagiannidis, T. A. Tsiftsis, and R. L. Mallik, "An Optimized User Selection Method For Cooperative Diversity Systems," *IEEE Globecom 2006*, vol. 5, pp. 2854-2859, December 2006.

[14] A. Bletsas, H. Shin, and M. Z. Win, "Cooperative Communications With Outage-Optimal Opportunistic Relaying," *IEEE Transactions on Wireless Communications*, Vol. 6, Issue 9, pp. 3450 3460, September 2007.

[15] K. J. R. Liu, A. K. Sadek, W. Su and A. Kwasinski, *Cooperative communications and networking*, Cambridge University Press, UK, 2009.

[16] A. Adinoyi, Y. Fan, H. V. Poor and F. A. Shaalan, *Performance of Selection Relaying and Cooperative Diversity*, vol. 8, no. 12, pp. 5790-5795, December 2009.

[17] I.S. Gradshteyn and I.M. Ryzhik, *Table of Integrals, Series, and Products*, 7th ed. London, Academic Press, Inc, 2007.

[18] L.L. Yang and H.H. Chen, "Error probability of digital communications using relay diversity over nakagami-m fading channels," *IEEE Trans. Wireless Commun.*, vol. 7, no. 5, pp. 1806–1811, May 2008.

[19] S. Ikki, and M. H. Ahmed "Performance analysis of cooperative diversity wireless networks over Nakagami-m fading channel," *IEEE communication letters*, vol. 11, no. 4, pp. 334–336, Apr. 2007

[20] Y.C. Ko, M.S. Alouini and M.K. Simon, "Outage Probability of Diversity Systems over Generalized Fading Channels," *IEEE Trans. Commun.*, vol. 48, no. 11, pp. 1783–1787, Nov. 2000.

[21] H. Jeong, and J. H. Lee, "Adaptive Relay Selection for Regenerative OFDMA Relay Networks with Fairness Constraints," *VTC Fall 2008*, pp-1-5.

M. Shamim Kaiser received his Ph. D degree in Telecommunications, School of Engineering and Technology From Asian Institute of Technology, Thailand. He has also received B.S (Honors.) and M.S. degree in Applied Physics Electronics and Communication Engineering from the University of Dhaka, Bangladesh in 2002, and 2004 respectively. Mr. Kaiser worked as special research student in Wireless Signal Processing and Networking Lab, Tohoku University, Japan. His research interest includes coded cooperative system, cognitive radio network, Resource allocation, Bio-inspired NGN, Femto cell.

Raza Ali Shah received his B.S. (Honors) in Electrical Engineering and M.E. in Information and Communications Technologies from N.W.F.P. University of Engineering and Technology, Peshawar, Pakistan and Asian Institute of Technology, Thailand respectively. He is now pursuing his PhD degree in Information and Communications Technologies from AIT, Thailand. His research interest includes cognitive radio and cooperative systems.

Kazi M. Ahmed was born in Bangladesh. He did his Master's in Telecommunications Engineering from the then Leningrad Electrical Engineering Institute of Communications, former USSR, in 1978. He finished his Ph.D. in Electrical Engineering from the University of Newcastle, NSW, Australia in 1983. At present, he is a Professor of Telecommunications and ICT at Asian Institute of Technology, Bangkok, Thailand. Dr. Ahmed has diverse interest in different fields of Telecommunications. His main research interest is in Wireless Communications and Communications Networks. Dr. Kazi Ahmed is a Member, IEEE; Member, IEICE, Japan; Fellow of IE Bangladesh; and Member and Advisor of many international and national associations and steering committees.