

Analysis of Energy Efficiency for MIMO Wireless Network using Manifold Techniques

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Applications for wireless networks are growing despite the challenge of the energy costs. Further, the number of users is increasing within the basic wireless facilities which are depending on the energy efficient systems. Apparently, users need minimum energy cost influenced with the efficient design of wireless network such as multiple-input, multiple-output (MIMO). In this research, I have considered some energy-saving ways for massive MIMO wireless system, which will be able to integrate with the next generation technology. The process of energy saving should be utilized between the source and destination of massive MIMO wireless network. Best and efficient processing will maximize the total energy efficiency (EE). To tackle the dilemma of supporting EE, MIMO with Pn -manifold or massive MIMO with feedback will be used as a new method. Manifolds are types of nonlinear multi-dimensional mathematics applied in MIMO system, which allow us to enhance the efficiency of the communication channel. Despite the less energy consumption used in the MIMO design, manifolds techniques are even better in terms of complexity and cost. In the proposed approach, feedback channel and computation of quantization influenced with Pn and Stiefel manifold, provide better resolution and spectrum during the communication than the existing systems. Therefore, this method will be useful to enhance the total EE.

Keywords: wireless network, Pn -manifold, MIMO network, energy efficiency, feedback

1. INTRODUCTION

In this special issue, massive MIMO, known as large-scale antenna system, is a key area of research. The massive MIMO expected in next-generation technology handles large numbers of services through high-speed channels. In order to increase the use of renewable energy systems and applications, low-power which holds the less complex hardware components may be employed. According to [1, 2], massive MIMO could be improved when the service providers increase the number of useable antennas in the base station. Massive MIMO enables a significant improvement in the use of renewable energy systems and applications. Large-scale antenna [3, 4] requires a lot of energy in real-time, but these complex configurations waste significant energy because unnecessary interference and alignments are affecting the total EE [5].

Interference, noise, and alignments are key areas of this EE research because it takes more power and reduces the EE [6]. Considering key areas with optimum EE, dimensions of matrices can be reduced during the transmission and reception which has a number of processing steps such as quantization feedback and optimization [7]. Using Pn -manifold in the quantization provides achievable rates between the infinite and finite

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rate feedback of the MIMO model. Current MIMO technology uses $N_t > 2$ transmitters and $N_r > 2$ receivers but massive MIMO should have practical limits of which an optimum energy saving depends on a number of antennas used in transmitter and receiver [8, 9]. In this research, authors have focused on the theoretical challenge of massive MIMO systems involved with feedback [10], and Pn -manifold [11, 12].

The Stiefel manifold is a set which has some random elements obtained from defined objects. In other words, it is a compact sub-manifold of any fixed $n \times k$ matrix of rank k . The space of unit vectors is also considered as the Stiefel manifold. The sphere and the orthogonal group of orthogonal matrices are special cases of Stiefel manifold. The definition, mathematical notation, *etc.* of the Stiefel manifold are applied directly to the quantization effects on a massive MIMO system. Stiefel manifold can be used in MIMO precoding, beamforming, channel estimation, and some specific modulation schemes. To optimize the functions used in massive MIMO, Stiefel manifold can be used because it converges very fast. Hence, it might be useful for energy saving and renewable energy techniques [13].

The motivation of this research is energy saving, which could be renewable energy and total EE of massive MIMO. Further, this research motivates us to reduce the energy cost in future medical, military, and business applications [14-16]. According to the prediction cost of energy, massive MIMO system is going to dominate the next few decades. It will not only support medical communications but also provide better solutions for other applications, such as energy-efficient routing designs using wireless sensors and mesh networks [17, 18]. Despite these applications and supports, other technical specifications such as different elements dipoles or patches [19, 20] are considered. Here, authors studied the mutual coupling and correlation effects for the downlink of a multi-user MIMO system. In this motivation, a massive MIMO process will take significant steps in tackling the problem, particularly on the application of renewable energy and total EE considered with antenna elements.

In this paper, we have contributed a new design of theoretical model created from manifold techniques and feedback channel with quantization. In this proposed design, the EE gain (G) of basic and massive MIMO can be defined as $G = \text{MIMO/SISO}$. Further, Pn -manifold is a nonlinear multi-dimensional matrix which helps us to characterize the channel matrix obtained from massive MIMO. In order to maximize the use of EE and renewable energy, matrices of basic and massive MIMO channel is optimized using Pn -manifolds. Following quick definitions help us to understand the use of antennas.

Definition 1: SISO (Single-Input Single-Output) which means that the transmitter and receiver of the radio system have only one antenna. It is a simple single variable control system.

Definition 2: In the MIMO (Multiple-Inputs Multiple-Outputs) system which employs multiple antennas in the transmitter and/or receiver.

This article has the following organized contents: In section 2, I present the overview of the manifolds of massive MIMO and how they work within the MIMO architecture, which provides renewable energy systems and applications. It also shows other types of manifolds that help to design an efficient energy-saving system. In section 3, the

proposed approach is described with the necessary details of energy-saving approaches based on Pn -manifold and its properties. Section 4 describes evaluation results that we have obtained from Matlab tools, and it also provides some analysis of the proposed method. Finally, section 5 concludes the article.

2. THEORETICAL BACKGROUND

In this section, we are going to give a brief introduction of software watermark, software watermark techniques, algorithms, different types of software watermark attacks and related work. In this section, manifolds' utilization in massive MIMO is considered with an existing MIMO technology. As shown in Fig. 1, examples of manifolds [21, 22] could be imagined for massive MIMO. Further, manifolds can take many shapes such as circles, spheres, and tori, which are formed from a single closed shape to complicated shapes. The transformation of different shapes changes the dimensions of manifolds, which is one of the ways to reduce the data size in MIMO applications. Thus, properties of manifolds, which include an optimized channel matrix through the geometrical approaches, can be used to control power and energy indirectly. Pn -manifolds, Stiefel manifolds, and other particular manifolds allow us to make a less complex design in massive MIMO precoding, beamforming, channel estimation, and some specific modulation schemes. Hence, total EE can be calculated from these components used in massive MIMO.

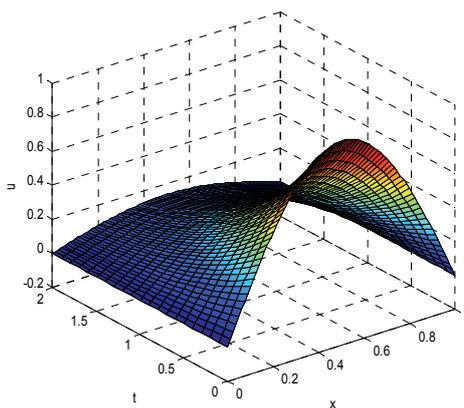


Fig. 1. Example of the manifold.

2.1 Pn -manifold

The manifold is a multi-dimensional field assumed as either complex or real matrix which takes the actual values of the complex numbers. In this research, I have studied that capacity and power changed through the manifold, which optimizes the overall problems in massive MIMO schemes.

Definition: Sets of positive semi-definite matrices are considered to identify the Pn -manifold with various trace and ranks [23]. As in Eq. (1), general Pn -manifolds can be written as:

$$Pn(p, \mathbb{F}, Tr(Q) \leq \rho^2, Rk(Q) = s). \quad (1)$$

According to [23], classification of eight different manifolds could be introduced to analyze the dimensions based on the categories of Pn -manifold. As mentioned in Table 1, eight different manifolds take different dimensions that lead us to calculate the complexities and EE. According to the size of the matrices and trace used in massive MIMO, Pn -manifold can be identified with various ranks (s). Here, dimension ($p = n$) and complexity in each category can be considered for energy saving.

Table 1. Comparison of energy saving.

Categories of Pn -manifold	Dimension	Notes for clarifications
$Pn(p, \mathbb{R}, = \rho^2, = s)$	$\frac{s}{2}(2n - s + 1) - 1$	When both trace (ρ) and rank (s) are fixed
$Pn(n, \mathbb{R}, = \rho^2, \leq s)$	$\frac{s}{2}(2n - s + 1) - 1$	Rank (Rk) can be set to less than or equal to s
$Pn(p, \mathbb{R}, \leq \rho^2, = s)$	$\frac{s}{2}(2n - s + 1)$	Power can be set to less than or equal to ρ^2
$Pn(n, \mathbb{R}, \leq \rho^2, \leq s)$	$\frac{s}{2}(2n - s + 1)$	Both should be smaller but can be set to high
$Pn(n, \mathbb{C}, = \rho^2, = s)$	$s(2n - s) - 1$	Both ρ^2 and s are fixed
$Pn(n, \mathbb{C}, = \rho^2, \leq s)$	$s(2n - s) - 1$	$Rk \leq s$
$Pn(n, \mathbb{C}, \leq \rho^2, = s)$	$s(2n - s)$	Power $\leq \rho^2$
$Pn(n, \mathbb{C}, \leq \rho^2, \leq s)$	$s(2n - s)$	$Rk \leq s$ & Power $\leq \rho^2$

Examples 1 and 2 show the original set and short form representation of Pn -manifold respectively.

Example 1: Complex case

$$Set\{Q \in \mathbb{C}^{16 \times 16} | \forall x \in \mathbb{C}^{16} x^H Q x \geq 0, Tr(Q) \leq 5, Rk(Q) = 4\}$$

$$\text{Short form } Pn(16, \mathbb{C}, \leq 5, = 4)$$

Example 2: Real case

$$Set\{Q \in \mathbb{R}^{16 \times 16} | Q^t = Q, \forall x \in \mathbb{R}^{16} x^t Q x \geq 0, Tr(Q) \leq 4, Rk(Q) = 3\}$$

$$\text{Short form } Pn(16, \mathbb{R}, \leq 4, = 3)$$

The channel state information on the transmitter (CSIT) defined in [24] is dependent on the energy that source provides variable power. The Pn -manifold influences with channel matrix that is a primary and main parameter obtained from massive MIMO system. Hence, CSIT should be controlled with optimum power and better EE.

$$C_{CSIT-Fb} \approx E_H \log \det(I + \tilde{H}_{AS}) Q_{AS} \tilde{H}_{AS}^H \quad (2)$$

In Eq. (2) E_H represents the usual expectation over the ensemble of H matrices which allow us to calculate optimal submatrix as below.

$$\tilde{H}_{AS} = \arg \max_{\tilde{H} \in \mathcal{H}} \log \det(I + \tilde{H}Q_w(\tilde{H})\tilde{H}^H) \quad (3)$$

Here, Eq. (3), matrix $Q_w(\tilde{H})$ is the output of the waterfilling and $Q_{AS} \in Pn(p, \mathbb{C}, = \rho^2, \leq k)$. Maximizing channel capacity of massive MIMO should be important, but power is crucial. Hence, manifold techniques (Grassmannian or Riemannian or Stiefel manifold) can be used because it provides the better matrix with better rank, and dimension.

2.2 Grassmannian Manifold

Quantization problems of the source (element of the channel matrix) that lives on complex Grassmann manifold are studied in [25]. The particular structure of the Grassmann manifold that affects the function of the overall MIMO system depends on the rank and dimension of the channel matrix. Traditional problem of quantization and Euclidean in MIMO communication system needs manifolds techniques that enhance the capacity of the channel.

$$\mu = 1 - \left[\frac{2 \times \Gamma(\frac{2}{N}) \times \alpha^{-\frac{2}{N}}}{s \times N} \right] 2^{-\frac{2N_f}{N}} \quad (4)$$

Where μ is Grassmannian power efficiency factor Eq. (4), could be applied in the capacity analysis based on Grassmannian manifold. Dimension (N) and feedback bits (N_f) are determined from manifolds used in MIMO channel matrix. The ball volume coefficient

$$\alpha = \frac{1}{\Gamma(\frac{N}{2}+1)} \prod_{i=1}^s \frac{\Gamma(n-i+1)}{\Gamma(s-i+1)}. \quad (5)$$

In Eqs. (4) and (5), dimension $N = 2s(n-s)$. This results in the Grassmannian finite-rate feedback capacity being approximated as

$$C_{CSI-Fb} \approx E_H \sum_{i=1}^s \log\left(1 + \frac{\mu \times d_i^2 \times SNR}{2}\right). \quad (6)$$

Maximizing the minimum distance between points on Grassmannian manifold allow us to maximize the average mutual information upper bound of a MIMO system with feedback [25]. Although the optimal distance metric depends on the receiver type, finite-rate feedback capacity Eq. (6) varies with SNR.

2.3 Riemannian Manifold

According to [26], it can be applied to many functions used in massive MIMO where quantization technique is one of the energy-consuming processes in massive MIMO. The precise power series expansion of the volume of small geodesic balls in a real manifold of arbitrary dimension is given in [27]. Capacity analysis, manifolds and the volumes of manifolds are used to find the solution of renewable energy in massive MIMO.

Capacity analysis based on optimization of interference alignment in MIMO and $G_{n,p}$

on the Riemannian manifold is currently a very active research field in distortion measurements that are part of the quantization, and it is used more broadly in the numerical optimization discipline. In a complete Riemannian view, the distance between the two selected points along the geodesic curve should be optimized. Geodesic curves and optimized distances around the manifold are expected to minimize the dimension and increase the smoothness of the curve used around the manifold. Definition 1 and Theorem 2 can be applied to identify the basic properties of the Riemannian manifold.

Definition 1: A matrix known as a Riemannian sub-manifold M_a of a Riemannian manifold M , is called *totally geodesic* if all geodesics in this sub-manifold M_a are also geodesics in M . [27]

Theorem 2: M_a is totally geodesic in M if and only if all second fundamental forms of M_a vanishing identically [27].

2.4 Stiefel Manifold

The Stiefel manifold $V_{p,k}^{\mathbb{C}}$ is the set of p -tuples of orthonormal vectors or equivalently $V_{p,k}^{\mathbb{C}} = \{Q \in \mathbb{C}^{k \times p} | Q^T Q = I_p\}$ where I_p is the $P \times P$ identity matrix. If Stiefel manifold has matrix Q with full column rank, the unique solution will be expected. According to [28], Stiefel manifold plays an important role to enhance the receiver performance of the MIMO system. Further, the definitions of the tangent space and the retraction explained in [28] allow us to improve the minimum distance within the Stiefel manifold concepts.

The collections of covariance matrices are the points on the Stiefel manifold $V_{p,k}$, which is $Q \in \mathbb{F}^{k \times p}$. Here, \mathbb{F} can be a real (\mathbb{R}) or complex (\mathbb{C}) field. The relationship between the complex Pn -manifold and Stiefel manifold volumes as in Eq. (7) is obtained through the Riemannian manifold.

$$Vol(P_n(p, \mathbb{C}, \leq \rho^2, = k)) = Vol(V_{p,k}^{\mathbb{C}}) \cdot \frac{(2\pi)^{-k}}{k!} \frac{(\rho^2)^{2pk-k^2}}{k(2p-k)!} \cdot \prod_{i=1}^k (2p-k-i)! \cdot i! \quad (7)$$

According to Eq. (7) and Pn -manifold concept, the capacity of the MIMO channel and the system can be obtained. The real case is introduced in [28]. According to [28], soft dimension reduction is used to develop an efficient feedback link between the receiver and transmitter of MIMO. Here, non-square pseudo-orthogonal matrix known as a matrix of Stiefel manifold is used to minimize the joint diagonalization cost function.

Although the mostly employed manifolds are Stiefel, Grassmann and Riemannian manifolds in the wireless communication systems, Pn -Manifold is better. According to the theoretical comparisons and investigations, it is not only flexible to employ in massive MIMO wireless channel, but also it allows us to reduce the rank and dimension of the channel matrix quickly and efficiently. Thus, Pn -manifold helps us to reduce the overall complexity of the design of massive MIMO system.

3. DESIGN OF THE PROPOSED SCHEME

The primary aim of this research is to enhance the EE in massive MIMO, which is the future problem in next-generation networks. In the massive MIMO, designing, optimizing,

and managing a number of antennas in both transmitting and receiving terminals are a challenge in individual applications. These antennas increase the dimension of channel matrices and the wireless transmissions through which the direction of antenna uses in the transmitter. Here, the power used for the transmission is increasing with a large number of antennas mentioned as massive MIMO. The novel approach is how to reduce the power in the transmission by using a renewable-energy system, which increases the EE in overall massive MIMO. Renewable energy obtained through manifold technique is very attractive, as explained in this section.

Although we study the theory of all manifolds, employing Pn -manifold to analyze the EE in massive MIMO can be highlighted as what we did to this paper. Further, applying Pn -manifold theory to massive MIMO system which includes transmission, feedback, quantization, etc. allows us to calculate the total EE. Hence, as the main contribution, we can highlight the design of the massive MIMO system which includes the feedback. In this research, Pn -manifold is dominating to improve the EE through the optimized design as the main objective of this research.

3.1 System Model for Power Reduction

As shown in Fig. 2, the current MIMO system may be assumed as a massive MIMO system when many antennas are used in both terminals. A massive system with a large number of antennas is still in the development stage theoretically, but power reduction and EE can be achieved with a reasonable number of antennas. This extra link between the receiver and transmitter is called feedback, which plays an important role in the mathematical model of the massive MIMO system.

In MIMO system model, the parameters of the input X_i , channel H_i , noise η_i , and output Y_i are used to form a mathematical model.

$$Y_i = \sqrt{\rho} X_i H_i + \eta_i \quad (8)$$

In this system equation Eq. (8), following dimensions are used, $X_i \in \mathbb{F}^{N_t}$, $\eta_i \in \mathbb{F}^{N_r}$, $H_i \in \mathbb{F}^{N_r \times N_t}$ and $Y_i \in \mathbb{F}^{N_r}$. In MIMO system, N_t and N_r are a number of transmitter and receiver antennas respectively.

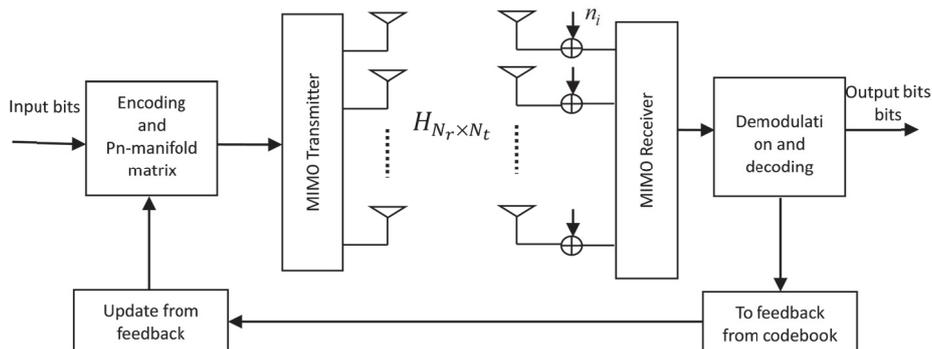


Fig. 2. System model of massive MIMO scheme.

In this research, 16×16 MIMO scheme is considered to verify the basic parameters depending on the H matrix. The system model in Fig. 2 depends on Eq. (8), which solves the problems between the channel and receiver output (Y_i). In order to have a complete system equation, input bits considered as original information (s) of the MIMO transmitter should be encoded and sent to the channel ($X_i = V_q s$). In this model, V_q is a quantized version of the channel matrix H .

3.2 Channel Matrix

Basic and current MIMO schemes use complex data for channel development, which is a $N_r \times N_t$ dimension matrix. The optimum design of the channel matrix depends not only on the size of the antennas but also on the calculation which takes unnecessary power. In order to increase the EE, optimum design and calculations are considered in the massive MIMO scheme. The MIMO Channel matrix influenced with transmitting and receiving antennas helps to calculate the quantized matrix through the singular value decomposition (SVD) procedures. Basically, the channel matrix and its decompositions characterize the overall system through the manifolds. Full CSI based on finite and limited feedback is calculated from the SVD and channel matrix of MIMO. The channel matrix of basic and current MIMO scheme can be written as

$$H_i(t) = \begin{bmatrix} h_{11}(t) & h_{12}(t) & \cdots & h_{1N_t}(t) \\ h_{21}(t) & h_{22}(t) & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ h_{N_r1}(t) & \cdots & h_{N_rN_t}(t) \end{bmatrix} \quad (9)$$

Where the individual elements used in Eq. (9) is a complex number could be written as Eq. (10), which is given below.

$$h_{nm}(t) = \text{Re}\{h_{nm}(t)\} + j\text{Im}\{h_{nm}(t)\} \quad (10)$$

3.3 Covariance Matrix

It is another approach to reducing power in some matrix calculations, which help us to design a Pn -manifold from the channel matrix of massive MIMO. In the existing technology of the MIMO channel, the covariance matrix Eq. (11) plays a major role. To analyze the essential features such as power and distortion, the idea of manifolds had not been used at all since researchers developed the MIMO technique. In recent years, the idea of using a manifold in MIMO systems has increased because the mathematics of manifold takes an important step to change the features of MIMO. So far, four different manifolds are employed in MIMO applications and MIMO channel improvement.

To calculate the energy when massive MIMO system is active, the covariance matrix is considered as an input to the feedback of MIMO system, and the capacity/rate of the

feedback is measured as an output. Designing a fixed covariance codebook to maximize the average rate is a challenging problem because EE influences the capacity.

$$C_m = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1N_t} \\ q_{21} & q_{22} & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ & & \cdots & \\ \vdots & \vdots & \vdots & \vdots \\ q_{N_r1} & \cdots & q_{N_rN_t} \end{bmatrix} \quad (11)$$

The covariance matrix C_m can be decomposed into the following form $C_m = U\Lambda U^H$ where U and Λ are $N_t \times N_t$ unitary and diagonal matrices respectively. The performance of the quantization codebook depends on the rank- N_t codebook but fewer elements than the lower-rank codebooks might be better. Regarding the future EE performance, it is not guaranteed that we can find a rank- N_t code word satisfying the requirement of $V^H U \approx I$. Further, considering a rank- N_t codebook of B bits, the computational complexity involved in exhaustively searching the optimal \mathbf{V} is on the order of $O(2^B \cdot N_t^{(N_t-1)})$, which can be prohibitively expensive for a large N_t . Rank of the C_m is equal to the number of eigenvalues. Eq. (11) can be rewritten with the eigenvectors and eigenvalues (λ).

$$C_m = \sum_{i=1}^i \lambda_i u u^H \quad (12)$$

The total number of feedback bits decided from the best rank of C_m and eigenvalues is useful to increase the EE. If the ratio between the eigenvalues is quantized with Δ bits, the total number of feedback bits can be calculated as $2B+\Delta$.

3.4 Manifold from SVD

Using SVD and matrix calculations, the mathematician proved that SVD saved much energy during the real-time processing. The decomposition of the channel matrix is given in Eq. (12), where the 3rd matrix (U_i) can be assumed as a representation of the manifold, which has some important properties to increase the quality of the massive MIMO channel. In addition to this quality, different dimensions and the types of manifolds not only provide cost reduction but also improve the capacity and CSI of the overall MIMO through the feedback.

The rank of H_i is H_m , which is less than or equal to either the number of transmitting antennas or number of receiving antennas ($H_m \leq N_t$ or $H_m \leq N_r$). To elaborate this concept, SVD of H_i can be written as

$$H_i = A_i \mathcal{L}_i U_i. \quad (13)$$

In Eq. (13), dimensions of matrices are such as $A_i \in \mathbb{F}^{N_t \times N_m}$, $\mathcal{L}_i \in \mathbb{R}^{N_m \times N_m}$ and $U_i \in \mathbb{F}^{N_t \times N_m}$. Complex case of Stiefel manifold can be written as

$$V_{p,k}^C = \{Q, U \in \mathbb{F}^{k \times p} | Q^T Q = U^T U = I_p\}. \quad (14)$$

In Eq. (14), the dimension of Stiefel manifold is $p = N_l$ and $k = N_m$. Singular values are obtained from, which channel matrix is represented by 3 matrices that contain 2 orthonormal column matrices and singular matrix. The middle of these 3 matrices is orthonormal matrices known as singular matrix.

A geometric approach of Grassmann manifold allows us to develop the necessary analysis of additive white Gaussian noise channel (AWGN). Further, matrix selection of beamforming in MIMO communication is influenced by a distortion-rate function obtained from channel capacity analysis [28-30].

3.5 Geometrical Approach of Manifold

It is another approach to reducing power in some matrix calculations, which help us to design a Pn -manifold from the channel matrix of massive MIMO. In Fig. 3, tangents are given in three different directions ($Q_a X_a$, $Q_a Y_a$ and $Q_a T_a$) corresponding through Q_a , which is the point on the manifold represented by a matrix. The norm of these tangents at the point Q_a is $Z_a Q_a$, which is vertical to the plane of $X_a Y_a$. This plane does not have to be parallel to the real xy plane. The geodesic curve is represented as $Q_a Q_b$, but it is perpendicular to this curve. All tangents drawn through this point (Q_a) are on the same plane, but they do not have to be perpendicular to that curve. The norm must be perpendicular to that plane, but it should be located at Q_a . So, we cannot have more than one norm for that particular manifold. Manifolds do not have to be a sphere, but MIMO communication uses a few examples based on the spherical form of manifolds.

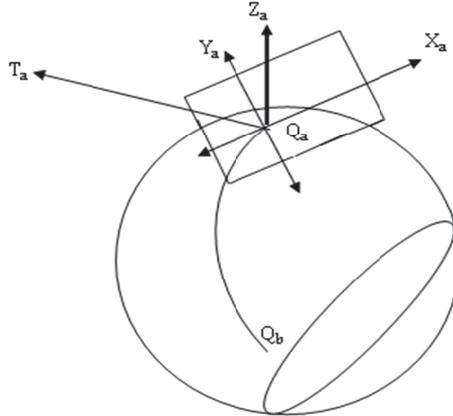


Fig. 3. Basic representation of the manifold.

The same manifold represented by different mathematical approaches (real and complex) that lead all the calculations used for MIMO applications is interesting. These different approaches reduce the complexity, rank, and dimensions of the matrices used in the manifold. A geodesic represented by the curve of the shortest length between two points on a manifold is determined carefully because distance properties are a fundamental problem in all the cases, including EE analysis in massive MIMO.

$$E_c = \zeta \sum_{i=1}^{N_T} \sum_{j=1}^{N_R} d_{ij}^{k_{ij}} + \frac{P_c}{R_b} \quad (15)$$

In Eq. (15), E_c is the average consumption per bit, P_c is the total circuit power used in the transmitter and receiver; N_t and N_r are the number of transmitter and receiver antennas, respectively; d_{ij} is the distance between node i and j ; and k_{ij} is the path loss factor from i to j . The value ζ and equation are considered in [31]. EE can be measured in bits per Joule (capacity is bits per channel we use and power is Joule per channel).

$$EE = \frac{\text{Capacity}}{\text{Power}} \quad (16)$$

In Eq. (16), capacity is limited by the hardware used in massive MIMO and the power includes all electronic circuits in all components during the processing.

The validity of proposed approach can be demonstrated through the following theoretical analysis. Overall EE depends on the optimized design (low complex design) of the massive MIMO system which influences the dimension of the channels including feedback. The theoretical EE can be achieved through the best or optimized dimension and rank of the channel matrices obtained from the massive MIMO channels. Using manifold theory, we can optimize the dimension and rank of the channel matrices and reduce the complexity of the massive MIMO system. For instance, full rank and optimized rank can produce the same performance. Thus, we can prove the proposed approach.

4. RESULTS AND DISCUSSIONS

In this analysis, a fixed number of 16 transmitting antennas were employed in the MIMO system, which has a variable number of receiving antennas. Fig. 4 shows the capacity/rate of the massive MIMO system with Pn -manifold, which provides variable results when feedback bits are up to 200 bits.

In Eq. (11), SVD decompositions of matrix H were used. This SVD was controlled by manifold's properties, which provide the MIMO scheme with better performance in all necessary essential elements such as capacity, and quantization simplifies the calculations.

$$C_{CSIT-Fb} = 5 - 1.5 \left(2^{-\left(\frac{N_f}{2N_r N_m - N_m^2 - 1}\right)} \right) \quad (17)$$

Fig. 4 is drawn from Eq. (15), where $N_m = \min(N_r, N_t)$. Details of Eqs. (17) and (18) can be found in [32].

$$C_{CSIT-Fb} = 5 - N_m \times \log \left(1 + n \times 2^{-\left(\frac{N_f}{2N_r N_m - N_m^2 - 2}\right)} \right) \quad (18)$$

Here, n is the constant considered between the small value of infinity, and it depends on the channel, and quality of antennas.

In Fig. 5, long and short-term power constraints are shown with increasing feedback bits. In order to analyze the power with rates, basic MIMO can be used, but it can be extended to massive MIMO with different feedback bits.

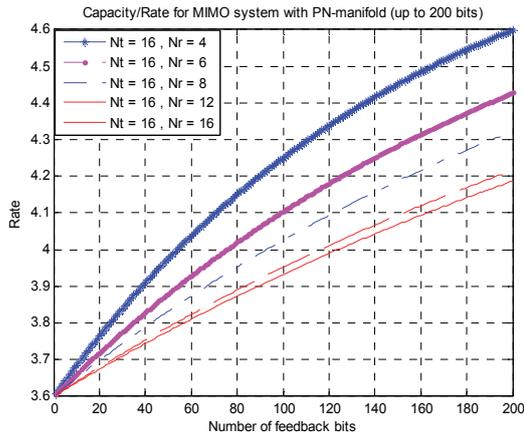


Fig. 4. Capacity variation for first 200 feedback bits.

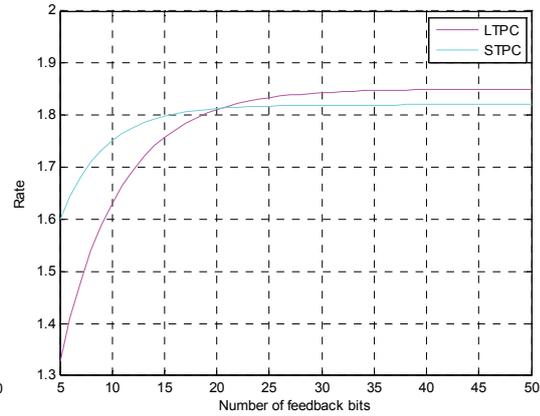


Fig. 5. Comparison of power using P_n -manifold.

In Fig. 6, we employed three different sets of transmitting antennas they are 10, 20 and 40. From these 3 sets and relevant parameters considered in [32], we calculated the power efficiency factors Eq. (4), which are very useful to analyze the EE in massive MIMO. Using the equation Eq. (16), we can calculate and renew EE for future services used in massive MIMO. As shown in Fig. 7, renewable energy depends on the number of antennas, capacity and signal power.

To analyze the energy efficiency (EE), energy-based experiments and simulations are preferred for the evaluation of performance in results and discussion. Although many key performance indicators (KPI) are available, we currently use selected KPIs investigated for analyzing EE in massive MIMO are given below.

As mentioned in Eq. (16), capacity/rate is the one of the KPIs, which increases the EE. Further, Eq. (17) influences with the capacity/rate, dimensions, ranks and the types of P_n -manifold. Figs. 4 and 5 show the capacity/rate increment when we increase the number of feedback bits.

Power efficiency factor is another KPI, which is also involved with the dimensions of the channel matrix. Further, reducing the dimension using manifold concept allows us to increase the power efficiency factor and EE. Fig. 6 shows the details to improve the EE via power efficiency factor calculations. Although the dimensions of the channel matrix involve directly in the EE calculations, the manifold concept allows us to reduce not only the rank and dimension but also provide the rank optimizations.

Path-loss is also one of the KPIs which affects the energy during the transmission. Further, it depends on the gains of the massive MIMO. Although gain calculation is not directly involved with the manifold, percentage or Improvement of capacity/rate changes can be used to calculate the gains.

Further, energy consumptions can be reduced using efficient design. In our analysis, EE depends on all these KPIs that we have employed in these simulations.

Using Eq. (15), different gains of the transmitting and receiving antennas (Fig. 8) allow us to calculate the energy consumption.

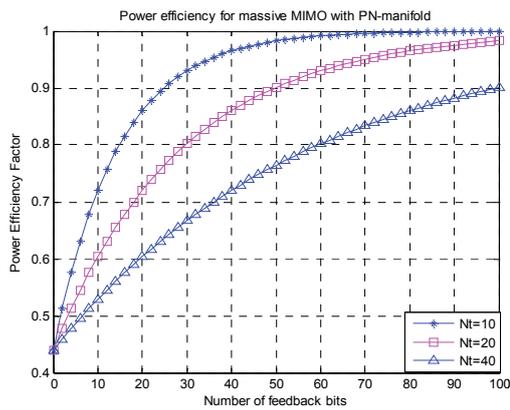


Fig. 6. Power efficiency.

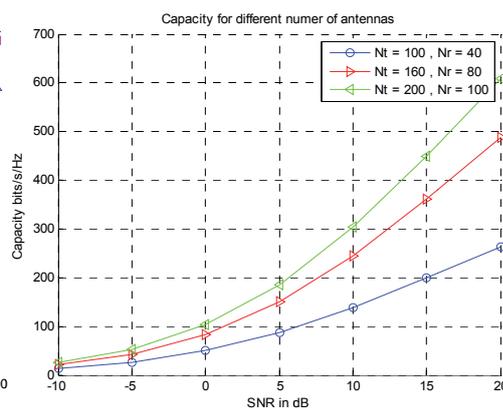


Fig. 7. Capacity of massive MIMO for the EE calculation.

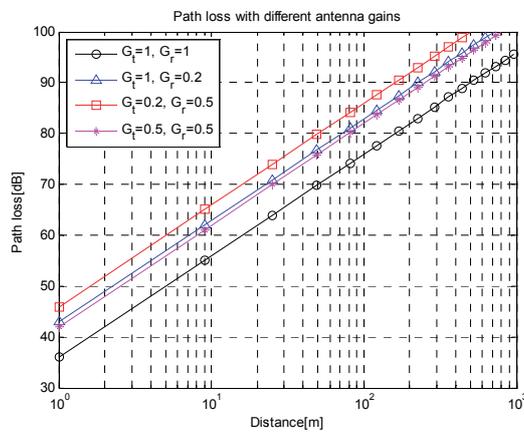


Fig. 8. Energy of the path loss based on distance.

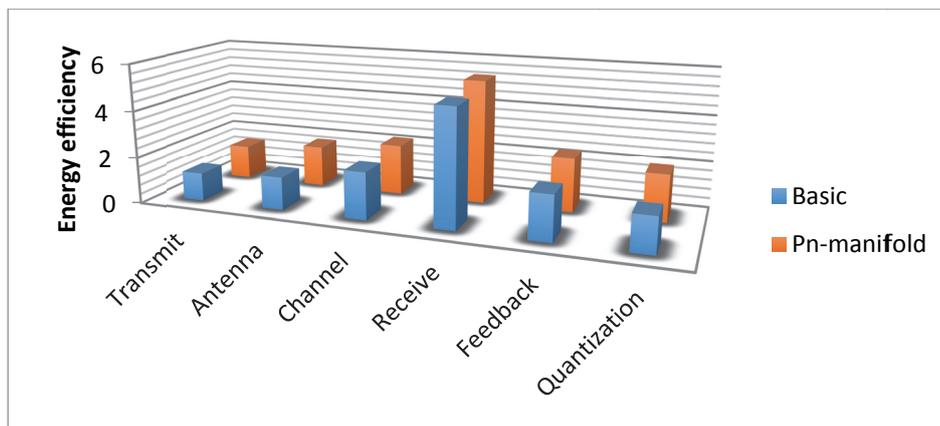


Fig. 9. Comparison of basic MIMO with and without *Pn*-manifold.

The strategic energy management of massive MIMO shown in Fig. 9 provides principal areas of EE used in basic MIMO. Points considered below maintain the power or renew the energy from a renewable energy source.

Multiplications: The complex product of manifolds including Pn -manifolds in the denominator affects the total energy in the MIMO channel.

Accumulation: The summation of complex manifolds in the denominator change the total energy in the MIMO channel.

Division: Normalized diversity is combining total energy in the MIMO channel.

5. CONCLUSIONS

In this study, the future direction of renewable-energy systems based on a MIMO wireless network is analyzed in various ways. Future energy systems and applications in the wireless environment depend on the optimized design of massive MIMO because the cost of energy is growing with a number of services.

The manifolds that we have studied in this research are multidimensional matrices influenced by quantization and feedback, as in Fig. 10. In each case, Pn -manifold provides better energy consumption. Rank optimization of the manifold increases EE.

From the results, we can see that different manifolds that increase energy efficiency allow us to investigate the renewable energy in massive MIMO. The capacity and rate of the feedback are very important points to enhance the energy efficiency factor in this investigation.

In our future work, **Minimum-energy LTE-A downlink Resource Scheduling (MARS)** approach [33] will be employed to improve EE of MIMO-Generalised Frequency Division Multiplexing (MIMO-GFDM) in a Long Term Evolution-Advanced (LTE-A) Platform.

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