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The Performance Improvement of Long Range Inter-relay Wireless Cooperative Network using Three Time Slot TDMA based Protocol

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Abstract— ***Time division multiple access (TDMA) amplify and forward based protocols for cooperative wireless networks have been investigated previously by various researchers. However, the analysis for these protocols is not considered for long range cooperative wireless networks over Rician fading channel. Therefore, the aim of this paper was to propose three time slot TDMA based transmission protocol for inter-relay cooperative wireless network with longer distances between source to relays and destination as well as between relays to destination. It is concluded that the proposed protocol shows less BER performance for long range inter-relay cooperative network over Rician fading channel as compared to two time slot long range cooperative network. Moreover, the proposed protocol shows better performance in terms of less BER values when the inter-relay distance is minimum.***

Keywords: Cooperative inter-relay wireless communication, AF Protocol, TDMA, Path Loss Models, BER.

I. INTRODUCTION

The mobile radio channel suffers due to fading effects during transmission of data from source to destination and undergoes through several signal variations at destination. In order to mitigate fading, diversity communication is used to send the same data over independent fading paths (diversity branches). There are some common techniques such as micro diversity, macro diversity, space diversity, frequency diversity and time diversity, which are used at the transmitter and receiver to achieve diversity communication [1]. The diversity achieved by the above methods tends to increase the size, complexity and total power of the wireless network devices. To solve this problem cooperative diversity communication has been introduced recently. In cooperative diversity communication the diversity is achieved due to cooperation among users or relays, for example, in case of two users or relays and one destination, each user or relay is not only responsible for transmitting their own information data, but the information of their partner user or relay as well to the destination, virtually seeking the advantages of MIMO spatial diversity [2-5]. Each user in cooperative diversity acts as a relay for another user using either amplify and forward (AF) or decode and forward protocol (DF) in order to transmit the information to destination. In DF the relay decodes the received signal from the source and forwards to destination, while, in AF the relay amplifies the received signal from source and forwards to destination [3], [6].

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Cooperative communication solves the issues of size, cost, and hardware limitations of multiple antennas [7]. Moreover, cooperative communication also helps to reduce the effects of multi-path fading and increase capacity of wireless channel as well as achieves high data rates [8-9].

Different multiple access techniques such as time-division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA) have been proposed by researchers to achieve high diversity order at destination [10-12].

In [13], the authors proposed three different two time slots TDMA based transmission protocols. The protocols implement varying degree of broadcasting and receive collision at destination. In each protocol the relay either amplify and forward or decode and forward the received signal from source. In [14] a novel scheme of cooperative network using three time slots is analyzed. The cooperative network is based on data exchange between relays in the third time slot in order to enhance the link performance between relays and destination. In [15], the authors proposed hybrid TDMA-FDMA based three time slots protocol with inter-relay communication over Nakagami-m fading channel. In [16] the authors proposed TDMA based three time slot protocol with inter-relay communication over Nakagami-m and Rician fading channels. In the first time slot the source broadcasts to both the relays and destination. in the second time slot the relays exchange their data as well broadcasts to destination. In the 3rd time the relays broadcasts the previously exchange data in the 2nd time slot to destination. The source remains silent in the 2nd and 3rd time slots and does not broadcasts to destination in these slots.

To the best of our knowledge the BER analysis for inter-relay communication using longer distances between source to destination and relays as well as between relays to destination has not been investigated. A path loss issue and shadowing effects arises in case of longer distances between source to destination and relays as well as between relays to destination. In order to coup the path loss and shadowing issues a proper path loss model is required during BER analysis for inter-relay communication.

In our work, a three time slot TDMA based protocol using path loss model with inter-relay communication is proposed. BER analysis is investigated and repeated for proposed model using 7 different selected path loss models. The BER analysis results are then compared with the results obtained from previously proposed protocol in [13]. It is shown that the proposed protocol performs better in terms of less BER as compared to two times slot protocol proposed in [13].

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A. *Description of Selected Path Loss Models*

In wireless communication systems, the information is transmitted between transmitter and receiver antenna by electromagnetic waves. The signal strength of electromagnetic waves weakens with respect to the distance during propagation [17]. The difference of signal strengths (power) from transmitter (source) to receiver (destination) antenna is termed as path loss. Path loss (PL) of signals at destination is generally determined by the use of different models. The brief descriptions of some mostly used path loss models in the literature are given in Table 1. Free Space Path Loss (FSPL) model estimates the signal strength during propagation from transmitter to receiver. The propagation environment is assumed as free space [17-18]. HATA model is applicable for a frequency range of 150-1500 MHz [17]. Different correction factors are being used for suburban and rural environments [19]. HATA model used the value of correction factor K from 35.94 for countryside and 40.94 for deserts [20]. HATA model provides extension to Okumura model for distances greater than 1km.

COST-231 HATA model is the extension of HATA model. It is used for frequency ranges from 1500-2000 MHz. It incorporates the signal strength prediction up to 20km from transmitter to receiver with the transmitter antenna height of 30 m to 200m and receiver antenna height of 1m to 10m [21]. It is used to predict signal strength in all environments. COST-231 WI model has separate equations both for line of sight and non line of sight communications regarding path loss estimation. However, the line of sight equation is more appropriate in environments when the communication is line of sight. ECC-33 model is one of the most extensively used models, which is based on Okumura model [22-23]. This model is widely used for urban environments especially. Ericsson model is applied for all the three environments such that urban, suburban and rural. In Ericsson model, different parameters values are provided for specific propagation environment [20].Lee model operates around 900 MHz. This model includes adjustment factors that can be adjusted to make the model more flexible to different regions of propagation as compared to other selected models [24].

TABLE 1 DESCRIPTION OF SELECTED PATH LOSS MODELS

S.N0	Models	Mathematical Formulae with Antenna Heights Corrections Factors
1.	Free Space	$PL = 32.45 + 20\log_{10}(d) + 20\log_{10}(f)$
2.	HATA	$PL = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t)\log_{10}(d)$
3.	COST-231 WI	$PL = 34.6 + 26\log(d) + 20\log(f)$
4.	COST_231 HATA	$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10} d + c_m$ $with \quad ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79 \quad for\ f > 400MHz$
5.	LEE	$PL = L_o + \gamma \log d - 10\log F_A$ $L_o = G_B + G_M + 20(\log \lambda - \log d) - 22$ $F_A = F_{BH} F_{BG} F_{MH} F_{MG} F_F$ $F_{BH}\left(\frac{h_B}{30.48}\right)^2 \quad F_{MH} = \begin{Bmatrix} h_M & if, h_M > 3 \\ (h_M/3)^2 & if, h \le 3 \end{Bmatrix}$ $F_{BH} = G_B/4 \quad F_{MG} = G_M \quad F_F = (f/900)^{-n}$
6.	ECC-33	$PL = A_{fs} + A_{bm} + G_b - G_r$ $A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f)$ $A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56[\log_{10}(f)]^2$ $G_b = \log_{10}(h_b/200)\{13.958 + 5.8[\log_{10}(d)]^2\}$ $G_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585]$
7.	Ericsson	$PL = a_0 + 30.2\log_{10}(d) + 12\log_{10}(h_b) + 0.1\log_{10}(h_b).\log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f)$

II. SYSTEM MODEL

A cooperative network with two relays is considered as shown in Fig. 1. The system model consists of source, two relays and destination. The source (S), relay 1 (R_1), relay2 (R_2) and destination (D) all are equipped with single antenna. The h_{SR1}, h_{SR2}, h_{R1D}, h_{R2D}, h_{R1R2} and h_{R2R1} are the path gains of S to R_1, S to R_2, R_1 to D, R_2 to D , R_1 to R_2 and R_2 to R_1 channels respectively. The amplify and forward (AF) communication is used by the relays. Maximum ratio combining (MRC) is used at the destination in order to obtain BER at the destination.

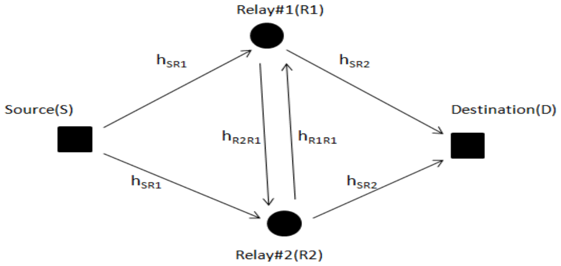

Fig. 1: Inter-relay communication using three time slot protocol

A. *Proposed Amplify and Forward (PAF) Three Time Slot TDMA based Protocol*

The system model used for three time slot proposed protocol is shown in Fig. 1. In the first time slot the source broadcast to destination, relay 1 and relay 2. In the second time slot the source does not remain silent and broadcasts to destination only. The R1 and R2 also broadcast to destination as well as also exchange their data in the second time slot. In the 3rd time slot R1 and R2 broadcast the previously exchange data in the second time to destination. The source keeps broadcasting to destination in the 3rd time as well and does not remain silent. Table -2 shows the summarized form of the proposed protocol.

TABLE 2 PROPOSED THREE TIMES SLOT TDMA BASED PROTOCOL

Time Slot 1	Time Slot 2	Time Slot 3
$S \to R_1, S \to R_2$ $S \to D$	$R_1 \to D, R_2 \to D$ $R_1 \to R_2, R_2 \to R_1$ $S \to D$	$R_1 \to D, R_2 \to D$ $S \to D$

The received signals at relay 1 relay 2 and destination in the first time slot are y_{SR1}, y_{SR2} and $y_{SD,1}$ respectively and given by

$$y_{SR1} = (PL)^{-1}.E_S.h_{SR1}.s + n_{SR1}$$

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$$y_{SR2} == (PL)^{-1} E_S . h_{SR2} . s + n_{SR2}$$

$$y_{SD,1} = (PL)^{-1} . E_S . h_{SD} + n_{SD}$$

Where d_{SR1}, d_{SR2} h_{SR1} and d_{SD} are the distances be S to R1, S to R2 and S to D channels respectively in the first time slot. The PL indicates the path loss model.

The relays R1 and R2 receive the signals from the source in the second time slot normalize the receive signals and broadcast to destination. The received signals at the destination from the R1, R2 and S at the destination in the second time slot are y_{R1D}, y_{R2D} and $y_{SD,2}$, respectively and given by

$$y_{R1D} = (PL)^{-1} . E_1 * h_{R1D} * \frac{y_{SR1}}{\sqrt{E_s |h_{SR1}|^2 + 1}} + n_{R1D}$$

$$y_{R2D} = (PL)^{-1} . E_2 * h_{R2D} * \frac{y_{SR2}}{\sqrt{E_s |h_{SR2}|^2 + 1}} + n_{R2D}$$

$$y_{SD,2} = (PL)^{-1} . E_S . h_{SD} + n_{SD}$$

Where d_{R1D}, d_{R2D} and d_{SD} are the distances be R1 to D, R2 to D and S to D channels respectively in the 2nd time slot.

Similarly, both relays normalize the received signals from source and exchange their data in the second time slot. The received signals at R2 from R1 and at R1from R2 are y_{R1R2} and y_{R2R1} respectively and given by

$$y_{R1R2} = (PL)^{-1} . E_1 * h_{R1R2} * \frac{y_{SR1}}{\sqrt{E_s |h_{SR1}|^2 + 1}} + n_{R1R2}$$

$$y_{R2R1} = (PL)^{-1} . E_2 * h_{R2R1} * \frac{y_{SR2}}{\sqrt{E_s |h_{SR2}|^2 + 1}} + n_{R2R1}$$

Where d_{R1R2} and d_{R2R1} are the distances be R1 to R2, R2 to R1 and S to D channels respectively in the 2nd time slot.

In the 3rd time slot both R1 and R2 normalize the exchange data received during 2nd time slot and broadcast to the destination. The received signals at D from R1, at D from R2 as well as at D from the source in the 3rd time slot are y_{R1D}, y_{R2D} and $y_{SD,3}$ respectively and given by

$$y_{R1D} = (PL)^{-1} . E_1 * h_{R1R2} * \frac{y_{R1R2}}{\sqrt{E_1 |h_{R1R2}|^2 + 1}} + n_{R1D}$$

$$y_{R2D} = (PL)^{-1} . E_2 * h_{R2R1} * \frac{y_{R2R1}}{\sqrt{E_2 |h_{R2R1}|^2 + 1}} + n_{R2D}$$

$$y_{SD,3} = (PL)^{-1} . E_S . h_{SD} + n_{SD}$$

Maximum Ratio Combining (MRC) is used at destination in order to extract the required information at destination. The derived received information signal at D using MRC using Matlab-7.8 is y_D and given by

$$y_D = y_{R1D} . h^*_{R1D} . h^*_{SR1} + y_{R2D} . h^*_{R2D} . h^*_{SR2} + y_{SD} . h^*_{SD}$$
$$+ y_{R2D} . h^*_{R2D} . h^*_{R1R2} . h^*_{SR1} + y \; . h^*_{R1D} . h^*_{R2R1} . h^*_{SR2}$$
$$+ y_{SD} . h^*_{SD} + y_{SD} . h^*_{SD}$$

III. SIMULATION AND RESULTS DISCUSSIONS

BER is used as performance metric and calculated at destination for Inter-Relay Cooperative wireless network as shown in Fig. 1. Bipolar Phase shift keying (BPSK) modulation is used to modulate the signal. The additive white Gaussian Noise (AWGN) with zero mean and variance along with the Rayleigh channel and Rician fading channels is used to make the channel noisy and multipath respectively. In order to plot the BER 10^5 number of symbols is used. Seven different path loss models (Lee Model, Free Space Model, HATA Model, COST-231 HATA Model, ECC-33 Model, COST-231 WI Model and Ericsson Model) were used by the proposed protocol. Similarly, the proposed protocol was tested 7 times i.e., each for a particular path loss model and to get the BER regarding each specified path loss model. The protocol using no path loss model while considering only distance between the source to relays and destination as well as between relays to destination is taken as a reference for comparison in simulation. Line of sight communication (LOS) is considered between source to relays and destination as well as between relays to destination. The operating frequency for each path loss model was fixed i.e., 1500MHz. In case of COST-231 WI model LOS equation was considered. Both relays were taken fixed and minimum inter-relay distance is considered. The correction factor S is taken 10dB.

A. BER Analysis for system model for short distances

Consider that the distance between $S \rightarrow D$ was fixed at 10m. Similarly, the distances between $S \rightarrow R_1$, $S \rightarrow R_2$ $R_1 \rightarrow D$ and $R_2 \rightarrow D$ were fixed at 5.59m. Moreover, the distances between $R_1 \rightarrow R_2$ and $R_2 \rightarrow R_1$ were fixed at 5 m. The transmitter and receiver antenna heights were taken 3m.

The bit error rates for the proposed protocol using different path loss models are shown in Fig. 1. It is observed that the proposed amplify and forward protocol (PAFP) COST-231 WI model shows heights BER. It is due to the fact that COST-231 WI model has no adjustment factors for antenna heights, antenna gains and frequency as compared to other models. Similarly, the proposed protocol using ECC-33 path loss model shows the second highest BER compared to the proposed algorithm using other path loss models. Owing to the fact that transmitter and receiver antenna height correction factors are not effective at lower transmitter and receiver heights. It is also observed during the simulation that ECC-33 model is not more effective at 1500MHz and beyond 1500MHz frequency as compared to other models. It is because this model has no additional frequency adjustment factor incorporated to account the effect of frequency.

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It is indicated that the second lowest BER was shown by proposed protocol using Ericson model as compared to other models. It is because of the use of constants a_0, a_1 and a_2 as adjustment factors which are very effective for the environment taken in the simulation. Moreover, an additional adjustment factor for frequency is also used.

The lowest BER was shown by proposed protocol using LEE path loss model as compared to other models. It is because the LEE model has additional extra correction factors like transmitter and receiver antenna gain correction factors. It is also observed that during simulation the transmitter and receiver antenna heights correction factors were more effective at lower transmitter and receiver antenna heights as compared to other models.

B. BER Analysis for system model for longer distances

Consider that the distance between $S \rightarrow D$ was fixed at 100m. Similarly, the distances between $S \rightarrow R_1$, $S \rightarrow R_2$ $R_1 \rightarrow D$ and $R_2 \rightarrow D$ were fixed at 55.9m. Moreover, the distances between $R_1 \rightarrow R_2$ and $R_2 \rightarrow R_1$ were fixed at 50 m. The operating frequency for each path loss model was fixed again i.e., 1500MHz. It is expressed that when the distance between source to relays and distance as well as between relays to destination increases, the BER increases However, the proposed protocol shows less BER performance as compared to the protocol using no path loss model as shown in Fig. 3. It is due to the fact that if the distance increases the channel conditions become more noisy and proposed protocol reduces the channel noise by using the path loss model. It is also expressed that the proposed protocol using Lee path loss model shows less BER compared to the proposed protocol using other path loss models. It is due to the fact that the adjustment or correction factors (i.e., transmitter and receiver antennas as well as frequency adjustment factors) for the current simulation environment are more effective as compared to the proposed algorithm using other path loss models.

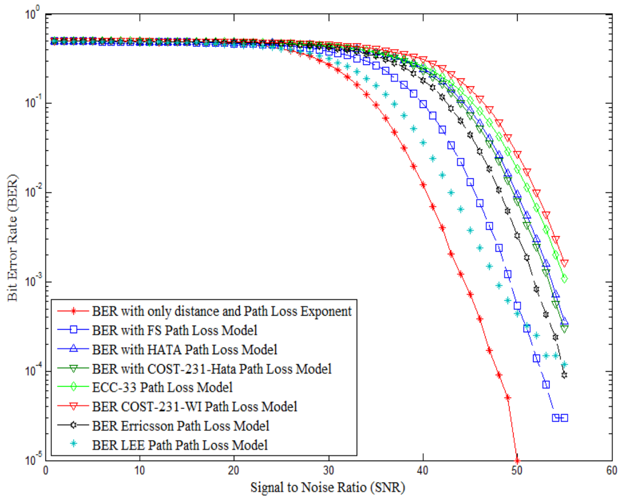

Fig. 2: Bit error rate for PAFP using different path loss models vs SNR

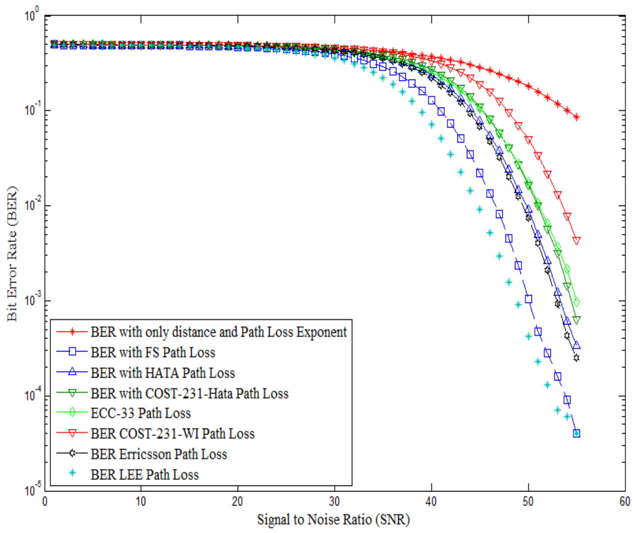

Fig. 3: BER vs SNR for PAFP using different path loss models

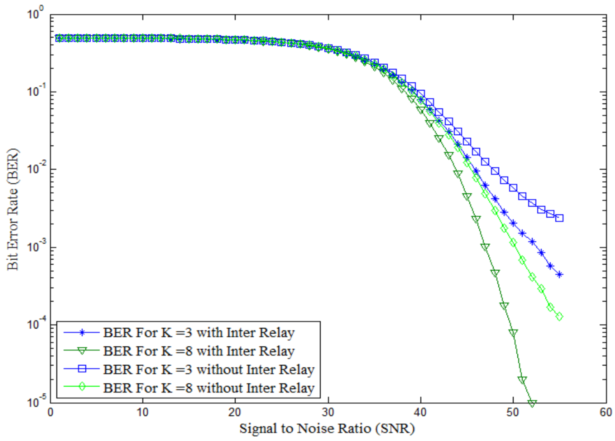

Fig. 4: Comparison of PAF three time slot protocol and two times slot protocol.

The proposed protocol is evaluated by doing comparison with the BER results from TDMA based two time slot protocol with inter-relay communication [13]. The proposed protocol with the third extra time slot shows less BER performance and high diversity order as compared to two time slot transmission protocol as shown in Fig. 4.

IV. CONCLUSIONS

A three time slot TDMA based transmission protocol is proposed and investigated for inter-relay cooperative network with longer distances between source to relays and destination as well as between relays to destination. It is concluded that the proposed protocol shows better performance in terms of less BER for long range inter-relay cooperative network over Rician fading channel as compared to two time slot long range cooperative network. Our analysis also emphasize on analysis of BER when the inter-relay distance is minimum. Mathematical modeling for the proposed protocol in order to design the channel matrix is left for future work. Moreover, the proposed protocol can be further evaluated with the three time slot decode and forward inter-relay network.

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