IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received December 23, 2017, accepted February 3, 2018, date of publication February 15, 2018, date of current version March 15, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2806375

Reduced Feedback Rate Schemes for Transmit Antenna Selection With Alamouti Coding

SUDHIR KUMAR MISHRA AND KISHORE DAMODAR KULAT
Visvesvaraya National Institute of Technology, Nagpur 440010, India

Corresponding author: Sudhir Kumar Mishra (er.sudhirkumarmishra@gmail.com)

ABSTRACT In this paper, we propose and analyze two novel reduced feedback rate schemes for transmit antenna selection (TAS) for multiple-input multiple-output systems. A detailed analysis and comparison of bit error performance, outage probability, and the feedback rate of the proposed TAS schemes are presented. The performance comparison of the proposed schemes with conventional and other well-known TAS schemes in literature is presented along with their pictorial representations. Using order statistics and moment generating function, an exact expression for bit error rate performance and outage probability for a special case of the proposed schemes with binary phase shift keying modulation has been derived and substantiated with numerical results through simulations. The results show that the proposed schemes successfully trade-offs the error performance loss with feedback rate of a TAS system in an optimum manner compared to previously reported schemes. The proposed schemes can play a crucial role in envisioned 5G communications where small, low power, robust systems will be required for varied applications. The proposed transmit antenna selection schemes can also be easily integrated with non-orthogonal multiplexing systems to improve their error performance.

INDEX TERMS MIMO, STBC, antenna selection, TAS, Alamouti, feedback rate, cooperative, 5G, cognitive.

I. INTRODUCTION

MIMO has successfully been able to improve error performance and system capacity of wireless communications. The success of any MIMO system depends on its ability to exploit diversity gain and the multiplexing gain offered by the MIMO Channel. However, both these gains cannot be maximized simultaneously. Hence, a trade-off between the diversity and multiplexing gain is carried out to obtain an optimum performance [1]. In any MIMO system, the increase in number of transmit antennas increases the complexity and cost considerably [2]. In a full complexity MIMO system, each antenna is associated with a costly RF-chain as shown in Fig. 1, where N_t is the number of available transmit antennas for transmission and N_r is the number of available receive antennas.

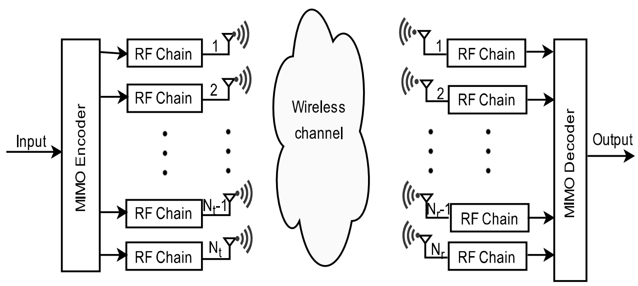

FIGURE 1. Generic MIMO system.

In this paper, we have proposed two novel transmit antenna selection schemes. Transmit antenna selection is one of the technique to reduce cost and complexity of MIMO systems. The most commonly used antenna selection criteria are maximization of the received signal-to-noise ratio (SNR) and maximization of the channel capacity [2], [3]. Thus, TAS is the process of selecting some of the available transmit antennas for transmission without much deterioration of the considered performance metric(s). In this paper, the criteria of maximization of the received signal-to-noise ratio has been considered for the transmit antenna selection. TAS helps in reducing complexity [2], [4]–[6] and the cost due to expensive RF chains [2], [4], [7] required for each antennas. A generic TAS system is shown in Fig. 2, where the information about which transmit antennas are to be selected for transmission is fed back from receiver to the transmitter through a band

2169-3536 © 2018 IEEE. Translations and content mining are permitted for academic research only.
Personal use is also permitted, but republication/redistribution requires IEEE permission.
See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

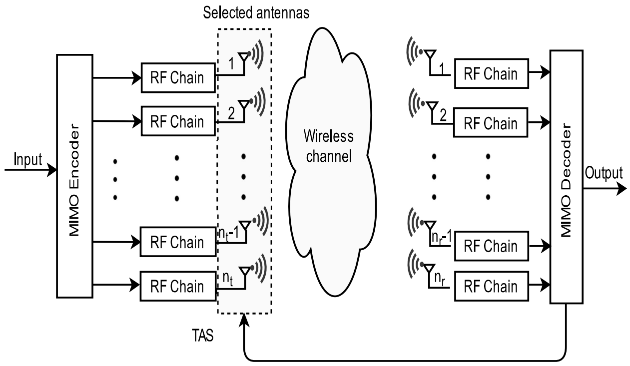

FIGURE 2. Generic transmit antenna selection.

limited feedback channel. In Fig. 2, n_t is the number of transmit antenna selected for transmission and n_r is the number of selected receive antenna if receive antenna selection is also used.

The commonly used metrics for TAS, i.e., received SNR and capacity depend on the characteristics of the MIMO channel between the transmitting and receiving antennas. In other words, channel state information (CSI) plays a crucial role in the performance of MIMO Systems. CSI can be estimated at the receiver and fed back to the transmitter for adaptive transmission. Due to the limited bandwidth of the feedback channel, it is of prime importance to have a mechanism to carry out TAS in such a way that the feedback rate reduction does not compromise with the chosen performance metric(s). Various studies have been done by the research community over the last decade with an aim to reduce feedback rate without compromising the error performance to much extent [4], [8], [9]. In this paper, we propose and analyze two novel TAS schemes in the same spirit.

To demonstrate the efficacy of the proposed schemes in a simple manner, we have considered an Alamouti coded multiple-input single-output (MISO) system with transmit antenna selection wherein depending on the feedback from receiver, an antenna subset of two transmit antennas is selected for transmission. The beauty of Alamouti code lies in the fact, that it is a full rate, even for complex constellations. However, for more than two transmit antenna MISO system, there does not exist any full-rate space-time block code with complex constellation [10].

Though in general, maximizing SNR does not always lead to maximizing capacity of a MIMO system, for a MISO system maximizing SNR leads to maximizing capacity [2], hence, the proposed TAS can achieve both better error performance and better capacity with lesser complexity for the considered MISO case.

The remainder of the paper is organized as:

Section II describes the system model, Section III gives a brief overview of related works in literature, the proposed schemes are described in Section IV, the performance analysis & comparison of the proposed schemes are presented in Section V along with the analytical derivation for bit error rate (BER) and outage probability of the proposed scheme for a special case and finally results and conclusions are presented in Section VI and Section VII respectively.

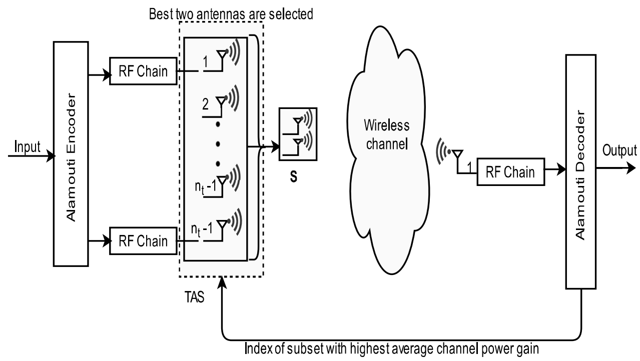

FIGURE 3. Conventional transmit antenna selection.

II. SYSTEM MODEL

We consider a closed loop MISO system with $N_t > 2$ transmit antennas as shown in Fig. 3. The channel fading coefficients between the i^{th} transmit antenna and the receive antenna is denoted by h_i, $1 \leq i \leq N_t$ are independent identically distributed (i.i.d.) circularly symmetric complex Gaussian random variables of zero mean and unit variance ($\mathcal{C}(0,\ 1)$). Hence, the instantaneous channel power gain between i^{th} transmit antenna and the receive antenna can be given as $\alpha_i = |h_i|^2$ which turns out to be a χ^2 distributed random variable as h_i is $\mathcal{C}(0,\ 1)$. Let us denote the i^{th} term of the series formed on arranging α_i in increasing order as $\alpha_{(i)}$. Thus, $\alpha_{(1)} \leq \alpha_{(2)} \leq \alpha_{(1)} \leq \cdots \leq \alpha_{(N_t-1)} \leq \alpha_{(N_t)}$ and consequently if there are N_t terms, $\alpha_{(N_t)}$, $\alpha_{(N_t-1)}$, $\alpha_{(i)}$ are termed as best antenna, second best and i^{th} best antenna respectively. As discussed in Section I, for a MISO system, maximizing SNR leads to maximizing capacity as well. Hence, for a MISO system, based on the TAS scheme used, the selected antennas subset $\{S\}$ provides both maximum average channel power gain or average signal to noise ratio and maximum capacity. Let n_t transmit antennas are to be selected for transmission from the available N_t transmit antennas for reducing the complexity involved while meeting the required performance metric(s). The information about the selected antennas can be conveyed to the transmitter either by feedback of the indexes of each individual antennas to be selected or by feedback of the index of the subset containing the transmit antennas to be selected. The total number of subset of n_t antennas out of available N_t transmit antenna is given as $\binom{N_t}{n_t}$.[1] The number of bits required for the first method is $n_t\lceil \log_2 N_t \rceil$[2] bits and for second method, the feedback bit is given as $\left\lceil \log_2 \binom{N_t}{n_t} \right\rceil$. It can be shown that for $n_t \geq 2$, $n_t \left\lceil \log_2 N_t \right\rceil$ is always greater

[1] $\binom{N_t}{n_t} = \frac{N_t!}{(N_t-n_t)!n_t!}$
[2] rounded to nearest higher integer

than $\left\lceil \log_2 \binom{N_t}{n_t} \right\rceil$. Hence, while feedback, we should feed back the index of the subset containing the selected transmit antennas instead of the indexes of the selected antennas. One more interesting point is that for $N_t = n_t + 1$, $\binom{N_t}{n_t} = n_t + 1$, i.e, when a subset of n_t antennas are formed out of $N_t = n_t + 1$, the total number of subset remains same as that of total number of available transmit antenna. Thus, one of the ways to reduce the feedback rate is to somehow reduce the number of antenna subsets to be used for antenna selection and for $N_t = 3, n_t = 2$, the number of subset formed is 3. For an Alamouti system with $n_t = 2$, the selected subset $\{S\}$ consists of those two transmit antennas for which, sum of channel power gain between them and receive antenna is maximum or average channel power gain is maximum. Let $\{S\} = \{U, V\}$, where U and V are the selected transmit antennas and the channel coefficients associated with them are h_u and h_v.

III. RELATED WORKS IN LITERATURE

There exists a vast literature on the study and analysis of TAS, however, there are not many reduced feedback rate TAS schemes which trade-offs feedback rate with BER performance in an optimum manner. The proposed schemes may prove to be good alternative to choose from the already existing literature. For the performance comparison of the proposed schemes, we have selected the conventional scheme and the well-known schemes proposed in [4] and [6]. The metrics considered for the performance comparison are feedback rate, SNR loss, BER and outage probability. In this section, a brief description and discussions on the reference schemes is provided along with their graphical representations.

A. CONVENTIONAL SCHEME

In conventional scheme, we select the subset containing the best and second best transmit antennas out of $\binom{N_t}{2}$ subset consisting of two different transmit antennas. As discussed earlier, the best antenna corresponds to antenna with channel power gain $\alpha_{(N_t)}$ and second best antenna corresponds to antenna with channel power gain $\alpha_{(N_t-1)}$. The selected subset $\{S\}$ consists of antennas U and V with channel power gain $\alpha_{(N_t)}$ and $\alpha_{(N_t-1)}$ respectively. This scheme is depicted in Fig. 3.

Since, in this scheme, best subset of antennas is selected, that is, both the best and the second best antenna are included in the selected subset, it leads to the best possible error performance. The total number of possible subsets to select from is $\binom{N_t}{2}$. Hence, the number of feedback bits required is $\left\lceil \log_2 \binom{N_t}{2} \right\rceil$ bits.

B. SCHEMES PROPOSED IN [4]

Three schemes have been proposed in [4] which trade-offs the number of feedback with error performance. Many researchers [11], [12] have analyzed these schemes for various cases. We have briefly described these schemes in this subsection along with providing the reasoning for their error performance and the number of possible subset to select from, so that an inference can be drawn on the relationship between the number of possible subset, feedback rate and error performance.

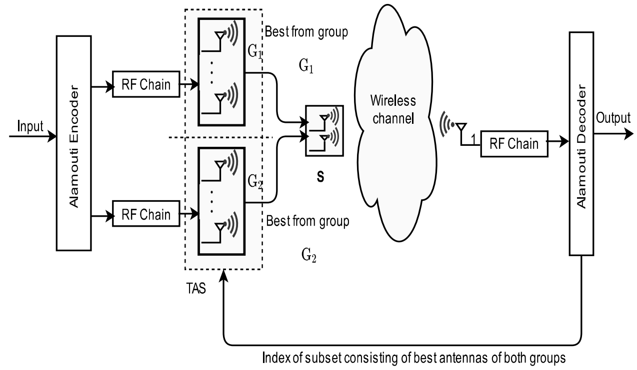

FIGURE 4. Scheme 1 [4].

1) SCHEME 1

In this scheme, the available antennas are divided into two groups viz., G_1 and G_2 where, G_1 consists of first $\left\lfloor \frac{N_t}{2} \right\rfloor$[3] consecutive antennas and G_2 consists of the remaining $\left\lceil \frac{N_t}{2} \right\rceil$ antennas. The selected antenna subset $\{S\}$ consists of antenna U and V s.t. U is the best antenna from group G_1 and V is the best antenna from group G_2. Since best antenna of both the groups are selected, the performance of this scheme deteriorates, whenever both the best and the second best antenna falls in the same group, as this leads to non selection of the second best. This scheme can be depicted as shown in Fig. 4.

The number of subset, to select the best subset is given as

$$\begin{cases} \left(\dfrac{N_t}{2}\right)\left(\dfrac{N_t}{2}\right), & N_t \text{ is even} \\ \left(\dfrac{N_t-1}{2}\right)\left(\dfrac{N_t+1}{2}\right), & N_t \text{ is odd} \end{cases} \tag{1}$$

Hence, the number of feedback bits required for this scheme, if index of subset containing the selected antennas are fed back is given as $\lceil 2\log_2 N_t - 2 \rceil$ when N_t is even and $\lceil \log_2 (N_t - 1) + \log_2 (N_t - 1) - 2 \rceil$ when N_t is odd.

The selected group $\{S\}$ always consists of the over-all best antenna and the other selected antenna is always better than atleast $\left\lfloor \frac{N_t}{2} \right\rfloor - 1$ of the available transmit antennas in terms of channel power gain. And the selected subset is always better than $\left(\frac{N_t}{2}\right)\left(\frac{N_t}{2}\right) - 1$ subset of two antennas when N_t is even and $\left(\frac{N_t-1}{2}\right)\left(\frac{N_t+1}{2}\right) - 1$ subset of two antennas when N_t is odd.

[3]Rounded to nearest smaller integer

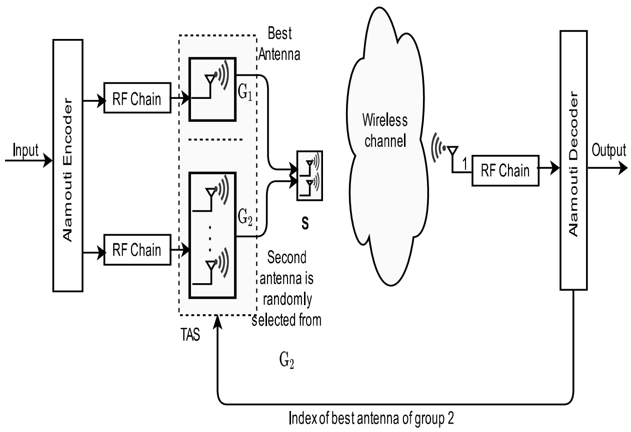

FIGURE 5. Scheme 2 [4].

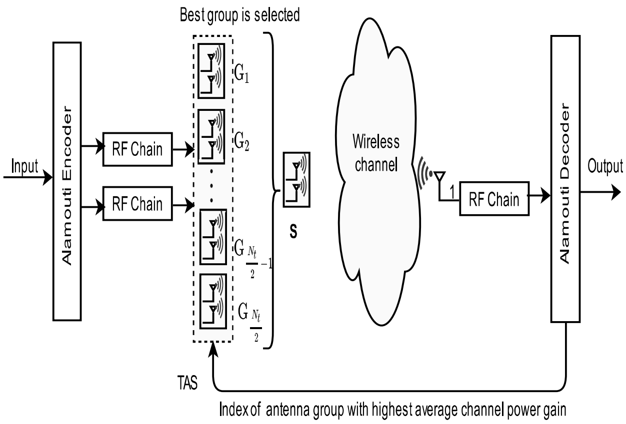

FIGURE 6. Scheme 3 [4].

2) SCHEME 2

Here, the index of the best antenna is fed back and the second antenna is randomly selected from the remaining transmit antennas. This scheme is depicted in Fig. 5. The selected subset $\{S\}$ consists of antenna U and V s.t. U is best antenna with channel power gain $\alpha_{(N_t)}$ and V is the randomly selected antenna from remaining $N_t - 1$ antennas. In this scheme, the probability of selecting any one antenna from the remaining antennas is same, hence, the selected subset may not always be the best one, which may lead to selection of an antenna subset whose average channel power gain is lower compared to other possible selections leading to poor performance compared to Scheme 1 [4] despite the presence of best antenna in the selected subset. The probability of selecting the second best or the worst antenna in the selected subset is $\frac{1}{N_t-1}$. This scheme is shown in Fig. 5. Since the index of only the best antenna is fed back, the number of feedback required for this scheme is given as $\lceil \log_2 N_t \rceil$.

3) SCHEME 3

In this scheme, the available transmit antennas are divided into subsets consisting of two adjacent antennas. If N_t is even, $\frac{N_t}{2}$ subsets are formed and that subset whose total channel power gain is maximum, is selected. The scheme is depicted in Fig. 6.

Mathematically, the selected subset is determined by I, s.t.

$$I = \underset{1 \le i \le \frac{N_t}{2}}{\operatorname{argmax}} \{\alpha_{2i-1} + \alpha_{2i}\} \tag{2}$$

and the selected antennas U and V are given by $U = 2I - 1$ and $V = 2I$.

If N_t is odd, $\frac{N_t+1}{2}$ subsets are formed, first $N_t - 1$ antennas are used to form $\frac{N_t-1}{2}$ subset and the last antenna will form a subset with the penultimate antenna. Mathematically, the selected subset, denoted by I is given as,

$$I = \underset{1 \le i \le \frac{N_t+1}{2}}{\operatorname{argmax}} \left\{ \underset{1 \le i \le \frac{N_t-1}{2}}{\alpha_{2i-1} + \alpha_{2i}}, \underset{i = \frac{N_t+1}{2}}{\alpha_{2i-2} + \alpha_{2i-1}} \right\} \tag{3}$$

and the two selected antennas are

$$\begin{cases} U = 2I - 1 \quad V = 2I, \; 1 \le I \le \dfrac{N_t - 1}{2} \\ U = N_t - 1 \quad V = N_t, \; I = \dfrac{N_t + 1}{2} \end{cases} \tag{4}$$

In this scheme, the group of antennas with highest average channel power gain is selected. The selected subset will always have average channel power gain higher than $\left\lceil \frac{N_t}{2} \right\rceil - 1$ other antenna subset. Since, the random selection is not involved here, the average channel power gain of the selected subset is expected to be better than that of [[4], Scheme 2] but may become worse compared to scheme 1 [4] as here, none of the subset may contain the best antenna whereas scheme 1 makes sure that best antenna is included in the subset.

The number of subset to select from is given as $\frac{N_t}{2}$ for N_t is even and $\frac{N_t+1}{2}$ for N_t is odd. Hence, the number of feedback bits required for this scheme is given as $\lceil \log_2 N_t \rceil - 1$ when N_t is even and $\lceil \log_2 (N_t + 1) \rceil - 1$ when N_t is odd.

C. SCHEMES PROPOSED IN [6]

Here, one antenna is randomly selected or fixed and the best of the remaining antenna is selected and its index is fedback. The selected subset $\{S\}$ consists of antenna U and V s.t. U is fixed and V is the best antenna from remaining $N_t - 1$ antennas. Since, in this scheme the fixed antenna is randomly selected, it may lead to lowering of average channel power gain similar to [[4], Scheme 2], except that in this scheme, the probability of selecting the worst antenna in the selected subset reduces to $\frac{1}{N_t}$ compared to $\frac{1}{N_t-1}$. The performance of this scheme is expected to be similar to that of scheme 2 [4] for large N_t This scheme is depicted in Fig. 7.

Since, the selection of the best antenna is carried from the remaining $N_t - 1$ antennas, the number of feedback required for this scheme is given as $\lceil \log_2 (N_t - 1) \rceil$. In terms of feedback bits, this scheme is better than that of scheme 2 [4], only when $N_t = 2^i + 1, 1 \le i \le \infty$.

TABLE 1. Subset Formation for various Schemes for $N_t = 3, 4, 5, 6$.

Scheme	N_t	Subset Available	No. of subsets	No. of feedback Bits
Conventional Scheme	3	(1,2),(1,3),(2,3)	3	2
Scheme 1 [4]	3	(1,2),(1,3)	2	1
Scheme 2 [4]	3	(2,1),(2,3)	2	2
Scheme 3 [4]	3	(1,2),(2,3)	2	1
Scheme Proposed in [6]	3	(1,2),(1,3)	2	1
Proposed Scheme 1	3	(1,2),(2,3),(3,1)	3	2
Proposed Scheme 2	3	(1,2),(2,3),(3,1)	3	2
Conventional Scheme	4	(1,2),(1,3),(1,4),(2,3),(2,4),(3,4)	6	3
Scheme 1 [4]	4	(1,3),(2,3),(1,4),(2,4)	4	2
Scheme 2 [4]	4	(2,1),(2,3),(2,4)	3	2
Scheme 3 [4]	4	(1,2),(3,4)	2	1
Scheme Proposed in [6]	4	(1,2),(1,3),(1,4)	3	2
Proposed Scheme 1	4	(1,2),(2,3),(3,4),(4,1)	4	2
Proposed Scheme 2	4	(1,2),(2,3),(3,1);(3,4)	4	2
Conventional Scheme	5	(1,2),(1,3),(1,4),(1,5),(2,3),(2,4),(2,5),(3,4),(3,5),(4,5)	10	4
Scheme 1 [4]	5	(1,3),(1,4),(1,5),(2,3),(2,4),(2,5)	6	3
Scheme 2 [4]	5	(2,1),(2,3),(2,4),(2,5)	4	3
Scheme 3 [4]	5	(1,2),(3,4),(4,5)	3	2
Scheme Proposed in [6]	5	(1,2),(1,3),(1,4),(1,5)	4	2
Proposed Scheme 1	5	(1,2),(2,3),(3,4),(4,5),(5,1)	5	3
Proposed Scheme 2	5	(1,2),(2,3),(3,1);(4,5)	4	2
Conventional Scheme	6	(1,2),(1,3),(1,4),(1,5),(1,6),(2,3),(2,4),(2,5),(2,6),(3,4),(3,5),(3,6),(4,5),(4,6),(5,6)	15	4
Scheme 1 [4]	6	(1,4),(1,5),(1,6),(2,4),(2,5),(2,6),(3,4),(3,5),(3,6)	9	4
Scheme 2 [4]	6	(2,1),(2,3),(2,4),(2,5),(2,6)	5	3
Scheme 3 [4]	6	(1,2),(3,4),(5,6)	3	2
Scheme Proposed in [6]	6	(1,2),(1,3),(1,4),(1,5),(1,6)	5	3
Proposed Scheme 1	6	(1,2),(2,3),(3,4),(4,5),(5,6),(6,1)	6	3
Proposed Scheme 2	6	(1,2),(2,3),(3,1);(4,5),(5,6),(6,4)	6	3

Scheme 2 [4]: Here, it is assumed antenna 2 is the best antenna
Scheme Proposed in [6]: Here, it is assumed that the first antenna is the fixed antenna

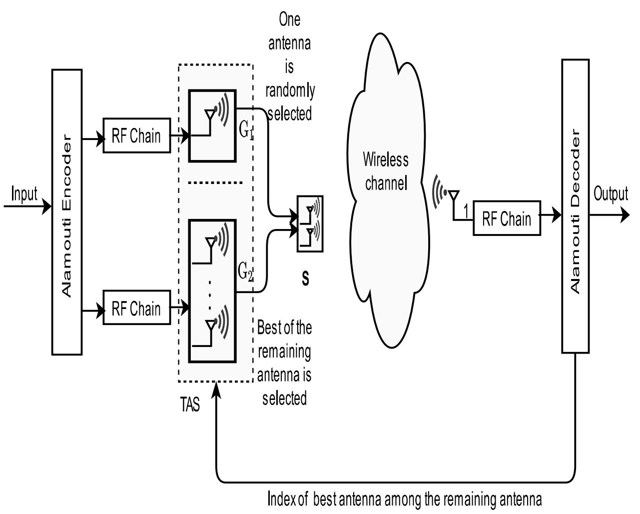

FIGURE 7. Scheme Proposed in [6].

IV. PROPOSED TAS SCHEMES

The proposed schemes are based on the observation that larger the number of subset selection base, higher the feedback rate and larger the average channel power gain as the probability of selecting a better subset of antenna will also increase. The proposed schemes trade-offs the number of feedback rate with error performance in an optimum manner. The proposed schemes makes sure that randomness is not involved in TAS and feedback rate remains almost same as that of scheme 2 [4] and the scheme proposed in [6] leading to an increase in average channel power gain.

A. PROPOSED TAS SCHEME 1

The proposed scheme 1 consists of forming antenna subsets consisting of each antennas with the subsequent antenna and the last antenna is grouped with the first antenna keeping the total number of subset of antennas so formed to N_t which is same as that of [[4], Scheme 2]. Examples are provided in Table1. The subset of antennas with maximum average channel power gain is selected. Each subset is indexed and index of the selected subset is fed back. The proposed scheme 1 can be depicted as shown in Fig. 8.

Mathematically, the selected subset is given as

$$I = \underset{1\le i\le N_t}{\operatorname{argmax}} \left\{ \underset{1\le i\le N_t-1}{\alpha_i + \alpha_{i+1}},\ \underset{i=N_t}{\alpha_i + \alpha_1} \right\} \tag{5}$$

The two selected antennas are

$$\begin{cases} U = I & V = I+1,\ I \neq N_t, \\ U = I & V = 1,\ \text{otherwise} \end{cases} \tag{6}$$

The total number of antenna subsets to select from is N_t. The number of feedback bits required is $\lceil \log_2 (N_t) \rceil$. Though the number of feedback bits required for this scheme is equal to

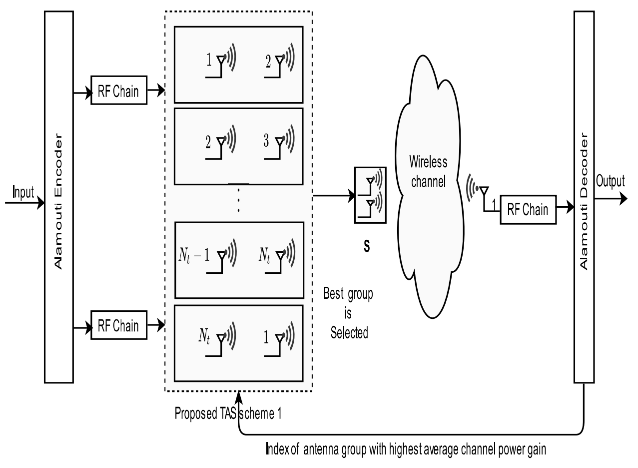

FIGURE 8. **Proposed TAS Scheme 1.**

that of [[4], Scheme 2] and almost same as that of scheme proposed in [6], the randomness in the selection of antenna is removed. The best antenna subset is selected from a set of N_t subsets, hence, it is expected that the average channel power gain of the selected subset should be better compared to [[4], Scheme 2] and the scheme proposed in [6] which we will observe while comparing SNR losses.

In this scheme, we also observe that the number of subset to select from is higher compared to that of [[4], Scheme 3], hence, the average channel power gain of the selected subset for this scheme should be higher as well. Numerical results shown in section V matches our expectations. Despite these advantages, due to the correlation among the subsets, the analytical derivations become too complicated, hence, exhaustive simulation results are provided along with intuitive reasons for its performance.

B. PROPOSED TAS SCHEME 2

This scheme provides results similar to the proposed scheme 1 when $3 \mid N_t$.[4] In this scheme, the subset selection is done in such a way that the theory of order statistics can be applied and expressions for BER and outage probability be derived for some special cases. The analytical results of better error performance with reduced feedback rate are substantiated through simulations. This proposed scheme 2 comprises of two stages, in first stage, if $3 \mid N_t$, N_t transmit antennas are divided into $\left\lceil \frac{N_t}{3} \right\rceil$ groups of antennas, each group consisting of three consecutive antennas. For $3 \nmid N_t$,[5] each first $\left\lfloor \frac{N_t}{3} \right\rfloor$ groups consists of three consecutive antennas and the last group consists of last and penultimate antenna.[6] And in second stage, within each $\left\lceil \frac{N_t}{3} \right\rceil$ groups, all possible subset of two antennas are formed and finally the best subset of two antennas from all the subsets so formed is selected for transmission.

For simplicity, the proposed scheme 2 is shown for $3 \mid N_t$ in Fig. 9.

The subset with maximum average channel power gain is selected.

For $\bmod (N_t, 3) = 0$, the selected subset is given as,

$$I = \underset{1 \le i \le N_t}{\operatorname{argmax}} \left\{ \underset{3 \nmid i}{\alpha_i + \alpha_{i+1}},\ \underset{3 \mid i}{\alpha_i + \alpha_{i-2}} \right\} \tag{7}$$

The two selected antennas are

$$\begin{cases} U = I & V = I + 1,\ 3 \nmid I, \\ U = I & V = I - 2,\ \text{otherwise} \end{cases} \tag{8}$$

If $\bmod (N_t, 3) = 1$

$$I = \underset{1 \le i \le N_t}{\operatorname{argmax}} \left\{ \underset{\substack{1 \le i \le N_t - 1 \\ 3 \nmid i}}{\alpha_i + \alpha_{i+1}},\ \underset{\substack{1 \le i \le N_t - 1 \\ 3 \mid i}}{\alpha_i + \alpha_{i-2}},\ \underset{i = N_t}{\alpha_i + \alpha_{i-1}} \right\} \tag{9}$$

The two selected antennas are

$$\begin{cases} U = I & V = I - 2,\ 3 \mid I, \\ U = I + 1 & V = I,\ \text{otherwise} \end{cases} \tag{10}$$

If $\bmod (N_t, 3) = 2$

$$I = \underset{1 \le i \le N_t - 1}{\operatorname{argmax}} \left\{ \underset{\substack{1 \le i \le N_t - 2 \\ 3 \nmid i}}{\alpha_i + \alpha_{i+1}},\ \underset{\substack{1 \le i \le N_t - 2 \\ 3 \mid i}}{\alpha_i + \alpha_{i-1}},\ \underset{i = N_t - 1}{\alpha_i + \alpha_{i+1}} \right\} \tag{11}$$

The two selected antennas are

$$\begin{cases} U = I & V = I - 2,\ 3 \mid I, \\ U = I & V = I + 1,\ \text{otherwise} \end{cases} \tag{12}$$

where α_i represents the channel power.

The number of subset available to select from is

$$\begin{cases} N_t - 1, & \bmod (N_t, 3) = 2 \\ N_t, & \text{otherwise} \end{cases} \tag{13}$$

Hence, the number of feedback bits required for $\bmod (N_t, 3) = 2$ is $\lceil \log_2 (N_t - 1) \rceil$ and for other cases, the number of feedback bit is $\lceil \log_2 (N_t) \rceil$. Since, similar to the proposed scheme 1, randomness is not involved in this scheme, it is expected to have better average channel power gain compared to [[4], Scheme 2] and that proposed in [6]. Also, similar to proposed scheme 1, the number of subset to select from has increased compared to [[4], Scheme 3], hence, we expect this scheme to be better in terms of average channel power gain compared to scheme 3 [4]. Numerical results shown in Section V matches our expectations. For the sake of clarity, the subset formation is given in Table 1.

[4] 3 divides N_t or N_t is divisible by 3

[5] 3 does not divides N_t or N_t is not divisible by 3

[6] For $\bmod (N_t, 3) = 2$, we can even increase the subset by forming one more subset of the last antenna with any of the antennas other than the penultimate to improve error performance but it leads to increase in feedback rate and correlation among the subset as well

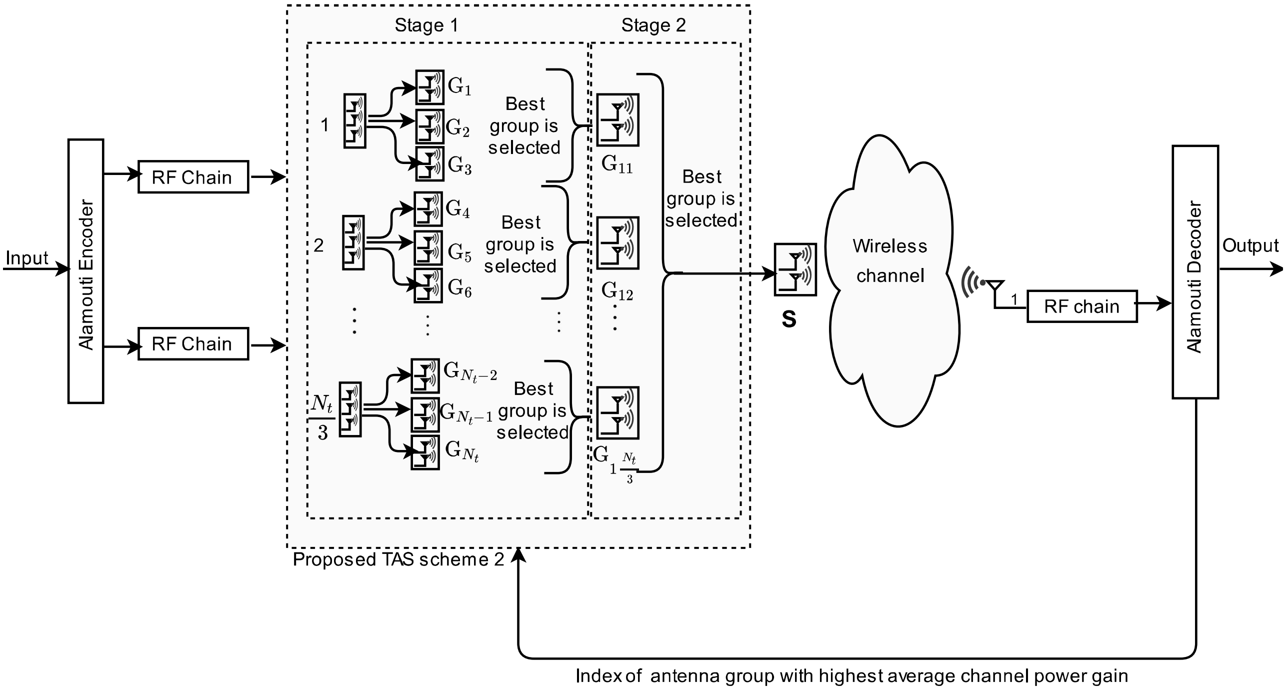

FIGURE 9. **Proposed TAS Scheme 2.**

V. PERFORMANCE ANALYSIS & COMPARISON

This section presents a detailed simulation results along with the necessary performance analysis and a comparison with the schemes presented in [4] and [6]. The metrics used for comparison are feedback rate, SNR loss, BER performance and outage probability. Before carrying out the analysis of BER and outage probability, an exact expression for a special case of the proposed scheme 2 is derived. The simulations has been carried out in Matlab environment and the analytical expressions has been evaluated in Mathematica.

A. FEEDBACK ANALYSIS

For the sake of clarity, the subset formation, number of subset, available to select from and number of feedback bits required for each schemes is given in Table1 for $N_t = 3, 4, 5, 6$. We can observe that for most cases, the proposed schemes and [[4], Scheme 2] and the scheme proposed in [6] require almost same number of feedback bits. Fig. 10 shows the number of feedback bits required for each schemes for $N_t = 3$ to $N_t = 24$.

It can also be observed from Fig. 10 that the proposed scheme 1 requires same number of feedback bits as that of scheme 2 [4] and as mentioned earlier the scheme proposed in [6] is also better than that of scheme 2 [4] only for $N_t = 2^i + 1, 1 \leq i \leq \infty$ is integer. For larger N_t, scheme 3 [4] requires 1 bit less for most cases. A more interesting finding is that the proposed scheme 2 requires same number of feedback as that of least feedback rate scheme 3 [4] for $N_t = 4^i+1,\ 1 \leq i \leq \infty$. Though, for these cases the feedback bits becomes same, the average channel power gain is expected to be better

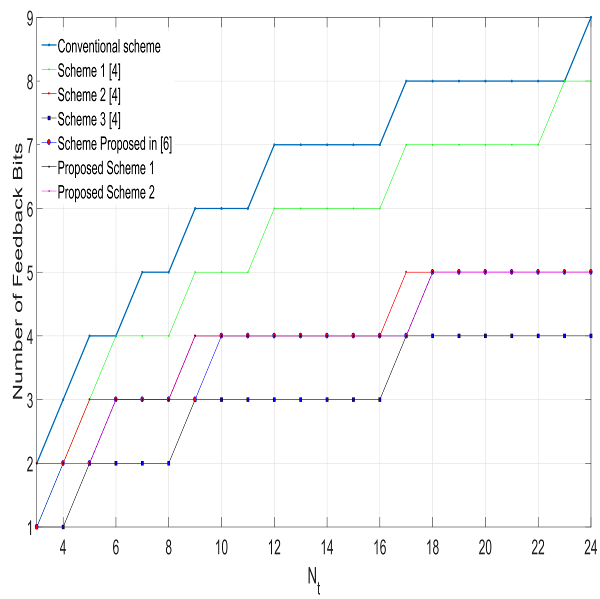

FIGURE 10. **Comparison of number of feedback bits for each schemes.**

as the number of subset to select from is more in the proposed schemes, which can be even observed from Fig. 11 as well.

B. ERROR PERFORMANCE ANALYSIS

The error performance comparison of the proposed algorithm has been carried out through the following metrics:

1) **SNR Loss**

As the methodology of each TAS scheme differs from each other, the average received SNR is also expected

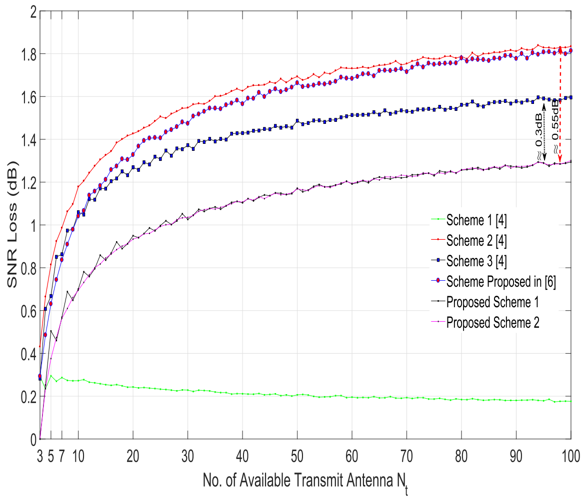

FIGURE 11. Simulated SNR loss comparison of the various schemes.

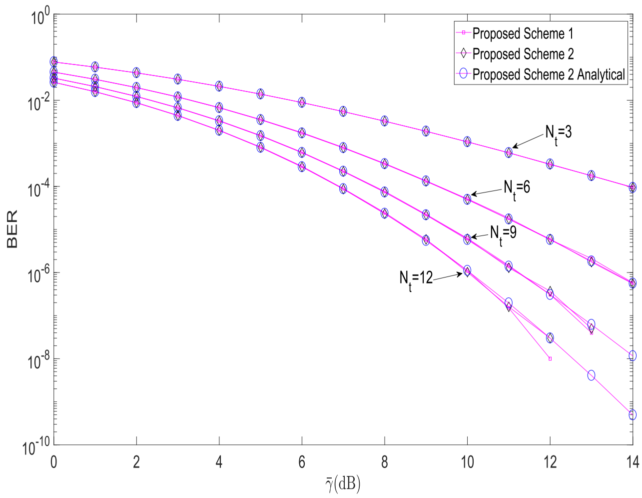

FIGURE 12. Analytical vs. Simulated BER performance of proposed transmit antenna selection schemes.

to be different. And since, the average received channel power gain will be maximum in conventional scheme, the relative SNR loss in each scheme can be understood from

$$\text{SNR loss in scheme i} = 10\log_{10}\frac{m_c}{m_i} \tag{14}$$

where m_c=average channel power gain for conventional scheme and m_i=average channel power gain for scheme i.

From Table 1, we can observe that for $N_t = 3$, both the proposed schemes reduces to the conventional scheme, hence, the SNR loss should be zero, which is even evident from Fig. 11. From Fig. 10 and Fig. 11, we can also infer that despite having same feedback rate as that of scheme 2 [4] for most cases, the proposed schemes offer an SNR gain of $\approx$ 0.55 dB compared to [[4], Scheme 2] and that of proposed in [6] when the number of antenna increases considerably. In scheme 3 [4], reduction of feedback bits is 1 bit for most cases compared to the proposed schemes but with an SNR loss of around $\approx$ 0.3 dB when the number of antenna increases considerably. Though number of feedback bits required by the proposed scheme 2 reduces to as that of scheme 3 for $N_t = 4^i + 1$, $1 \le i \le \infty$, it still offers better received SNR compared to scheme 3 [4] as evident from Fig. 11.

2) **Error Performance**

As mentioned in Section II, a MISO system in a frequency flat Rayleigh fading channel is considered. We assume that perfect CSI is available to the receiver, and the feedback information does not suffer from any delay or errors [4]. For the sake of simplicity, an exact formula for the proposed scheme 2 is derived for N_t divisible by 3 and for $3 \le N_t \le 12$, the analytically evaluated BER has been validated with the simulated BER as shown in Fig. 12.

Order Statistics [13] is used to derive the probability density function (pdf) of the average received SNR obtained by the selected subset of antenna and the methodology of [4] and [14], is used to derive the expression for probability of error (P_e) for binary phase shift keying (BPSK) modulation for the proposed scheme in frequency flat channel as explained below:
Order statistics can be easily used for finding extremes of independent and identically distributed (i.i.d.) random variables. From the methodology of forming antenna groups in the first stage of proposed scheme 2, we can observe that for $3 \mid N_t$, the channel power gains for each set of three consecutive antennas are independent and identically distributed. For a set of three independent χ^2 distributed random variable, pdf and cumulative distribution function (CDF) of the sum of the best subset of two random variable can be evaluated using (21) and (22) of [4], that is, for n=3 and m=2, the CDF and pdf of the sum of instantaneous channel power gain of the two selected transmit antennas in the selected subset formed by all combinations of available three antennas is given as

$$P_Y(y) = -4e^{\frac{-3}{2}y} + 3e^{-y} - 3ye^{-y} + 1 \tag{15}$$

and

$$p_Y(y) = 6e^{\frac{-3}{2}y} - 6e^{-y} + 3ye^{-y} \tag{16}$$

respectively.
where Y is the random variable representing the sum of instantaneous channel power gain of the two selected transmit antennas in the selected subset. For BPSK modulation with Alamouti, the instantaneous SNR, γ is given as [4]

$$\gamma = \frac{\bar{\gamma}}{2}Y \tag{17}$$

where $\bar{\gamma}$ is the average SNR. Since each subset of three antennas of stage one are independent and identically distributed, the pdf and CDF of sum of the best subset of every group of three antennas is given by (16) and (15) respectively.

From the theory of order statistics as given in [15, eq. (2.2.10)], we know that the pdf of the highest order statistics of a set of n i.i.d. random variables with pdf $f(x)$ and CDF $F(x)$ of each random variable is given as

$$f_{(n)}(x) = n[F(x)]^{n-1} f(x) \tag{18}$$

Using (18), the pdf of sum of instantaneous channel power gain of the best subset from the second stage of proposed scheme 2 can be evaluated as

$$p_{(N_t)}(y) = \frac{N_t}{3}\left(1-4e^{-\frac{3y}{2}}+3e^{-y}-3ye^{-y}\right)^{\frac{N_t}{3}-1} \times\left(6e^{-\frac{3y}{2}}-6e^{-y}+3ye^{-y}\right) \tag{19}$$

Here, $p_{(N_t)}(y)$ is the pdf of the sum of instantaneous channel power gain of the best subset among the N_t subset formed to select from in proposed scheme 2.

On simplifying

$$p_{(N_t)}(y) = \frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k} \times(-4)^i\left(-\frac{3}{4}\right)^j e^{-\frac{3y}{2}i}\left(e^{\frac{y}{2}j}\right) \times(-1)^k y^k\left(6e^{-\frac{3y}{2}}-6e^{-y}+3ye^{-y}\right) \tag{20}$$

$$p_{(N_t)}(y) = \frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k} \times(-4)^i\left(-\frac{3}{4}\right)^j \times(-1)^k\left(6y^k e^{-\left(\frac{3i-j+3}{2}\right)y}-6y^k e^{-\left(\frac{3i-j+2}{2}\right)y} +3y^{k+1}e^{-\left(\frac{3i-j+2}{2}\right)y}\right) \tag{21}$$

Using (17) and the methodology of [4], for BPSK modulation (21) can be written in terms of instantaneous SNR, γ as

$$p_\gamma(\gamma) = \left(\frac{2}{\bar{\gamma}}\right)\frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j} \times\binom{j}{k}(-4)^i\left(-\frac{3}{4}\right)^j(-1)^k \times\left(6\left(\frac{2\gamma}{\bar{\gamma}}\right)^k e^{-\left(\frac{3i-j+3}{2}\right)\left(\frac{2\gamma}{\bar{\gamma}}\right)} -6\left(\frac{2\gamma}{\bar{\gamma}}\right)^k e^{-\left(\frac{3i-j+2}{2}\right)\left(\frac{2\gamma}{\bar{\gamma}}\right)} +3\left(\frac{2\gamma}{\bar{\gamma}}\right)^{k+1} e^{-\left(\frac{3i-j+2}{2}\right)\left(\frac{2\gamma}{\bar{\gamma}}\right)}\right) \tag{22}$$

The MGF associated with γ is given by

$$M_\gamma(s) = \int_0^\infty p_\gamma(\gamma)\, e^{s\gamma}\, d\gamma \tag{23}$$

$$M_\gamma(s) = \frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k} \times(-4)^i\left(-\frac{3}{4}\right)^j(-1)^k\left(\frac{2}{\bar{\gamma}}\right)^{k+1} \times\left(6\int_0^\infty e^{-\left(\frac{3i-j+3}{\bar{\gamma}}-s\right)\gamma}\gamma^k d\gamma -6\int_0^\infty e^{-\left(\frac{3i-j+2}{\bar{\gamma}}-s\right)\gamma}\gamma^k d\gamma +3\left(\frac{2}{\bar{\gamma}}\right)\int_0^\infty e^{-\left(\frac{3i-j+2}{\bar{\gamma}}-s\right)\gamma}\gamma^{k+1} d\gamma\right) \tag{24}$$

Using the identity [16, eq. (3.381-4)],

$$\int_0^\infty x^{\nu-1}e^{-\mu x}dx = \frac{1}{\mu^\nu}\Gamma(\nu),\ Re\{\mu\}>0, Re\{\nu\}>0$$

$$M_\gamma(s) = \frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k} \times(-4)^i\left(-\frac{3}{4}\right)^j(-1)^k\left(\frac{2}{\bar{\gamma}}\right)^{k+1}k! \times\left(6\left(\frac{3i-j+3}{\bar{\gamma}}-s\right)^{-(k+1)} -6\left(\frac{3i-j+2}{\bar{\gamma}}-s\right)^{-(k+1)} +3(k+1)\left(\frac{2}{\bar{\gamma}}\right)\left(\frac{3i-j+2}{\bar{\gamma}}-s\right)^{-(k+2)}\right) \tag{25}$$

As given in [14], the BER expression for BPSK can be given as

$$P_e = \frac{1}{\pi}\int_0^{\pi/2} M_\gamma\left(-\frac{1}{\sin^2\theta}\right)d\theta \tag{26}$$

$$P_e = \frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k}(-4)^i \times\left(-\frac{3}{4}\right)^j(-1)^k\left(\frac{2}{\bar{\gamma}}\right)^{k+1}k! \times\left(6\frac{1}{\pi}\int_0^{\pi/2}\left(\frac{3i-j+3}{\bar{\gamma}}-\frac{1}{\sin^2\theta}\right)^{-(k+1)}d\theta -6\frac{1}{\pi}\int_0^{\pi/2}\left(\frac{3i-j+2}{\bar{\gamma}}-\frac{1}{\sin^2\theta}\right)^{-(k+1)}d\theta\right.$$

$$+3(k+1)\left(\frac{2}{\bar{\gamma}}\right) \times \frac{1}{\pi}\int_0^{\pi/2}\left(\frac{3i-j+2}{\bar{\gamma}}-\frac{1}{\sin^2\theta}\right)^{-(k+2)}d\theta\Bigg) \tag{27}$$

On further simplifications, using [14, eq. (5A.4a)]

$$\begin{aligned}P_e = N_t &\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k}(-4)^i \\ &\times\left(\frac{-3}{4}\right)^j(-1)^k k! \\ &\times\Bigg\{\left(\frac{2}{3i-j+3}\right)^{k+1}\times\Bigg[1-\sqrt{\frac{\bar{\gamma}}{3i-j+3+\bar{\gamma}}} \\ &\times\sum_{k_1=0}^{k}\binom{2k_1}{k_1}\left(\frac{3i-j+3}{4\,(3i-j+3+\bar{\gamma})}\right)^{k_1}\Bigg] \\ &-\left(\frac{2}{3i-j+3}\right)^{k+1}\times\Bigg[1-\sqrt{\frac{\bar{\gamma}}{3i-j+3+\bar{\gamma}}} \\ &\times\sum_{k_1=0}^{k}\binom{2k_1}{k_1}\left(\frac{3i-j+3}{4\,(3i-j+3+\bar{\gamma})}\right)^{k_1}\Bigg] \\ &+\left(\frac{2}{3i-j+3}\right)^{k+1}(k+1) \\ &\times\Bigg[1-\sqrt{\frac{\bar{\gamma}}{3i-j+3+\bar{\gamma}}} \\ &\times\sum_{k_1=0}^{k}\binom{2k_1}{k_1}\left(\frac{3i-j+3}{4\,(3i-j+3+\bar{\gamma})}\right)^{k_1}\Bigg]\Bigg\}\end{aligned} \tag{28}$$

From Fig. 12, we can observe that the analytical BER of the proposed scheme 2 is in conformity with the simulation results and the error performance of both the proposed schemes are almost same as, the total number of subset to select from remains same.

Similar to the observation from Table1 and Fig. 11, for $N_t = 3$ the proposed scheme reduces to Conventional TAS, we can observe this from the BER simulation of conventional scheme [4], [17] as well as from the plot of the expression of BER for proposed scheme 2 as shown in Fig. 13. The BER performance comparison of the proposed schemes is shown in Fig. 14.

From Fig. 13, we can observe that since the slope of the BER performance of the proposed TAS is same as that of the conventional TAS scheme hence, we can infer that the proposed TAS is also a full diversity system [2], [18] just like those proposed in [4].

As per the analysis and comparison till now, we have found that the analytical results are in conformity with simulations for the proposed schemes. In Fig. 14, we can observe that the performance of both the proposed schemes are almost same except when mod $(N_t, 3) = 2$. In Section V-A, we have observed that due to the methodology adopted for subset formation, the number of available subset to select from is one less for proposed scheme 2 compared to proposed scheme 1 for mod $(N_t, 3) = 2$. This reduction in the number of subset deteriorates the BER performance of the proposed scheme 2 compared to proposed scheme 1 for mod $(N_t, 3) = 2$. Also from Fig. 14, we can observe that with increase in N_t the difference in their BER performance reduces which is similar to our observation of SNR loss between the two proposed schemes as shown in Fig. 11.

Now we compare the BER performance of the proposed schemes with those discussed in Section III. From the BER performance comparison as shown in Fig. 15, we can observe that for $N_t = 3$ the proposed scheme is better compared to [[4], Schemes 2 and 3] and the scheme proposed in [6]. Even for $N_t = 4$ and $N_t = 5$, the proposed schemes have better error performance compared to scheme 2, scheme 3 of [4] and the scheme proposed in [6].

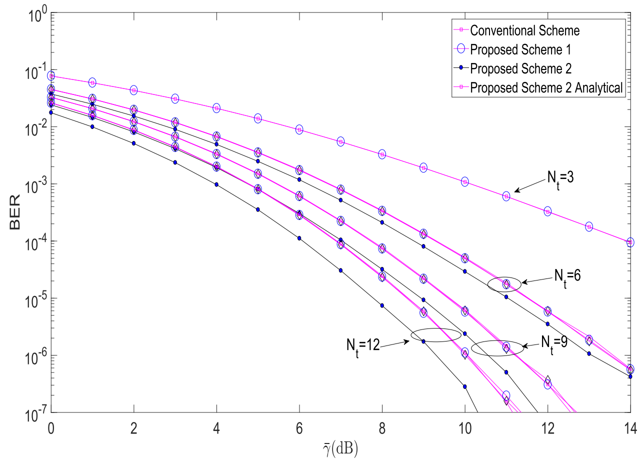

FIGURE 13. Diversity order analysis of proposed transmit antenna selection schemes.

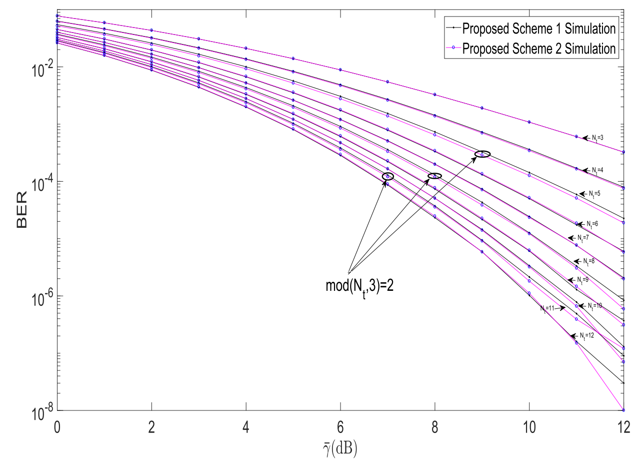

FIGURE 14. BER performance analysis of proposed transmit antenna selection schemes.

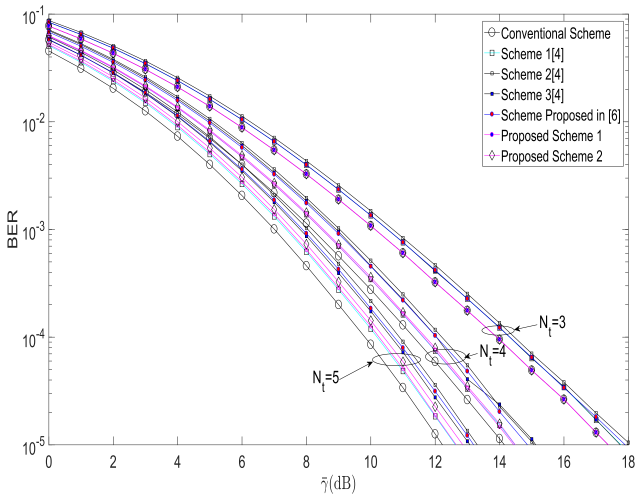

FIGURE 15. BER performance comparison of the proposed transmit antenna selection schemes with those proposed in [4] and [6].

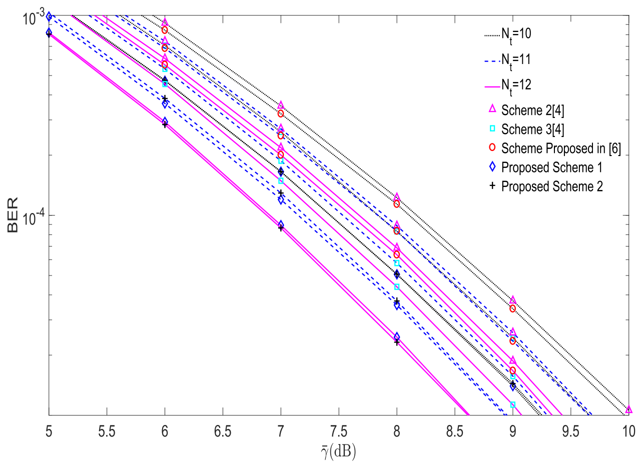

FIGURE 16. BER performance comparison of the proposed transmit antenna selection schemes with schemes 2 [4], scheme 3 [4] and schemes proposed in [6]

From Fig. 11, we observe that the proposed scheme have lesser SNR loss compared to schemes comparable in terms of feedback bits i.e., [[4], Scheme 2] and the scheme proposed in [6]. To see its effects on BER performance, the proposed schemes are simulated for $N_t = 3$ to $N_t = 12$ and for the sake of clarity, the BER performance for $N_t = 10$ to $N_t = 12$ is shown in Fig. 16. An interesting point to observe is that BER performance of both the proposed schemes are not only better rather even with $N_t = 10$, the proposed schemes outperforms scheme 2 and scheme 3 with $N_t = 12$. Similar to the analysis and comparisons carried for BER, outage probability has been discussed in next section.

3) **Outage Probability**

Considering the information theoretic aspects of MIMO, the following definition of outage probability has been used:

The outage probability is defined as the probability that the instantaneous capacity C is less than a given capacity R [19]. In this subsection an analytical expression for the special case of proposed scheme 2 has been considered and after validating it with numerical simulations, the performance comparison of the proposed scheme is carried out with the schemes described earlier.

Mathematically, outage probability, P_{out} is given as

$$P_{out} = Pr[C \leq R] \tag{29}$$

$$P_{out} = Pr[\log_2(1+\gamma) \leq R] = Pr[\gamma \leq 2^R - 1] \tag{30}$$

Let $y = 2^R - 1$

$$P_{out} = P_\gamma(\gamma) = \int_0^y p_\gamma(\gamma)d\gamma \tag{31}$$

Using [16, eq. (3.351, 1)], $\int_0^u x^n e^{-ax}dx = \frac{n!}{a^{n+1}} - e^{-au}\sum_{j=0}^{n}\frac{n!}{j!}\frac{u^j}{a^{n-j+1}}$, (31) can be simplified into

$$\begin{aligned}
&P_{out}\\
&= \left(\frac{2}{\bar{\gamma}}\right)\frac{N_t}{3}\sum_{i=0}^{\frac{N_t}{3}-1}\sum_{j=0}^{i}\sum_{k=0}^{j}\binom{\frac{N_t}{3}-1}{i}\binom{i}{j}\binom{j}{k}\\
&\quad\times(-4)^i\left(-\frac{3}{4}\right)^j(-1)^k\left(\frac{2}{\bar{\gamma}}\right)^k\\
&\quad\times\Bigg(6k!\left(\frac{3i-j+3}{\bar{\gamma}}\right)^{-(k+1)}\\
&\quad-e^{-\left(\frac{3i-j+3}{\bar{\gamma}}\right)y}\sum_{m=0}^{k}\frac{k!}{m!}y^m-\left(\frac{3i-j+3}{\bar{\gamma}}\right)^{-(k-m+1)}\\
&\quad-6k!\left(\frac{3i-j+2}{\bar{\gamma}}\right)^{-(k+1)}\\
&\quad-e^{-\left(\frac{3i-j+2}{\bar{\gamma}}\right)y}\sum_{m=0}^{k}\frac{k!}{m!}y^m-\left(\frac{3i-j+2}{\bar{\gamma}}\right)^{-(k-m+1)}\\
&\quad+3k!\left(\frac{3i-j+2}{\bar{\gamma}}\right)^{-(k+1)}\\
&\quad-e^{-\left(\frac{3i-j+2}{\bar{\gamma}}\right)y}\sum_{m=0}^{k+1}\frac{(k+1)!}{m!}y^m\\
&\quad-\left(\frac{3i-j+2}{\bar{\gamma}}\right)^{-(k+1-m+1)}\Bigg)
\end{aligned} \tag{32}$$

In Fig. 17, the analytical outage probability for the proposed schemes are compared to the simulations results for $N_t = 3, 6, 9, 12$ and $R = 3, 4, 5$ bits/(sHz). This performance comparison validates the performance of the proposed schemes. As expected, with the increase in the number of available antennas to select from, the outage probability performance improves.

In Fig. 18, the outage probability of the two proposed scheme are compared and a performance similar to the one observed in Fig. 14. The performances of both the proposed

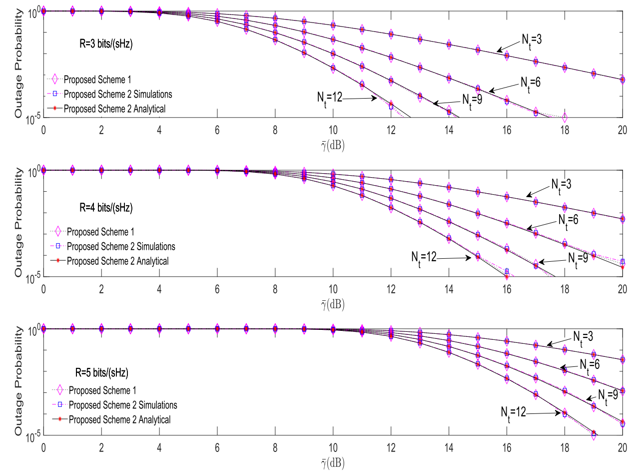

FIGURE 17. Outage probability performance analysis of proposed transmit antenna selection schemes.

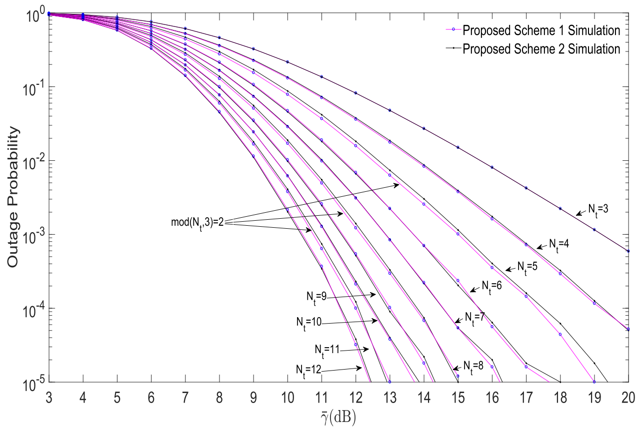

FIGURE 18. Outage probability performance analysis of proposed transmit antenna selection schemes.

schemes are almost same except when $\mod (N_t, 3) = 2$, the reason being the number of subset to select from is more in proposed scheme 1 compared to proposed scheme 2 which leads to a SNR gap between the two schemes. But as N_t increases the SNR gap decreases and the outage probability becomes almost same for both the proposed Schemes.

Next, the outage probability of the proposed scheme is compared to the schemes discussed in Section III.

In Fig. 19, we can observe that the outage probability is in line with the BER performance, as we remove randomness in selection and increase the number of antenna subset to select from, the performance improves. The proposed schemes are better compared to [[4], Schemes 2 and 3] and that of scheme proposed in [6]. From Fig. 20, we can observe that, similar to the BER performance, the proposed schemes even with $N_t = 10$ outperforms scheme 2 [4] with $N_t = 11, 12$ and the proposed schemes with $N_t = 10$ also outperforms scheme 3 [4] with $N_t = 11$.

VI. RESULTS

The results of various performance analysis & comparison of both the proposed schemes vs the reference schemes carried

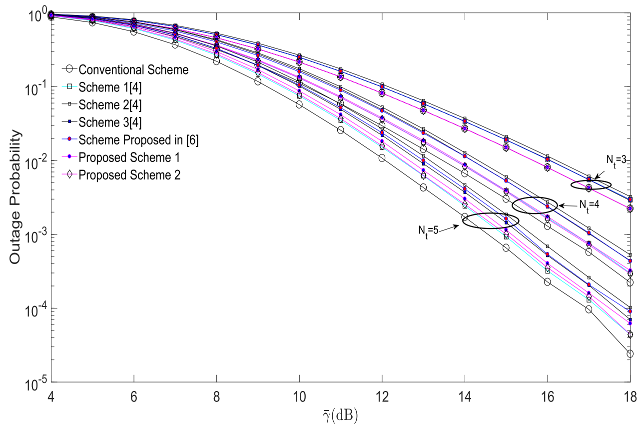

FIGURE 19. Outage probability performance comparison of proposed transmit antenna selection schemes with those proposed in [4] and [6].

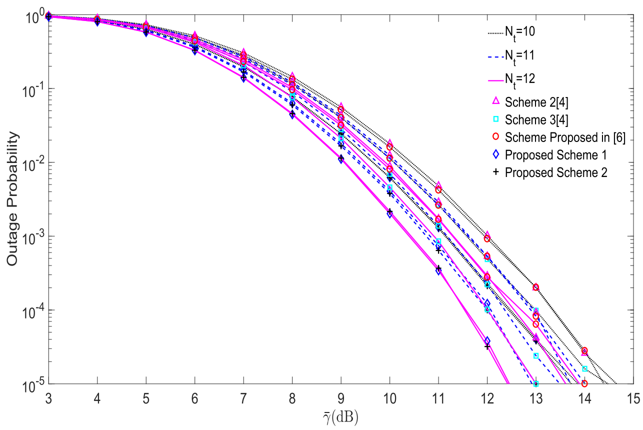

FIGURE 20. Outage probability performance comparison of the proposed transmit antenna selection schemes with scheme 2 [4], scheme 3 [4] and the Scheme proposed in [6].

TABLE 2. Performance comparison of proposed schemes.

Metrics	Scheme 1 [4]	Scheme 2 [4]	Scheme 3 [4]	Scheme Proposed in [6]
Feedback Rate (Fig.10)	Better	Equal[7]	1 Bit[8] More	Equal for most cases
SNR Loss (Fig.11)	≈ 1.1dB Worse	≈ 0.5dB Better	≈ 0.3dB Better	≈ 0.5dB Better
BER (Fig.16)	Poor	Better	Better	Better
Outage Probability (Fig.19)	Poor	Better	Better	Better
Diversity (Fig.13)	Same	Same	Same	Same

out in Section V can be summarized as tabulated in Table 2. Both the proposed schemes perform similar except that proposed scheme 2 requires 1 bit less feedback bits compared to proposed scheme 1 when $N_t = 4^i + 1,\ 1 \le i \le \infty$. Proposed scheme 1 and proposed scheme 2 have the same

[7] except at $N_t = 4^i + 1,\ 1 \le i \le \infty$
[8] except at $N_t = 4^i + 1,\ 1 \le i \le \infty$

number of feedback bit as that of the scheme proposed in [6] except when $N_t = 2^i + 1,\ 1 \leq i \leq \infty$ and $N_t = 2^i + 1,\ 1 \leq i \leq \infty,\ 3 \mid N_t$ respectively. As N_t increases the difference in performance of both the proposed scheme reduces.

VII. CONCLUSIONS

In this work, two novel transmit antenna selection schemes with reduced feedback rate are proposed. The performance of the proposed schemes are compared to the conventional and previously proposed schemes in literature w.r.t. feedback rate, SNR loss, BER and outage probability. The analytical BER and outage probability expressions for a special case of the proposed scheme 2 with BPSK Alamouti STBC derived using order statistics on pdf of the instantaneous SNR are substantiated with simulations. The proposed schemes tradeoffs feedback rate with other metrics in an optimum manner compared to previously presented schemes in literature. With the feedback rate and BER performance of the proposed schemes between that of scheme 1 [4] and scheme 3 [4], the proposed schemes successfully bridges the gap as a better alternative compared to scheme 2 [4] and the scheme proposed in [6]. Derivation of analytical expressions for the remaining cases, its validation through simulations and system level performance will be subject of future research efforts. It would also be interesting to study the performance gain which it offers when integrated with GFDM systems.

ACKNOWLEDGMENTS

We would like to Thank Adarsh Tripathi of Pukhrayan from Kanpur Dehat for fruitful discussions on techniques to reduce feedack rate.

REFERENCES

[1] L. Zheng and D. N. C. Tse, "Diversity and multiplexing: A fundamental tradeoff in multiple-antenna channels," *IEEE Trans. Inf. Theory*, vol. 49, no. 5, pp. 1073–1096, May 2003.

[2] T. M. Duman and A. Ghrayeb, *Coding for MIMO Communication Systems*. Hoboken, NJ, USA: Wiley, 2008.

[3] B. Kumbhani and R. S. Kshetrimayum, *MIMO Wireless Communications Over Generalized Fading Channels*. Boca Raton, FL, USA: CRC Press, 2017.

[4] Z. Chen, I. B. Collings, Z. Zhou, and B. Vucetic, "Transmit antenna selection schemes with reduced feedback rate," *IEEE Trans. Wireless Commun.*, vol. 8, no. 2, pp. 1006–1016, Feb. 2009.

[5] A. P. Shrestha, T. Han, Z. Bai, J. M. Kim, and K. S. Kwak, "Performance of transmit antenna selection in non-orthogonal multiple access for 5G systems," in *Proc. 8th Int. Conf. Ubiquitous Future Netw. (ICUFN)*, Jul. 2016, pp. 1031–1034.

[6] A. F. Coskun and O. Kucur, "Feedback-rate efficient transmit antenna selection/alamouti scheme with robust error performance in the presence of feedback errors," *IEEE Commun. Lett.*, vol. 17, no. 5, pp. 908–911, May 2013.

[7] Z. Zhou, N. Ge, and X. Lin, "Reduced-complexity antenna selection schemes in spatial modulation," *IEEE Commun. Lett.*, vol. 18, no. 1, pp. 14–17, Jan. 2014.

[8] P. Yang, Y. Xiao, Y. L. Guan, S. Li, and L. Hanzo, "Transmit antenna selection for multiple-input multiple-output spatial modulation systems," *IEEE Trans. Commun.*, vol. 64, no. 5, pp. 2035–2048, May 2016.

[9] S. E. El-Khamy, K. H. Moussa, and A. A. El-Sherif, "Performance of enhanced massive multiuser mimo systems using transmit beamforming and transmit antenna selection techniques," *Wireless Pers. Commun.*, vol. 94, no. 3, pp. 1825–1838, 2017.

[10] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Trans. Inf. Theory*, vol. 45, no. 5, pp. 1456–1467, Jul. 1999.

[11] Y. N. Trivedi and A. K. Chaturvedi, "Performance analysis of multiple input single output systems using transmit beamforming and antenna selection with delayed channel state information at the transmitter," *IET Commun.*, vol. 5, no. 6, pp. 827–834, Apr. 2011.

[12] J. Wang, A. I. Pérez-Neira, and M. Gao, "A concise joint transmit/receive antenna selection algorithm," *China Commun.*, vol. 10, no. 3, pp. 91–99, 2013.

[13] H. A. David and H. N. Nagaraja, *Order Statistics*. Hoboken, NJ, USA: Wiley, 2003.

[14] M. K. Simon and M.-S. Alouini, *Digital Communication Over Fading Channels*, vol. 95. Hoboken, NJ, USA: Wiley, 2005.

[15] B. C. Arnold, N. Balakrishnan, and H. N. Nagaraja, *A First Course in Order Statistics*. Philadelphia, PA, USA: SIAM, 2008.

[16] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*. San Diego, CA, USA: Academic, 2014.

[17] Z. Chen, J. Yuan, B. Vucetic, and Z. Zhou, "Performance of Alamouti scheme with transmit antenna selection," *Electron. Lett.*, vol. 39, no. 23, pp. 1666–1668, Nov. 2003.

[18] H. Jafarkhani, *Space-Time Coding: Theory and Practice*. Cambridge, U.K.: Cambridge Univ. Press, 2005.

[19] İ. E. Telatar, "Capacity of multi-antenna Gaussian channels," *Eur. Trans. Telecommun.*, vol. 10, no. 6, pp. 585–595, 1999.

SUDHIR KUMAR MISHRA is currently a Ph.D. Research Scholar with a focus on wireless communication with the Department of Electronics and Communication Engineering, Visvesvaraya National Institute of Technology, Nagpur. His current research interests include MIMO systems, non-orthogonal multiplexing techniques for future generation communications, and time frequency analysis for wireless applications.

KISHORE DAMODAR KULAT is currently a Professor with the Department of Electronics and Communication Engineering, Visvesvaraya National Institute of Technology, Nagpur. He has authored or co-authored over 100 papers in international/national journals and conferences. His current research interests include wireless, communication systems, networking, and real-time embedded system design. He is a Life Member of the Indian Society for Technical Education, a Fellow Member of the Institution of Electronics and Telecommunication Engineers, and a member of the Institution of Engineers.