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Impact of Relay Location of STANC Bi-Directional Transmission for Future Autonomous Internet of Things Applications

SHUJAAT ALI KHAN TANOLI[1], SYED AZIZ SHAH[2], MUHAMMAD BILAL KHAN[1], FAIZA NAWAZ[1], AMIR HUSSAIN[3], AHMED Y. AL-DUBAI[3], IMRAN KHAN[4], SYED YASEEN SHAH[5], AND AYOUB ALSARHAN[6]

[1]Department of Electrical and Computer Engineering, COMSATS University Islamabad, Islamabad 43600, Pakistan
[2]Department of Computing and Mathematics, Manchester Metropolitan University, Manchester M15 6BH, U.K.
[3]School of Computing, Edinburgh Napier University, Edinburgh EH11 4DY, U.K.
[4]Department of Electrical Engineering, University of Engineering and Technology at Mardan, Mardan 23200, Pakistan
[5]School of Computing, Engineering and Built Environment, Glasgow Caledonian University, Glasgow G4 0BA, U.K.
[6]Department of Computer Information Systems, Hashemite University, Zarqa 150459, Jordan

Corresponding author: Ahmed Y. Al-Dubai (a.al-dubai@napier.ac.uk)

ABSTRACT Wireless communication using existing coding models poses several challenges for RF signals due to multipath scattering, rapid fluctuations in signal strength and path loss effect. Unlike existing works, this study presents a novel coding technique based on Analogue Network Coding (ANC) in conjunction with Space Time Block Coding (STBC), termed as Space Time Analogue Network Coding (STANC). STANC achieves the transmitting diversity (virtual MIMO) and supports big data networks under low transmitting power conditions. Furthermore, this study evaluates the impact of relay location on smart devices network performance in increasing interfering and scattering environments. The performance of STANC is analyzed for Internet of Things (IoT) applications in terms of Symbol Error Rate (SER) and the outage probability that are calculated using analytical derivation of expression for Moment Generating Function (MGF). In addition, the ergodic capacity is analyzed using mean and second moment. These expressions enable effective evaluation of the performance and capacity under different relay location scenario. Different fading models are used to evaluate the effect of multipath scattering and strong signal reflection. Under such unfavourable environments, the performance of STANC outperforms the conventional methods such as physical layer network coding (PNC) and ANC adopted for two way transmission.

INDEX TERMS Analogue network coding, space time block code, Internet of Things, Nakagami-*m* fading channels, Rician fading channels, Rayleigh fading channels, moment generating function.

I. INTRODUCTION

The future of IoT encompasses a much broader range of applications. This technology is bringing innovation in conventional telecommunication facilities like speech, video, web browsing, social networking, etc., Authors in [1] present a survey report regarding state-of-the-art of 5G IoT, however they only provide a review on research trends and challenges faced by 5G IoT. Efficient solution to these problem are not discussed or recommended. The future wireless networks are expected to provide pervasive broadband coverage in large areas with high capacity [2]. Under realistic propagation conditions, signal loss in any wireless environment will be the combined effect of multipath scattering, path loss and rapid fluctuations in signal strength. Fading is the most fundamental characteristics of the wireless channels and attributes to the random variations in signal strength. To overcome fading and improve the diversity gain, a space-time block code can be applied [3], [4]. Cooperative network concepts have been an important area of research to combat channel fading, where signal transmissions between communicating terminals are assisted by one or more co-operative relays [5], [6]. Performance analysis of various relays and co-operative systems operating in fading channels are reported in literature [7]–[11]. Inspite of gaining significant amount of research attention and theoretical explorations

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in wired networks, the potential use of network coding in the field of co-operative wireless networks for improving throughput is also being recognized [12], [13]. The network coding schemes takes advantage of the unique and inherent characteristics, namely the broadcast nature of the wireless networks. Various wireless network coding schemes in bi-directional relay networks have been investigated and reported in [14]–[19]. In the recent years, Analogue Network Coding (ANC) has been considered as a variant of Physical Network Coding (PNC). It has also been proposed as a potential scheme to enhance network resources. ANC offers unique capacity-boosting advantage and improved throughput performance as compared to its conventional counterparts such as direct transmissions and Digital Network Coding (DNC) [20], [21]. ANC adopts a revolutionary approach, by encouraging interference of simultaneously transmitted signals which otherwise is considered harmful in wireless transmissions. In ANC approach, the communicating terminals i.e. source and destination transmit the signal simultaneously, the signals interfere with each other as the medium of communication is free space. This interfered signal is then received at the relay which is located between communicating terminals. The relay simply amplifies and broadcasts the interfered signal to both terminals. Each terminal subtract its own information from interfered signal and get the information of other terminal. By doing so, it takes only two time slots to exchange information between the communicating terminals. Amplify and forward ANC is highly robust and provides improved performance in the absence of synchronization [22]–[25].

IoT based smart devices operate in wireless environment which is a dynamic medium. Multipath scattering and path loss effect are the two major problems that may arise in this type of communication resulting in performance degradation. In order to resolve these issues, this research work contributed as in the following points:

- An innovative network coding strategy i.e. Space Time Analog Network Coding (STANC) is introduced for wireless environment in order to compensate the effect of Multipath scattering and path loss by achieving the spatial diversity and improved performance as compared to conventional PNC and direct transmission schemes that are designed for IoT applications.
- The optimal position of relay node is evaluated by deploying it at various positions between the source and destination nodes. The finest point is identified where the system performance is significantly enhanced.
- The performance of the proposed STANC based system is evaluated through analytical analysis. In doing so, the effective closed-form expressions for moment generating function (MGF), mean and second moment is derived for performance metrics SER, outage and capacity under realistic propagation scenario over Rayleigh, Nakagami and Rician fading channels that incorporate the multipath scattering and path loss effect.
- The Analytical results validate the significant performance of STANC based system for IoT applications and proved that the derived numerical expressions are tight and can be efficiently used for performance and capacity analysis by changing parameters of interest randomly and in any SNR regime.

Rest of this paper is structured as follows: The system model, which includes path loss model, channel model, transmission protocol, and Input-Output equations, is described in Section 2. Section 3 presents equivalent SNR and detailed derivations of closed-form MGF expressions. The approximate closed-form expressions of Outage probability and Ergodic capacity for both Nakagami and Rician distributions are derived in Section 4 and Section 5 respectively. Section 6 discusses the analytical results of the system performance. Finally, Section 7 concludes the paper.

II. THE PROPOSED RELAY MODEL

Fig. 1 represents the STANC relay system model. There are two terminals T_1 and T_2. Both terminals correspond with each other through $L = 2$ number of relays R_j, where $j = \{1, 2\}$. The relay terminals are positioned at different locations between source and destination terminals and operating in amplify-and-forward (AF) relaying mode. We are considering single antenna on each terminal for transmission.

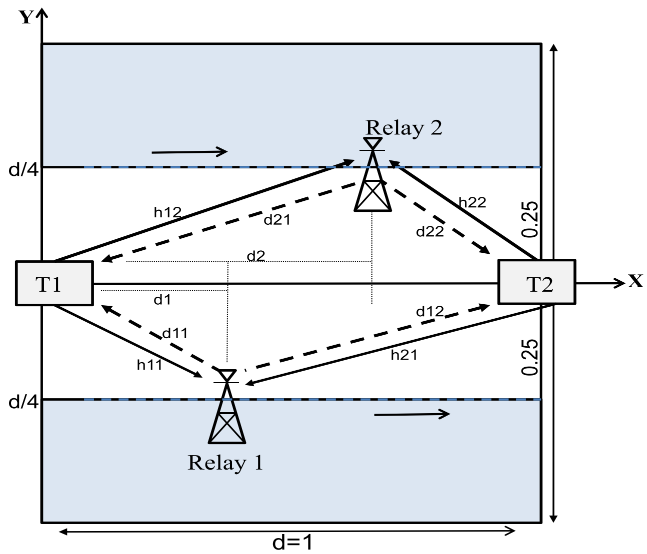

FIGURE 1. STANC System Model under path loss effect.

A. NOTATIONS

E_x, γ_i, $\mathcal{M}_{\gamma_i}(s)$ and n_{xk} represent the transmitted symbol energy by terminal X over $X \rightarrow Y$ link, equivalent signal-to-noise ratio (SNR) at i-th terminal, total unconditional moment generating function of γ_i and AWGN at terminal X in the k-th time slot, respectively.$\mathbb{E}(\cdot)$, $|\cdot|$, $\Gamma(\cdot)$ and $\psi(., ., .)$ denote the expectation operator, the magnitude of complex value, the gamma function and confluent hypergeometric function of the second kind, respectively. $W(., ., .)$ is the Whittaker function modified from confluent hypergeometric function.

$T_1 \to T_2$ describes the link from source terminal T_1 to T_2. α_{ij}, K_{ij} and m represent the multipath gain coefficient, Rician-K factor, Nakagami-m factor, respectively from i-th terminal to j-th relay. T_i and R_j denote the i-th terminal and j-th relay, respectively.

B. PATH LOSS MODEL

Here, we are considering the projection of R_j, it is on a straight line from source to destination terminal as shown in the Fig. 1. The total distance between source terminal (T_1) to destination terminal (T_2) is normalized to $d = 1$, the perpendicular distance between T_1 and R_1 is $d/4$ and the distance between T_1 and projection of R_1 on the horizontal line is d_1. The exact distances of R_1 from T_1 and T_2 is denoted by d_{11} and d_{12} respectively and is given by Pythagorean theorem as $d_{11} = \sqrt{d_1^2 + 0.25^2}$ and $d_{12} = \sqrt{(1-d_1)^2 + 0.25^2}$. Similar symmetry is from R_2 to T_1 and T_2.

The faded SNR is attenuated by factor $d_{11}^{-\mu}$ and $d_{12}^{-\mu}$ for first-hop and the second-hop, respectively, and are influenced by the path loss effect. This influence of the transmission medium is described by an empirical constant which recognized itself as path loss exponent (μ). Path loss exponent defines the limits for different sort of signal propagation depending upon the radio environment [26]. For example in open free space, μ is set to 2, and its range extend to 5 in case of outdoor propagation and become larger when obstructions are present. In this system model, we concentrate on the practical example of a sub urban area with $\mu = 3$.

C. CHANNEL MODEL

It is assumed that the channel state information (CSI) is only available at the receiver terminal which is obtain by estimating the whole channel link only at the receiver terminal through training based channel estimation technique as report in [27]. The transmitter of the system is unaware about the channel information. The fading coefficients are also assumed to be same during two stages. It is also assumed that the channel link from both terminals to relays are Nakagami-m and Rician-K identical and independently distributed (i.i.d). The gamma distributed random variables is denoted by $\alpha_{ij} = |h_{ij}|^2$ where h_{ij} is the fading magnitude of the link from i-th terminal $i = \{1, 2\}$ to j-th relay $j = \{1, 2\}$. The probability density function of α_{ij} for Nakagami-m distribution is given in [28] as:

$$f(\alpha_{ij}) = \frac{m^m \alpha_{ij}^{m-1}}{\Omega_{ij}^m \Gamma(m)} \exp\left(\frac{-m\alpha_{ij}}{\Omega_{ij}}\right) \tag{1}$$

where $\Gamma(.)$ represent gamma function. Here we consider mean channel power $E\{|h_{1j}|^2\} = \Omega_{1j}$. Now by using path loss model $\Omega_{ij} \propto d_{xy}^{-\mu}$ [29] where μ is the path loss exponent and d_{xy} is the distance of link $X \to Y$.

The signal experiences the channel fading problem because of the reason that terminal, relay and destination are located in the same fading environment. Here, the fading conditions are described by the fading parameters m as, when $m = 1$, it corresponds to the area which is heavily populated and both the relays and the destination terminals experience severe multipath fading, resulting in exponential distribution (Rayleigh fading). Similarly $m = 2$ corresponds to moderate multipath scenario with less scattering and the signal strength variations are reduced as compared to Rayleigh Fading.

Similarly, for Rician-K distribution, the probability density function (PDF) of α_{ij} by using [32] is given as:

$$f(\alpha_{ij}) = \frac{(1+K_{ij})}{\Omega_{ij}} \exp\left(\frac{-(1+K_{ij})\alpha_{ij} - K_{ij}}{\Omega_{ij}}\right) \times I_0\left(\frac{2\sqrt{(K_{ij}(1+K_{ij}))\alpha_{ij}}}{\Omega_{ij}}\right) \tag{2}$$

where K_{ij} denotes the Rician fading factor of the link from i-th terminal to j-th relay. $I_0(.)$ is the zero-th order modified Bessel function of the first kind. Similar to Nakagami-$m = 1$, the Rician distribution becomes the Rayleigh distribution at $K_{ij} = 0$.

D. TRANSMISSION PROTOCOL

The signalling of proposed protocol is carried out in two stages as shown in Table 1. From the table, both the terminals T_1 and T_2 simultaneously transmitted their signal x_{ik} to relay R_j where $j = \{1, 2\}$ in first stage where x_{ik} represents the signal of k-th symbol from i-th terminal. Due to broadcast nature of wireless medium, the wireless channel naturally mixes the signals that are transmitted from both terminals. This exploits the basic analog network coding scheme (ANC) [21] as given in Table 1.

TABLE 1. Two stage transmission protocol.

Stage 1	Stage 2
$T_1, T_2 \to R_j$	$R_j \to T_1, T_2$

And In the second stage, the j-th relay amplifies the combined signal which contained the information of both terminals (detailed describe in next section). This signal is then broadcasted as a combined signal to the terminals. When the Alamouti codes are implemented, each stage is repeated twice for the conjugate and negative conjugate of the signal x_{ik}. The Alamouti codes for i-th terminal is best described by the matrix given as:

$$\mathbf{C_i} = \begin{pmatrix} x_{i1} & x_{i2} \\ -x_{i2}^* & x_{i1}^* \end{pmatrix}$$

The entire signaling of the proposed protocol takes place in total of 6 time slots for transmitting 4 signals, as shown in Table 2. In the first time slot terminals T_1 and T_2 transmits x_{11} and x_{21} respectively to R_1. In second time slot, both terminals again transmits x_{12} and x_{22} respectively to R_2. R_1 and R_2 amplify and forward the combined signals to both T_1 and T_2 on two different sub carrier in third time

TABLE 2. Six time slot transmission protocol.

Time slot	Terminal i=1,2 Relay j=1,2	Symbol
1	$T_1, T_2 \rightarrow R_1$	x_{11}, x_{21}
2	$T_1, T_2 \rightarrow R_2$	x_{12}, x_{22}
3	$T_1, T_2 \leftarrow R_1, R_2$	r_{ij}
4	$T_1, T_2 \rightarrow R_2$	x_{11}^*, x_{21}^*
5	$T_1, T_2 \rightarrow R_1$	$-x_{12}^*, -x_{22}^*$
6	$T_1, T_2 \leftarrow R_1, R_2$	r_{ij}^*

slot. In fourth and fifth time slots, the terminals T_1 and T_2 again transmits the conjugate x_{11}^* and x_{21}^* respectively to R_2 and negative conjugate $-x_{12}^*$ and $-x_{22}^*$ respectively to R_1. R_1 and R_2 finally broadcast the amplified version of received combined signals on two orthogonal channels to T_1 and T_2 in sixth time slot.

E. INPUT-OUTPUT EQUATIONS

1) STAGE 1

The signals x_{i1} and x_{i2} are transmitted by T_i (where $i \in \{1, 2\}$) to the relays R_1 and R_2, respectively. The signals received at R_1 and R_2 are given by:

$$y_{r_1} = h_{11}\sqrt{E_1}x_{11} + h_{21}\sqrt{E_2}x_{21} + n_{r_1} \tag{3}$$
$$y_{r_2} = h_{12}\sqrt{E_1}x_{12} + h_{22}\sqrt{E_2}x_{22} + n_{r_2} \tag{4}$$

where $n_{r_j} \sim \mathcal{CN}(0, N_0)$ and E_i is the transmitted symbol energy at i-th terminal.

2) STAGE 2

In this stage, the j-th relay normalizes the received signal by a factor of $\sqrt{E(|y_{r_j}|^2)}$ and broadcost the combined signal to $T_1$and T_2. The amplification factor (β_j) at the j-th relay is given by

$$\beta_j = \sqrt{\frac{E_{r_j}}{\Omega_{1j}E_1 + \Omega_{2j}E_2 + N_0}} \tag{5}$$

where E_{r_j} is the average transmitted symbol energy at R_j and mean channel power $E\{|h_{1j}|^2\} = \Omega_{1j}$. Now by using path loss model $\Omega_{ij} \propto d_{xy}^{-\mu}$ where μ is the path loss exponent and d_{xy} is the distance of link $X \rightarrow Y$. The two terminals T_i ($i \in \{1, 2\}$), receive the signal from j-th relay through two orthogonal channels and the general form of received signal is given as:

$$r_{ij} = h_{ij}\beta_j y_{r_j} + n_i \tag{6}$$

where $n_i \sim \mathcal{CN}(0, N_0)$ at i-th terminal T_i. T_i knows x_{i1} and h_{ij}. The terminals know self information so by removing self information, the terminals get the information of other terminal and we assume that each terminal knows the value of β_j.

$$y_{ij} = r_{ij} - |h_{ij}|^2\beta_j\sqrt{E_i}x_{ik} \tag{7}$$

Hence, the recovered signals at the ith terminal where $i \in \{1, 2\}$ from both relays in second phase is given as:

$$y_{11} = \beta_1 h_{11}h_{21}\sqrt{E_2}x_{21} + \tilde{n}_{11} \tag{8}$$
$$y_{12} = \beta_2 h_{12}h_{22}\sqrt{E_2}x_{22} + \tilde{n}_{12} \tag{9}$$
$$y_{21} = \beta_1 h_{11}h_{21}\sqrt{E_1}x_{11} + \tilde{n}_{21} \tag{10}$$
$$y_{22} = \beta_2 h_{12}h_{22}\sqrt{E_1}x_{12} + \tilde{n}_{22} \tag{11}$$

where $\tilde{n}_{ij} = \beta_j h_{ij}n_{r_j} + n_i$, having variance $\left(\beta_j^2|h_{ij}|^2 + 1\right)N_0$.

Similarly,T_i transmits the signals conjugate x_{i1}^* and negative conjugate $-x_{i2}^*$ where $i \in \{1, 2\}$ to the relays R_1 and R_2, respectively. The signals received at i-th terminal through R_1 and R_2 are given by:

$$y_{11}^* = -\beta_1 h_{11}h_{21}\sqrt{E_2}x_{22}^* + \tilde{n}_{11}^* \tag{12}$$
$$y_{12}^* = \beta_2 h_{12}h_{22}\sqrt{E_2}x_{21}^* + \tilde{n}_{12}^* \tag{13}$$
$$y_{21}^* = \beta_1 h_{11}h_{21}\sqrt{E_1}x_{12}^* + \tilde{n}_{21}^* \tag{14}$$
$$y_{22}^* = -\beta_2 h_{12}h_{22}\sqrt{E_1}x_{11}^* + \tilde{n}_{22}^* \tag{15}$$

where $\tilde{n}_{ij}^* = \beta_j h_{ij}n_{ij} + n_i$, having variance $\left(\beta_j^2|h_{ij}|^2 + 1\right)N_0$.

3) MATRIX REPRESENTATION

The received signals at T_2 can be represented in matrix form as:

$$Y = HX + \acute{N} \tag{16}$$

where

$$Y^T = \begin{pmatrix} y_{21} & y_{22} & y_{21}^* & y_{22}^* \end{pmatrix}_{1\times 4}$$
$$H^T = \begin{pmatrix} A_{21} & 0 & A_{22}^* & 0 \\ 0 & A_{22} & 0 & -A_{21}^* \end{pmatrix}_{2\times 4}$$
$$X^T = \begin{pmatrix} x_{11} & x_{12} \end{pmatrix}_{1\times 2}$$
$$\acute{N}^T = \begin{pmatrix} n_{21} & n_{22} & n_{22}^* & n_{21}^* \end{pmatrix}_{1\times 4}$$

and

$$A_{21} = \frac{\beta_1}{\omega_{21}}h_{11}h_{21}\sqrt{E_1}$$
$$A_{22} = \frac{\beta_2}{\omega_{22}}h_{12}h_{22}\sqrt{E_1}$$

where

$$\omega_{ij} = \sqrt{\left(\beta_j^2|h_{ij}|^2 + 1\right)}$$

is a normalizing factor at the receiver. By multiplying H^H on both side of (16), we arrive at:

$$H^H Y = \left(|A_{21}|^2 + |A_{22}|^2\right)\begin{pmatrix} x_{11} \\ x_{12} \end{pmatrix} + H^H\acute{N} \tag{17}$$

III. PERFORMANCE ANALYSIS

A. STANC EQUIVALENT SNR

Maximal ratio combining (MRC) is used at Terminal T_i, to combine the signals received from L relays. where

$$|A_{22}|^2 = \frac{{\beta_2}^2|h_{12}|^2|h_{22}|^2E_1}{\omega_{22}}$$

In general, the STANC equivalent SNR at i-th terminal can be expressed as:

$$\gamma_i = \frac{1}{N_0}\sum_{j=1}^{L}|A_{ij}|^2 = \sum_{j=1}^{L}\frac{\bar{\gamma}\beta_j^2|h_{1j}|^2|h_{2j}|^2}{\beta_j^2|h_{ij}|^2+1} \tag{18}$$

where $\bar{\gamma} = \frac{E}{N_0}$ and $E = E_1 = E_2$.

B. GENERAL STANC MOMENT GENERATING FUNCTION

In this section, we derive the expressions for unconditional MGFs to evaluate the above average SER for ANC communication over Nakagami-m, Rician and Rayleigh fading channels. The MGF of γ_i is given as

$$\mathcal{M}_{\gamma_2}(s) = \mathbb{E}_{\alpha_{1j},\alpha_{2j}}\left(e^{-s\gamma_2}\right) \tag{19}$$

We assume that α_{1j} and α_{2j} are independent random variables. The MGF for given α_{2j} is represented as:

$$\mathcal{M}_{\gamma_2|\alpha_{2j}}(s) = \mathbb{E}_{\alpha_{1j}}\left(e^{-\sum_{j=1}^{L}\frac{\beta_j^2\bar{\gamma}\alpha_{1j}\alpha_{2j}}{\beta_j^2\alpha_{2j}+1}s}\right). \tag{20}$$

1) FOR NAKAGAMI-m FADING CHANNELS

As $\alpha_{ij} = |h_{ij}|^2$ (for $i,j = \{1,2\}$) are gamma distributed random variables, (20) can be written as

$$\mathcal{M}_{\gamma_2|\alpha_{2j}} = \prod_{j=1}^{L}\frac{1}{\left(1+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}\alpha_{2j}}{(\beta_j^2\alpha_{2j}+1)m}s\right)^m} \tag{21}$$

(20) can also be written as

$$\mathcal{M}_{\gamma_2|\alpha_{2j}} = \frac{1}{\left(1+\frac{\Omega_{1j}\bar{\gamma}}{m}s\right)^{Lm}}\prod_{j=1}^{L}\left(\frac{\alpha_{2j}+\frac{1}{\beta_j^2}}{\alpha_{2j}+\frac{1}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{m}s}}\right)^m \tag{22}$$

(22) can be further simplified as:

$$\mathcal{M}_{\gamma_2|\alpha_{2j}} = \frac{1}{\left(1+\frac{\Omega_{1j}\bar{\gamma}}{m}s\right)^{Lm}}\prod_{j=1}^{L}\left(1+G(\alpha_{2j})\right) \tag{23}$$

where $G(\alpha_{2j}) = \frac{g_{m-1}\alpha_{2j}^{m-1}+\cdots+g_1\alpha_{2j}+g_0}{(\alpha_{2j}+\frac{1}{\beta_j^2+\frac{\beta_j^2\bar{\gamma}}{m}s})^m}$, with $g_{m-1},\cdots,g_1,g_0$ as real constants. The unconditional MGF is obtained by averaging (23) over α_{2j} and given in (24), where $C_{v,j}$ and $\psi(\cdot,\cdot,\cdot)$ is the confluent hypergeometric function of the second kind.

$$\begin{aligned}\mathcal{M}_{\gamma_2}(s) = \frac{1}{\left(1+\frac{\Omega_{1j}\bar{\gamma}}{m}s\right)^{Lm}}\prod_{j=1}^{L}1 &+ \sum_{v=1}^{m}\frac{m^m C_{v,j}}{\Omega_{2j}^m}\left(\frac{1}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{m}s}\right)^{m-v}\\ &\psi\left(m, m-v+1, \frac{m}{\Omega_{2j}\beta_j^2+\frac{\Omega_{2j}\Omega_{1j}\beta_j^2\bar{\gamma}}{m}s}\right)\end{aligned} \tag{24}$$

where $C_{v,j}$ is given as,

$$\begin{aligned}C_{v,j} = \frac{1}{(m-v)!}\frac{d^{m-v}}{d\alpha_{2j}^{m-v}}&\left(\left(\alpha_{2j}+\frac{1}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{m}s}\right)^m\right.\\ &\left.G(\alpha_{2j})\right)|_{\alpha_{2j}=-\frac{1}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{m}s}}\end{aligned}$$

2) FOR RICIAN FADING CHANNELS

The conditional MGF for given α_{2j} of the SNR for STANC over Rician fading channels is given by:

$$\begin{aligned}\mathcal{M}_{\gamma_2|\alpha_{2j}}(s) = \prod_{j=1}^{L}&\frac{(1+K_{1j})}{(1+K_{1j})+\frac{\Omega_{1j}\bar{\gamma}\alpha_{2j}}{\beta j^2\alpha_{2j}+1}s}\\ &\exp\left\{-\frac{K_{1j}\frac{\Omega_{1j}\bar{\gamma}\alpha_{2j}}{\beta_j^2\alpha_{2j}+1}s}{(1+K_{1j})+\Omega_{1j}\bar{\gamma}\alpha_{2j}\beta_j^2\alpha_{2j}+1s}\right\}\end{aligned} \tag{25}$$

where K_{1j} and K_{2j} are the Rician factor for link $T_1 \rightarrow R_j$ and $T_2 \rightarrow R_j$ respectively. The unconditional MGF is obtained by averaging (25) over α_{2j} and given as in (32), shown at the bottom of the next page.

3) FOR RAYLEIGH FADING CHANNELS

The unconditional MGF of the SNR for $K = 0$ or $m = 1$ (special case: Rayleigh) is given as

$$\mathcal{M}_{\gamma_2}(s) = \prod_{j=1}^{L}\beta_j^2 k_j(e^{k_j}Ei(-k_j)(k_j-1/\beta_j^2)+1) \tag{26}$$

where $k_j = \frac{1}{\beta_j^2(1+\bar{\gamma}s)}$ and $Ei(.)$ is an exponential integral function.

C. AVERAGE SER

The SER equations (P_e) for M-PSK and M-QAM modulation are as given below.

1) M-PSK: The average SER for M-PSK is given in [32] as:

$$P_{e(MPSK)} = \frac{1}{\pi}\int_0^{(M-1)\pi/M}\mathcal{M}_{\gamma_i}\left(\frac{g_{PSK}}{sin^2\theta}\right)d\theta \tag{27}$$

where $g_{PSK} = sin^2(\pi/M)$.

2) M-QAM: The average SER for M-QAM is given in [32] as:

$$\begin{aligned}P_{e(MQAM)} = \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\pi/2}\mathcal{M}_{\gamma_i}\left(\frac{g_{QAM}}{sin^2\theta}\right)d\theta\\ -\frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\pi/4}\mathcal{M}_{\gamma_i}\left(\frac{g_{QAM}}{sin^2\theta}\right)d\theta\end{aligned} \tag{28}$$

where $g_{QAM} = \frac{3}{2(M-1)}$.

IV. OUTAGE PROBABILITY

We characterize the STANC performance analysis in terms of the outage probability. In particular, we present a unified approach to derive the CDF of γ_i, under the assumption that CSI is only available at the receiver and the transmitter does not know the channel information, in Nakagami-m and Rician-K fading channel conditions. The outage probability (P_{Outage}) is evaluated by relying on these numerical results and is defined as the probability that the instantaneous total SNR ($\gamma_i = \gamma_{MRC}$) falls below the given threshold SNR (γ_{th}).

$$P_{Outage} = P[\gamma_i \leq \gamma_{th}]$$

P_{Outage} is the CDF of γ_i evaluated at γ_{th}:

$$P_{Outage} = f_{\gamma_i}(\gamma_{th}) = \Im^{-1}\left(\mathcal{M}_{\gamma_i}(s)/s\right)|_{\gamma_{th}} \tag{29}$$

where, $\Im(.)$ denotes the inverse Laplace transform. The procedure to evaluate the inverse Laplace here is the same as in [31]. The outage probability can be evaluated as

$$\begin{aligned} P_{Outage} = & \frac{2^{-Q}e^{A/2}}{\gamma_{th}} \sum_{q=0}^{Q} \binom{Q}{q} \\ & \times \sum_{n=0}^{N+q} \frac{(-1)^n}{\beta_n} \Re\left\{ \frac{\mathcal{M}_{\gamma_i}\left(-\frac{A+2\pi jn}{2\gamma_{th}}\right)}{\frac{A+2\pi jn}{2\gamma_{th}}} \right\} \\ & + E(A,N,Q) \end{aligned} \tag{30}$$

where $\Re\{.\}$ denotes the real part, $E(A,Q,N)$ is the overall error term approximately bounded by

$$\begin{aligned} |E(A,N,Q)| \simeq & \frac{e^A}{1-e^{-A}} + \left| \frac{2^{-Q}e^{A/2}}{\gamma_{th}} \times \right. \\ & \sum_{q=0}^{Q} (-1)^{N+1+q} \binom{Q}{q} \times \\ & \left. \Re\left\{ \frac{\mathcal{M}_{\gamma_i}\left(-\frac{A+2\pi j(N+1+q)}{2\gamma_{th}}\right)}{\frac{A+2\pi j(N+1+q)}{2\gamma_{th}}} \right\} \right| \end{aligned} \tag{31}$$

Q is the number of partial series of length $N, N+1, \cdots, N+Q$ respectively, used for binomial average for convergence by using Euler summation technique and

$$\beta_n = \begin{cases} 2 & \text{if } n = 0 \\ 1 & \text{if } n = 1, 2, \cdots, N \end{cases}$$

where $W(.,.,.)$ is the Whittaker function modified from confluent hypergeometric function [30].

V. ERGODIC CAPACITY ANALYSIS

The capacity of a system is more important to analyze the performance and efficiency of the system under path loss affect and different fading environment. In this regard, we present an ergodic capacity of STANC channel approximated by a Gaussian random variable assuming that CSI is only available at the receiver and transmitter have no knowledge of channel.

In [33] the ergodic capacity is defined as the expectation of the information rate over the channel distribution between the source destination link and is given as:

$$C_{erg} = \mathbb{E}\left\{\frac{1}{L}\log(1+\gamma_2)\right\} \tag{33}$$

By applying the Jensen's Inequality approach as reported in [34] the ergodic capacity can be upper bounded as:

$$C_{erg} \leq \frac{1}{L}\log\left(1+\mathbb{E}\{\gamma_2\}\right) \tag{34}$$

where γ_2 is given by (18). Based on the Gaussian approximation as in [21], we present the STANC ergodic capacity analysis over Nakagami and Rician fading channels that only required the mean and variance that can be evaluated by:

$$\mathbb{E}\{\gamma_{ij}\} = \int_0^\infty \gamma_{ij} f(\alpha_{ij}) d\gamma_{ij} \tag{35}$$

$$\mathbb{E}\left\{\gamma_{ij}^2\right\} = \int_0^\infty {\gamma_{ij}}^2 f(\alpha_{ij}) d\gamma_{ij} \tag{36}$$

$$\begin{aligned} \mathcal{M}_{\gamma_2}(s) = & \prod_{j=1}^{L}\sum_{k=0}^{\infty}\sum_{n=0}^{k}\binom{k}{n} \frac{K_{2j}^{n}K_{1j}^{k-n}(1+K_{2j})^{\frac{k}{2}}(1+K_{1j})^{n-k}}{n!(k-n)!\Omega_{2j}^{\frac{k}{2}}\Omega_{1j}^{n-k}} \times \frac{(\bar{\gamma}s)^{k-n}}{\beta_j^k\left(1+\frac{\Omega_{1j}\bar{\gamma}}{(1+K_{1j})}s\right)^{\frac{3k}{2}-n+1}} \\ & \exp\left\{ -K_{2j} - \frac{\frac{K_{1j}}{(1+K_{1j})}\Omega_{1j}\bar{\gamma}s}{1+\frac{\Omega_{1j}\bar{\gamma}}{(1+K_{1j})}s} + \frac{\frac{1+K_{2j}}{\Omega_{2j}}}{2\left(\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{(1+K_{1j})}s\right)} \right\} \\ & \times \left[W_{-\frac{k}{2},-n+\frac{k}{2}-\frac{1}{2}}\left(\frac{\frac{1+K_{2j}}{\Omega_{2j}}}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{(1+K_{1j})}s}\right) - \left(\frac{1}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{(1+K_{1j})}s} - \frac{1}{\beta_j^2}\right) \right. \\ & \left. \times \left(\beta_j^2\left(\frac{1+K_{2j}}{\Omega_{2j}}\right)\left(1+\frac{\Omega_{1j}\bar{\gamma}}{(1+K_{1j})}s\right)\right)^{\frac{1}{2}} W_{-\frac{k}{2}-\frac{1}{2},-n+\frac{k}{2}}\left(\frac{\frac{1+K_{2j}}{\Omega_{2j}}}{\beta_j^2+\frac{\Omega_{1j}\beta_j^2\bar{\gamma}}{(1+K_{1j})}s}\right) \right] \end{aligned} \tag{32}$$

Here, $\gamma_{ij} = \frac{\bar{\gamma}\beta_j^2|h_{1j}|^2|h_{2j}|^2}{\beta_j^2|h_{ij}|^2+1}$ and $f(\alpha_{ij})$ represents the probability density function (PDF) of α_{ij}.

A. MEAN AND SECOND MOMENT OVER NAKAGAMI-M FADING CHANNELS

The PDF for Nakagami-m distribution is given in [28] as:

$$f(\alpha_{ij}) = \frac{m^m \alpha_{ij}^{m-1}}{\Omega_{ij}^m \Gamma(m)} \exp\left(\frac{-m\alpha_{ij}}{\Omega_{ij}}\right) \tag{37}$$

where $\alpha_{ij} = |h_{ij}|^2$, $\Gamma(.)$ is a gamma function. Here we consider $E\{|h_{1j}|^2\} = \Omega_{1j}$. Now by using path loss model $\Omega_{ij} \propto d_{xy}^{-\mu}$ where μ is the path loss exponent and d_{xy} is the distance of link $X \rightarrow Y$. For $m = 1$ the Nakagami-m distribution becomes the exponential distribution.

Now by evaluating (35), (36), the mean and second moment of γ_{ij} over Nakagami-m fading channels are given as:

$$\mathbb{E}\{\gamma_{ij}\} = \frac{\Omega_{2j} m^{m+1}}{\Omega_{1j}^m \beta_j^{2m}} \bar{\gamma} \exp\left\{\frac{m}{\Omega_{1j}\beta_j^2}\right\} \Gamma\left(-m, \frac{m}{\Omega_{1j}\beta_j^2}\right) \tag{38}$$

$$\mathbb{E}\left\{\gamma_{ij}^2\right\} = \frac{\Omega_{2j}^2 \bar{\gamma}^2 m^{m+2}(1+m)^2}{\Omega_{1j}^m \beta_j^{2m}} \psi\left(m+2, m+1; \frac{m}{\Omega_{1j}\beta_j^2}\right) \tag{39}$$

where $\psi(., ., .)$ represent the confluent hypergeometric function of the second kind.

B. MEAN AND SECOND MOMENT OVER RICIAN-K FADING CHANNELS

The PDF of α_{ij} for Rician-K distribution by using [32], is given as:

$$f(\alpha_{ij}) = \frac{(1+K_{ij})}{\Omega_{ij}} \exp\left(\frac{-(1+K_{ij})\alpha_{ij} - K_{ij}}{\Omega_{ij}}\right) \times I_0\left(\frac{2\sqrt{(K_{ij}(1+K_{ij}))\alpha_{ij}}}{\Omega_{ij}}\right) \tag{40}$$

where K_{ij} is the Rician fading factor of the link from i-th to j-th terminal and $I_0(.)$ is the zero-th order modified Bessel function of the first kind.

Similarly, we compute the mean and second moment of γ_{ij} over Rician-K fading channels by substituting (40) in (35) and (36) are given as:

$$\mathbb{E}\{\gamma_{2j}\} = \sum_{n=0}^{\infty} \frac{\Omega_{1j}\bar{\gamma}}{\Omega_{2j}^{n+1}\beta_j^{2n+2}} \frac{K_{2j}^n(1+K_{2j})^{n+1}}{(n!)^2} \exp\left\{-K_{2j} + \frac{1+K_{2j}}{\Omega_{2j}\beta_j^2}\right\} \Gamma(n+2)\Gamma\left(-1-n, \frac{1+K_{2j}}{\Omega_{2j}\beta_j^2}\right) \tag{41}$$

$$\mathbb{E}\left\{\gamma_{2j}^2\right\} = \sum_{n=0}^{\infty} \frac{\Omega_{1j}\bar{\gamma}^2}{\Omega_{2j}^{n+1}\beta_j^{2n+2}} \times \frac{K_{2j}^n(1+K_{2j})^{n+1}(2+4K_{1j}+K_{1j}^2)(1+K_{1j})^{-2}}{(n!)^2} \times \Gamma(n+3)\exp\left\{-K_{2j}\right\} \psi\left(n+3, n+2; \frac{1+K_{2j}}{\Omega_{2j}\beta_j^2}\right) \tag{42}$$

C. THE SECOND-ORDER APPROXIMATED ERGODIC CAPACITY

To achieve the second-order approximation expression for C_{erg}, the Taylor expansion of $\ln\left[1+\mathbb{E}\left\{\gamma_{ij}\right\}\right]$ with the mean of $\mathbb{E}\left\{\gamma_{ij}\right\}$ resort to the numerical computation approach, given in [35] as:

$$C_{erg} \approx \frac{1}{L}\log_2 e\left(\ln\left[1+\sum_{j=1}^{L}\mathbb{E}\left\{\gamma_{ij}\right\}\right] - \frac{\sum_{j=1}^{L}\mathbb{E}\left\{\gamma_{ij}^2\right\} + 2\sum_{j=1}^{L}\sum_{k=j+1}^{L}\mathbb{E}\left\{\gamma_{ij}\right\}\mathbb{E}\left\{\gamma_{ik}\right\}}{2\left(1+\sum_{j=1}^{L}\mathbb{E}\left\{\gamma_{ij}\right\}\right)^2} - \frac{\left(\sum_{j=1}^{L}\mathbb{E}\left\{\gamma_{ij}\right\}\right)^2}{2\left(1+\sum_{j=1}^{L}\mathbb{E}\left\{\gamma_{ij}\right\}\right)^2}\right) \tag{43}$$

Consequently, by substituting (38), (39) in (43), we approximated the second-order ergodic capacity for STANC relay network over Nakagami fading channels and similarly by substituting (41),(42) in (43) we obtained, the second-order approximated ergodic capacity for Rician fading channel.

VI. RESULTS AND DISCUSSIONS

Analytical study results are used to analyse the performance of proposed STANC system in terms of SER, Outage and capacity over Nakagami and Rician fading channels. Initially, the SER performance of two sources in STANC relay network is evaluated. For simplicity, the SER performance is used only at T_2 due to the symmetrical system model, as SER performance at T_1 is same.

For obtaining analytical results, various assumptions are made. The channel coefficients are assumed to remain same during the two transmission stages, as discussed in Section 2. Nakagami-m and Rician-K channel distributions are consider for the uncorrelated propagation channel coefficients. It is also assumed that the perfect CSI is only available at the receiver and the transmitter does not have channel information. The modulation schemes BPSK, QPSK and 16- QAM are consider for ideal coherent modulation and demodulation. The fading channel gains are computed using the path loss model $d_{xy}^{-\mu}$, with $\mu = 3$ (suburban environment). Here, the distances $d_{xy} \in [0-1]$.

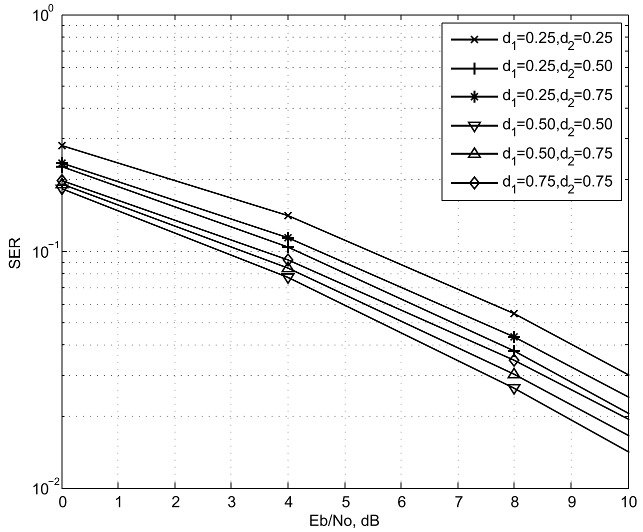

FIGURE 2. SER analysis of STANC over Rayleigh fading channels with QPSK constellation size at distance d_1 and d_2 from the relays ($L = 2$).

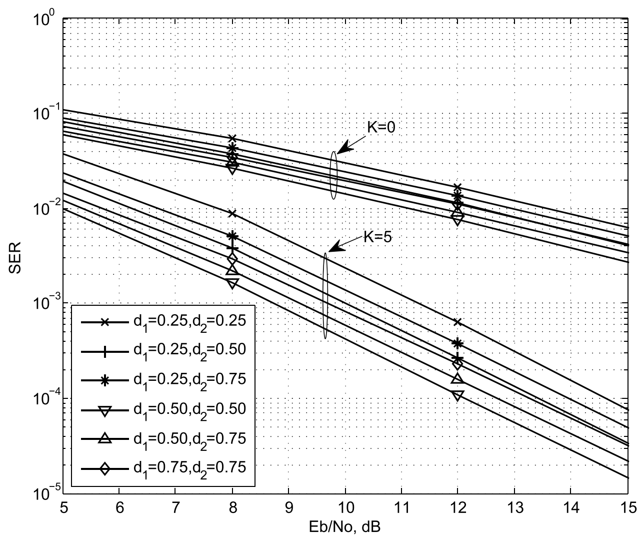

FIGURE 3. Performance comparison of STANC schemes under Relay positioning over Rician fading channels.

The precise SER performance is analytically derived in section 3. Similarly, we achieve analytical results for system outage by using SER and MGF respectively derived in section 3 and we derived the mean and second moment for ergodic capacity as discussed in section 6 over Nakagami and Rician fading channels respectively. The SER and capacity results are drawn w.r.t. the average SNR as well as relay positions, the result for ergodic capacity are drawn in 3-D w.r.t. different relay positions and the outage results are only drawn w.r.t. SNR.

A. SER PERFORMANCE VS RELAY LOCATION

Fig. 2 and Fig. 3 shows the behaviour of SER versus SNR of STANC cooperative network with the different combination of relay location, d_1 and d_2. The SER curves are shown for QPSK modulation schemes and for Rayleigh and Rician

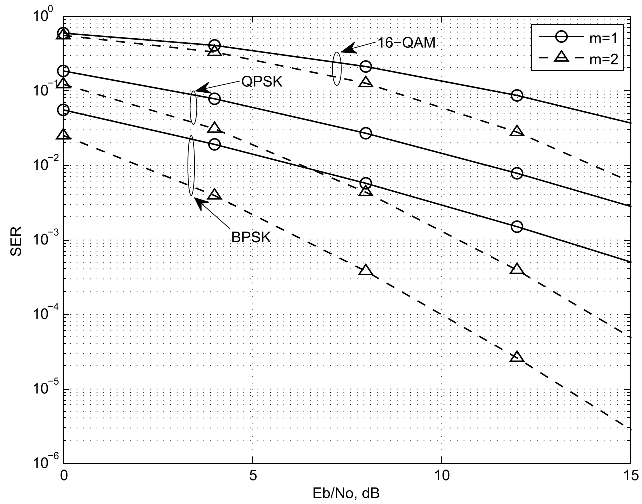

FIGURE 4. SER analysis of STANC over Nakagami fading channels under path loss effect for ($L = 2$).

fading channel respectively. Fig. 3 shows that the increase in Rician-K factor improves the performance of the system in terms of SER, especially for high SNR values. Both figures depict the STANC performance in terms of SER curves at six positions of the relays. Here, we assume the location of relay (R_j), $j \in (1, 2)$ is on a line between source and destination as shown in fig.1. The path distance between source terminal (T_1) to destination terminal (T_2) is normalized to 1 and the distances from R_1 to T_1 and T_2 is denoted by d_{11} and d_{12} respectively. Where $d_{11} = \sqrt{d_1^2 + 0.25^2}$ and $d_{12} = \sqrt{(1 - d_1)^2 + 0.25^2}$. Similar symmetry is from T_1 and T_2 to R_2. The curves show that the STANC system performs best with $d_1 = 0.5$ and $d_2 = 0.5$ (relays located in the middle of $T_1 \rightarrow T_2$) at lower SNR values. It is also observed that the performance of the system is worst when both the relays are located closer to the source terminal $d_1 = 0.25$ and $d_2 = 0.25$.

Fig. 4 shows numerical analysis for Nakagami $m = 1, 2$ fading channels. These curves present the performance of the system with 2 relays operating in AF mode under path loss effect. The received signal at the destination terminal, which carry modulated symbol brings significant performance improvement by exploiting spatial diversity gain through STANC. It can be seen from Fig. 4 that performance of STANC improves as move from higher order modulation to lower order modulation. Due to the decreased constellation size e.g 16-QAM, QPSK and BPSK, the average minimum distance is expected to increase, thus resulting in a reduced SER due the resilience of lower rate modulations.

Fig. 5 shows the average SER performance with BPSK and QPSK signal over nakagami fading channel, where AF STANC protocol is used at the relay. Fig. 5 shows that the increase in Nakagami-m factor improves the performance of the system in terms of SER, especially for high SNR values. The figure also illustrates that better performance will be achieved when the relay is near the middle of the source

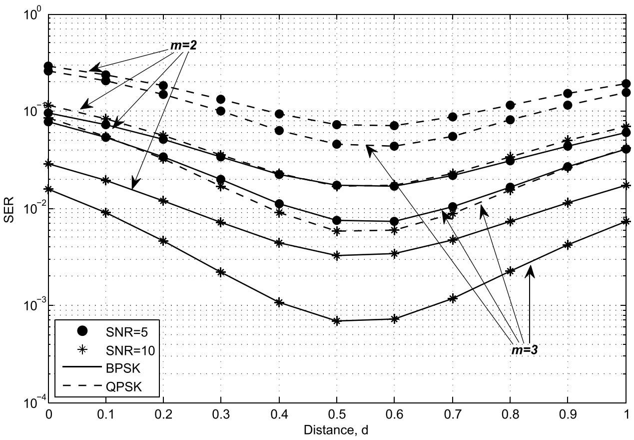

FIGURE 5. **Performance comparison of STANC schemes in terms of SER Vs Relay Distance over Nakagami fading channels.**

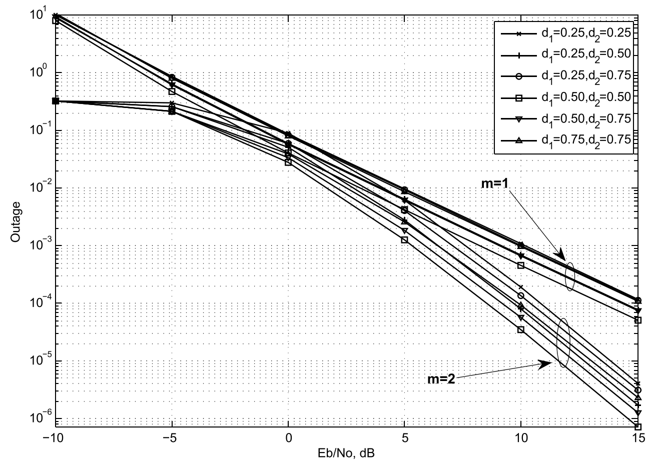

FIGURE 6. **STANC outage probability vs relay positioning over Nakagami-$m = 1, 2$ fading channels, for QPSK modulation scheme.**

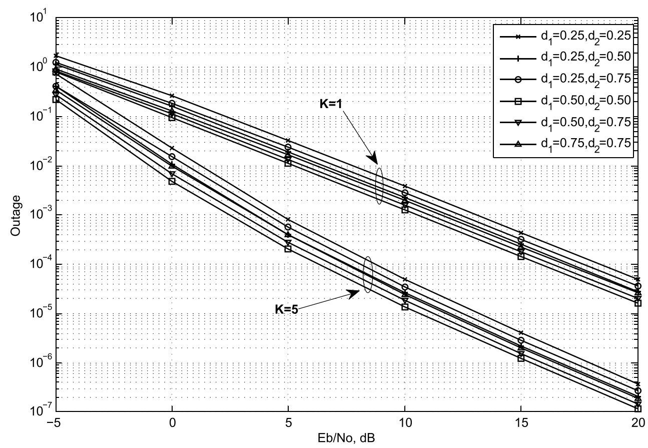

FIGURE 7. **STANC outage probability vs relay positioning over Rician-$K = 1, 5$ fading channels, for QPSK modulation scheme.**

and the destination terminals. We find that when $d = 0.5$ the SER has the minimal value for a given SNR. It can be seen that the optimal location of AF protocol with BPSK and QPSK signals are the same, i.e. $d = 0.5$ which is similar to the conclusion in [36], for one way cooperative channel.

B. OUTAGE PROBABILITY VS RELAY LOCATION

In this section, the performance of STANC network is evaluated under various channel parameters. In particular, the effect of relays is analysed with asymmetrical hops on the end-to-end outage probability. The Nakagami and Rician fading parameters are varied and the per-hop average faded SNR γ_i and $i = 1, 2$. It is assume that the distance between source terminal T_1 and destination terminal T_2 is normalized to unity as shown in Fig. 1. In addition, the transmit energies at the terminals and the relays R_i are assumed to be equal and the information symbols are modulated using QPSK. The faded SNR is attenuated by factor $d_{11}^{-\mu}$ and $d_{12}^{-\mu}$ for first-hop and the second-hop, respectively, and are influenced by the path loss effect. Where $\mu = 3$ path loss exponent for sub-urban area.

In this research work, the impact of the relay location on the outage probability of STANC is observed by setting the relays at different positions while keeping the same fading parameters. The relay node as well as the destinations terminal is situated in the same fading environment so the signals received at both terminals experience same fading conditions which are described as. When $m = 1$, it corresponds to the area which is heavily populated and both the relays and the destination terminals undergo in severe multipath fading and the distribution reduces to Rayleigh fading. Similarly $m = 2$ corresponds to the moderate multipath scenario with less scattering and the signal strength variations are reduced as compared to Rayleigh Fading.

We now show the outage probability of STANC, taking into account three cases based on the different positions of 2 relays between source-destination terminals, as follows.

1) Case I: In this case we discussed three scenarios:*1)* when $d_1 = 0.25$ and $d_2 = 0.25$ (both the relays is located close to the source). *2)* When $d_1 = 0.25$ and $d_2 = 0.75$ (one the relays is located close to the source and other is located near destination terminal). *3)* when $d_1 = 0.75$ and $d_2 = 0.75$ (both the relays is located close to the destination terminal). Fig. 6 and Fig. 7 plot the outage probability for Nakagami-m and Rician-K fading channels respectively against Es/N0 using IV.

Fig. 6 illustrated that when $m = 1$ at the outage probability of 10^{-4} is same for all scenarios while for $m = 2$, it can be observed that scenario 3 is superior by about 0.5 dB to the scenario 2 and 1 dB to scenario 1. On the other hand Fig. 7 shows that scenario 3 outperforms the scenario 2 and scenario 1 by about 1 dB and 2 dB respectively for $K = 1, 5$.

2) Case II: In this case we discussed two scenarios: *1)* when $d_1 = 0.25$ and $d_2 = 0.50$ (one relay is located at middle between source-destination and second relay located closed to the source). *2)* When $d_1 = 0.50$ and $d_2 = 0.75$ (one relay is located at middle between source-destination

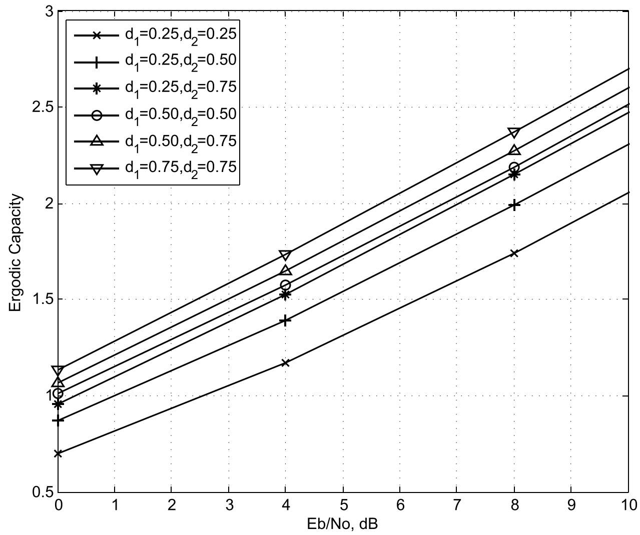

FIGURE 8. Ergodic capacity Vs Relay positioning over Rician-$K = 5$ fading channels with $L = 2$. The approximated analytical results given in (43) using (41) and (42).

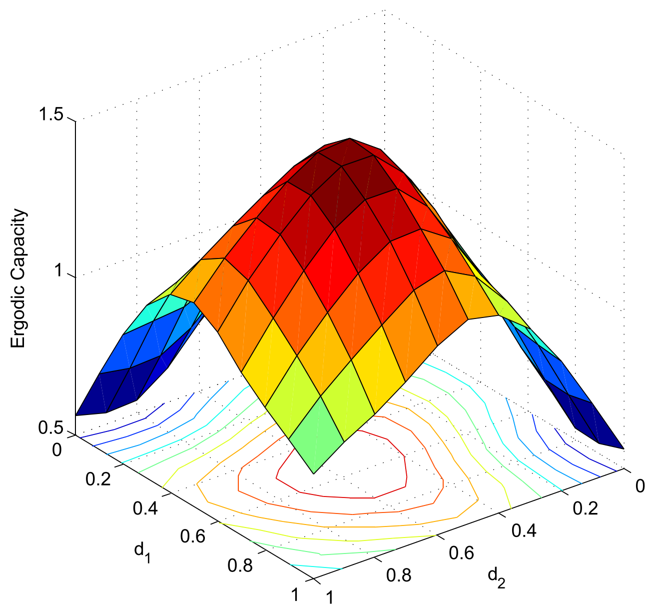

FIGURE 9. Ergodic capacity Vs Relay positioning over Nakagami-$m = 2$ fading channels with $L = 2$ and $SNR = 10$.

and second relay located closed to the destination). Fig. 6 showed that 0 dB gain is achieved at the outage probability of 10^{-4} for $m = 1$ while for $m = 2$, it can be observed that scenario 2 obtained 0.5 dB gain with respect to scenario 1. It can be observed from Fig. 7 that for $K = 1, 5$ the scenario 1 shows approximately same outage probability to scenario 3 of Case I at higher SNR regime.

3) Case III: In this case we discussed the scenario when $d_1 = 0.50$ and $d_2 = 0.50$ (Both relays are located at the middle of source-destination link). Fig. 6 showed that this scenario achieved 1 dB and 2 dB gain w.r.t *Case I* and *Case II* respectively at the outage probability of 10^{-3} for $m = 1$ while for $m = 2$, it can be observed that this scenario is superior by about $0.5 - 1$ dB to the *Case II* and $1.5 - 2.5$ dB to *Case I*. Similarly, it can be seen from Fig. 7 that this scenario show minimum outage probability w.r.t all other scenarios in *Case II* and *Case I* for $K = 1, 5$.

C. ERGODIC CAPACITY VS RELAY LOCATION

Fig. 8 and Fig. 9 illustrate the achievable ergodic capacity over Rician $K = 5$ and Nakagami $m = 2$ respectively as a function of the Eb/N_0 with number of paths (Relays) $L = 1, 2$. It can be seen from the Fig.8 that the ergodic capacity of the STANC system increases as the relays moves from source terminal to destination terminal and the maximum achievable ergodic capacity was attained when both the relays are near to the destination. Similarly the figure shows the minimum ergodic capacity when the relays are located near the source terminal. This is because of the increased path loss of relay→ destination link. Fig. 9 present the 3-dimensional view where the minimum ergodic capacity values are obtained at the corners and particularly when the relays are nearby the source terminal. There is non- symmetrical characteristic with respect to the location of relays; therefore it is not necessary the same ergodic capacity if the location of the relays swapped. Moreover, we observe that more ergodic capacity is highly probable when the relays are closer to destination terminal stemming from the fact that the path loss of relays→ destination link become less.

VII. CONCLUSION

The performance of the proposed network coding strategy for IoT applications is validated through analytical analysis, by deriving the mathematical expressions for error and outage probability. Similarly, the approximate closed-form expression of ergodic capacity is obtained by using the derived mean and second moment. The received signal envelope is modelled as Rayleigh, nakagami and Rician random variable which incorporate the real propagation scenarios such as densely populated with severe multipath fading, moderate multipath scenario with less scattering, line of sight propagation multipath scattering, and path loss for smart devices network in wireless medium.

Analytical results proved that the derived numerical expressions are simple, efficient and can be used in any SNR regime and by changing different parameters of interest. It is evident from the analytical results that STANC system with the implementation of diversity combination shows a significant performance improvement as compare to conventional network coding such as ANC or PNC.

On the other hand, the number of relays and its location, both plays a vital role on the system performance. The analytical analysis from different scenarios of relay deployment shows that the performance of such system suffers if the relays are placed near the source, because path loss between relay to destination terminal is close to that between sources to destination and therefore spectrum efficiency suffers. In this scenario, the overall performance depends on that of the relay to destination link. As location of relay is moved towards destination, system performance again suffers. This is due to large path-loss, resulting in poor received SNR at the relay. Under such conditions, increasing number of relays improves the system performance.

Significant research contribution of this research work is the design of an innovative network coding scheme, i.e. STANC, that can significantly improve the system. The proposed design is validated through analytical expressions under different fading environments that are faced by IoT applications.

REFERENCES

[1] S. Li, L. Da Xu, and S. Zhao, "5G Internet of Things: A survey," *J. Ind. Inf. Integr.*, vol. 10, pp. 1–9, Jun. 2018.

[2] H. Beyranvand, M. Lèvesque, M. Maier, J. A. Salehi, C. Verikoukis, and D. Tipper, "Multilevel diversity coding with distortion," *IEEE/ACM Trans. Netw.*, vol. 25, no. 2, pp. 690–707, Apr. 2017.

[3] R. Agrawal, "Performance of routing strategy (bit error based) in fading environments for mobile adhoc networks," in *Proc. IEEE Int. Conf. Pers. Wireless Commun. (ICPWC)*, May 2005, pp. 550–554.

[4] H. Wang, X. Yue, D. Qiao, and W. Zhang, "A massive MIMO system with space-time block codes," in *Proc. IEEE/CIC Int. Conf. Commun. China (ICCC)*, Jul. 2016, pp. 1–5.

[5] S. A. Farès, F. Adachi, and E. Kudoh, "A novel cooperative relaying network scheme with inter-relay data exchange," *IEICE Trans. Commun.*, vol. E92-B, no. 5, pp. 1786–1795, 2009.

[6] H. Katiyar and R. Bhattacharjee, "Performance of MRC combining multi-antenna cooperative relay network," *AEU-Int. J. Electron. Commun.*, vol. 64, no. 10, pp. 988–991, Oct. 2010.

[7] Y. Ding and M. Uysal, "Amplify-and-forward cooperative OFDM with multiple-relays: Performance analysis and relay selection methods," *IEEE Trans. Wireless Commun.*, vol. 8, no. 10, pp. 4963–4968, Oct. 2009.

[8] A. Afana, R. Mesleh, S. Ikki, and I. E. Atawi, "Performance of quadrature spatial modulation in amplify-and-forward cooperative relaying," *IEEE Commun. Lett.*, vol. 20, no. 2, pp. 240–243, Feb. 2016.

[9] S. Ikki and M. H. Ahmed, "Performance analysis of incremental relaying cooperative diversity networks over Rayleigh fading channels," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Mar. 2008, pp. 1311–1315.

[10] W. Limpakom, Y.-D. Yao, and H. Man, "Outage probability analysis of wireless relay and cooperative networks in Rician fading channels with different K-factors," in *Proc. IEEE 69th Veh. Technol. Conf.*, Apr. 2009, pp. 1–5.

[11] Y. Wang and F. Lin, "SER performance analysis and power allocation for amplify-and-forward relay networks," in *Proc. Int. Conf. Wireless Commun., Netw. Mobile Comput.*, Sep. 2007, pp. 1274–1277.

[12] R. Ahlswede, N. Cai, S.-Y. R. Li, and R. W. Yeung, "Network information flow," *IEEE Trans. Inf. Theory*, vol. 46, no. 4, pp. 1204–1216, Jul. 2000.

[13] Y. Wu, P. A. Chou, and S.-Y. Kung, "Information exchange in wireless networks with network coding and physical-layer broadcast," in *Proc. 39th Annu. Conf. Inf. Sci. Syst. (CISS)*, Baltimore, MD, USA, Mar. 2005, pp. 1–7.

[14] Y. Chen, S. Kishore, and J. Li, "Wireless diversity through network coding," in *Proc. IEEE Wireless Commun. Netw. Conf., (WCNC)*, vol. 3, Apr. 2006, pp. 1681–1686.

[15] C. Peng, Q. Zhang, M. Zhao, and Y. Yao, "On the performance analysis of network-coded cooperation in wireless networks," in *Proc. 26th IEEE Int. Conf. Comput. Commun. (INFOCOM)*, May 2007, pp. 1460–1468.

[16] L. Xiao, T. Fuja, J. Kliewer, and D. J. Costello, "A network coding approach to cooperative diversity," *IEEE Trans. Inf. Theory*, vol. 53, no. 10, pp. 3714–3722, Oct. 2007.

[17] S. J. Kim, P. Mitran, and V. Tarokh, "Performance bounds for bidirectional coded cooperation protocols," *IEEE Trans. Inf. Theory*, vol. 54, no. 11, pp. 5235–5241, Nov. 2008.

[18] T. Oechtering and H. Boche, "Optimal time-division for bidirectional relaying using superposition encoding," *IEEE Commun. Lett.*, vol. 12, no. 4, pp. 265–267, Apr. 2008.

[19] R. Louie, Y. Li, and B. Vucetic, "Practical physical layer network coding for two-way relay channels: Performance analysis and comparison," *IEEE Trans. Wireless Commun.*, vol. 9, no. 2, pp. 764–777, Feb. 2010.

[20] S. Katti, S. Gollakota, and D. Katabi, "Embracing wireless interference: Analog network coding," *ACM SIGCOMM*, Kyoto, Japan, Aug. 2007, pp. 1–12.

[21] H. Gacanin and F. Adachi, "Broadband analog network coding," *IEEE Trans. Wireless Commun.*, vol. 9, no. 5, pp. 1577–1583, May 2010.

[22] Z. Li, X.-G. Xia, and B. Li, "Achieving full diversity and fast ML decoding via simple analog network coding for asynchronous two-way relay networks," *IEEE Trans. Commun.*, vol. 57, no. 12, pp. 3672–3681, Dec. 2009.

[23] M. Riemensberger, Y. E. Sagduyu, M. L. Honig, and W. Utschick, "Comparison of analog and digital relay methods with network coding for wireless multicast," in *Proc. IEEE Int. Conf. Commun.*, Jun. 2009, pp. 1–5.

[24] L. Song, G. Hong, B. Jiao, and M. Debbah, "Joint relay selection and analog network coding using differential modulation in two-way relay channels," *IEEE Trans. Veh. Technol.*, vol. 59, no. 6, pp. 2932–2939, Jul. 2010.

[25] R. Zhang, C. C. Chai, Y.-C. Liang, and S. Cui, "On capacity region of two-way multi-antenna relay channel with analogue network coding," in *Proc. IEEE Int. Conf. Commun.*, Jun. 2009, pp. 1–5.

[26] X. Zhao, J. Kivinen, P. Vainikainen, and K. Skog, "Propagation characteristics for wideband outdoor mobile communications at 5.3 GHz," *IEEE J. Sel. Areas Commun.*, vol. 20, no. 3, pp. 507–514, Apr. 2002.

[27] F. Gao, T. Cui, and A. Nallanathan, "On channel estimation and optimal training design for amplify and forward relay networks," *IEEE Trans. Wireless Commun.*, vol. 7, no. 5, pp. 1907–1916, May 2008.

[28] S. Atapattu, N. Rajatheva, and C. Tellambura, "Performance analysis of TDMA relay protocols over Nakagami-*m* fading," *IEEE Trans. Veh. Technol.*, vol. 59, no. 1, pp. 93–104, Jan. 2010.

[29] S. Ikki and M. H. Ahmed, "Performance analysis of incremental relaying cooperative diversity networks over Rayleigh fading channels," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Las Vegas, NV, USA, Mar. 2008, pp. 1311–1315.

[30] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*, 6th ed. New York, NY, USA: Academic, 2000.

[31] M. Rao, F. J. Lopez-Martinez, M.-S. Alouini, and A. Goldsmith, "MGF approach to the analysis of generalized two-ray fading models," *IEEE Trans. Wireless Commun.*, vol. 14, no. 5, pp. 2548–2561, May 2015.

[32] M. K. Simon and M.-S. Alouini, *Digital Communication Over Fading Channels*. Hoboken, NJ, USA: Wiley, 2005.

[33] J. G. Proakis, *Digital Communications*, 3rd ed. New York, NY, USA: McGraw-Hill, 1995.

[34] G. Farhadi, and N. C. Beaulieu, "Ergodic capacity analysis of wireless relaying systems in Rayleigh fading," in *Proc. IEEE Int. Conf. Commun.*, May 2008, pp. 3730–3735.

[35] S. Chen, W. Wang, and X. Zhang, "Ergodic and outage capacity analysis of cooperative diversity systems under Rayleigh fading channels," in *Proc. IEEE Int. Conf. Commun. Workshops*, Jun. 2009, pp. 1–5.

[36] J. Chen and K. Djouani, "Space time coding in amplify-and-forward cooperative channel," in *Proc. Int. Conf. Wireless Commun., Netw. Mobile Comput.*, Shanghai, China, Sep. 2007, pp. 267–270.

SHUJAAT ALI KHAN TANOLI received the B.Sc. degree in computer engineering from COMSATS University Islamabad, Pakistan, in 2006, and the M.S. leading to Ph.D. degrees in telecommunications engineering from the Asian Institute of Technology, Thailand, in 2011. He was affiliated with Telecoms SANS Frontiers (TSF), Asia and The Pacific, Bangkok, Thailand, in 2008, for the establishment of Emergency deployments to operate a remote Satellite Telecom Centre in areas affected by earthquake, flood, and cyclone. He is currently working as an Assistant Professor with the Electrical Engineering Department, COMSATS University Islamabad. He is also involved in funded projects of HEC, Pakistan including Integration of Wireless Sensor Networks (WSN) with RFID for remote pipeline monitoring and extending the vision of the IoT to include passive identification and sensing. His research interests include wireless communications systems, the IoT, MIMO systems, antennas design, BICM-ID-based systems, and cooperative networks.

SYED AZIZ SHAH received the bachelor's degree from Xidian University, China, the master's degree from Linkoping University, Sweden, and the Ph.D. degree from COMSATS University Pakistan. He joined the University of Glasgow as a Post Doctorate Research Associate. He is currently working as an Assistant Professor (Lecturer) with Manchester Metropolitan University, U.K. He has coauthored more than 30 technical articles in top-rank cross-disciplinary journals (three transactions). His research interests include machine learning in wireless sensing, radar technology, software defined radios, antennas and propagation, healthcare, and agriculture technologies.

MUHAMMAD BILAL KHAN received the B.S. degree in electronics engineering and the M.S. degree in electrical engineering from COMSATS University Islamabad, Abbottabad Campus, Pakistan, in 2009 and 2013, respectively. Since 2012, he has been with COMSATS University Islamabad, Attock campus, Pakistan where he is currently working as a Lecturer. His main areas of research interests are wireless communication, MIMO, OFDMA, cooperative networks, and software defined radios.

FAIZA NAWAZ received the Ph.D. degree in electrical and electronics engineering from Universiti Teknologi PETRONAS, Malaysia, in 2015. She is currently working as an Assistant Professor with the Department of Electrical and Computer Engineering, COMSATS University Islamabad, Attock campus, Pakistan. Her research interests are in the area of wireless networking with emphasis on wireless SAW-based sensor networks and its application in the Internet of Things.

AMIR HUSSAIN received the B.Eng. (Hons.) and Ph.D. degrees from the University of Strathclyde, Glasgow, U.K., in 1992 and 1997, respectively. He is currently a Professor and the Founding Head of the Cognitive Big Data and Cybersecurity (CogBiD) Research Lab, Edinburgh Napier University, U.K. He is a Founding Editor-in-Chief of two leading journals *Cognitive Computation* (Springer Nature) and *BMC Big Data Analytics* (BioMed Central), and of the Springer Book Series on Socio-Affective Computing, and Cognitive Computation Trends. He is an Associate Editor for a number of prestigious journals, including *Information Fusion* (Elsevier), *AI Review* (Springer), the IEEE Transactions on Neural Networks and Learning Systems, the *IEEE Computational Intelligence Magazine*, and the IEEE Transactions on Emerging Topics in Computational Intelligence. Amongst other distinguished roles.

AHMED Y. AL-DUBAI received the Ph.D. degree in computing from the University of Glasgow, in 2004. In 2004, he joined the University of West London, and then in 2005, he joined Edinburgh Napier University, where he became a Professor and the Program Leader of the Postgraduate Research Degrees with the School of Computing. He is currently the Head of the Networks Research Group. He has been working on the area of group communication algorithms, smart spaces, and high-performance networks. He published in world leading journals. He is a Fellow of the British Higher Academy. He has been the recipient of several academic awards and recognitions and a member of several editorial boards of leading scholarly journals. He served as a Guest Editor for more than 30 special issues in scholarly journals and Chaired and Co-Chaired more than 30 International conferences/workshops.

IMRAN KHAN received the B.Sc. degree in electrical engineering from the N-W.F.P. University of Engineering and Technology, Peshawar, Pakistan, in 2003, and the M.Sc. degree in telecommunication engineering from the Asian Institute of Technology, Thailand, in 2007. He is currently pursuing the Ph.D. degree with the Telecommunications FOS, School of Engineering and Technology, Asian Institute of Technology, Thailand. He is currently working as a Professor with the Electrical Engineering Department, University of Engineering Technology at Mardan, Mardan. His research interests include performance analysis of wireless communications systems, OFDM, OFDMA, MIMO, cooperative networks, and cognitive radio systems.

SYED YASEEN SHAH received the master's degree from Glasgow Caledonian University, U.K., where he is currently pursuing the Ph.D. degree. His research interests include machine learning in wireless sensing, radar technology, software defined radios, antennas and propagation, and healthcare and agriculture technologies.

AYOUB ALSARHAN received the B.E. degree in computer science from the Yarmouk University, Jordan, in 1997, the M.Sc. degree in computer science from Al-Bayt University, Jordan, in 2001, and the Ph.D. degree in electrical and computer engineering from Concordia University, Canada, in 2011. He is currently an Associate Professor with the Computer Information System Department, Hashemite University, Zarqa, Jordan. His research interests include cognitive networks, parallel processing, cloud computing, machine learning, and real time multimedia communication over the Internet.