

# SIC-MMSE Method Based Wireless Precoding Technique for Millimetre-Wave MIMO System

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## Abstract

**Objectives:** A communication method is proposed using Minimum Mean Square Error (MMSE) precoding and Successive Interference Cancellation (SIC) technique for millimetre-wave multiple-input multiple-output (mm-Wave MIMO) based wireless communication system. **Background:** The mm-Wave MIMO technology for wireless communication system is the base potential technology for its high data transfer rate followed by data instruction and low power consumption compared to Long-Term Evolution (LTE). The mm-Wave system is already available in indoor hotspot and Wi-Fi backhaul for its high bandwidth availability and potential lead to rate of numerous Gbps/user. But, in mobile wireless communication system this technique is lagging because the channel faces relative orthogonal coordination and multiple node detection problem while rapid movement of nodes (transmitter and receiver) occur. **Methods/Improvement:** To improve the conventional mm-wave MIMO nodal detection and coordination performance, the system processes data using symbolized error vector technique for linearization. Then the MMSE precoding detection technique improves the link strength by constantly fitting the channel coefficients based on number of independent service antennas (M), Signal to Noise Ratio (SNR), Channel Matrix (CM) and mean square errors (MSE). To maintain sequentially encoded user data connectivity and to overcome data loss, SIC method is used in combination with MMSE. **Improvements:** MATLAB was used to validate proposed system performance. Simulation analysis shown that, with the increase number of antennas use, the spectral efficiency also increased and higher than millimetre-wave MIMO or Single MMSE system. This research observed that, hybrid controller or combined control method have the better efficiency than single method, where SIC-MMSE based hybrid controller is a good example.

**Keywords:** Wireless communication, Millimetre-wave, Minimum mean square error, Successive Interference-Cancellation, Long-term evolution, Channel matrix & Quantized System.

## 1. Introduction

The millimetre wave technology in communication system still in progress mode, where it is fall behind because of having exponentially increase number of path losses, high shadow fading, requires high power to overcome blockage and the most important is penetration losses. where this system also leading some other issues to have poorer link margin than legacy systems [1]-[3]. The millimetre wave also uses spatial sparsity for the channels with large antenna array system with physical layer beamforming for directional transmission of

signals. Many researchers have done their studies on the design and analysis the performance of the beamforming directionally as well as system precoding for best multi-input multi-output (MIMO) performance [4]-[7]. In practice, apart from the small cell coverage, it's also possible to increase array gains in case of using large antenna arrays for the long-distance communication, a significant improvement can be found. Researchers also discover that directional array are good for fast data transfer standpoint and robust to phase changes across clusters and allow a smooth trade-off between peak beamforming gain and initial user

discovery latency. There has also been progress in generalizing such directional constructions for multi-user MIMO transmissions [8]-[11]. Researcher proposed several types of hybrid beamforming or array system for wireless millimetre technology. They combined the solutions of the millimetre wave limitations with optimal precoder technique and controlled with hybrid architecture addressed as a sparse reconstruction solution [12], where basis pursuit method was used for the algorithms and solutions. The combined hybrid solutions shown some good performance, where the performance gap of the proposed systems addressed in the reference paper [12], large array structure with an iterative method proposed in [13] and adaptive estimation according to hierarchical training codebook for the channels shown in [14]. Both [13] & [14] shown performance comparison with previous works and result that, with the little addition of iteration schemes are enough for optimal performance. Some researcher proposed and successfully found that, when they combined hybrid system in digital architecture and twice the number of data-streaming RF channels, the performance

dramatically increases [15]. A heuristic algorithm with good performance is developed when this condition is not satisfied. Several other works such as [16]-[17] have also explored iterative/algorithmic solutions for hybrid beamforming. A common theme that underlies most of these works is the assumption of phase-only control in the RF/analogue domain for the hybrid beamforming architecture. This assumption makes sense at the user end with a smaller number of antennas (relative to the base-station end), where operating the PAs below their peak rating across RF chains can lead to a substantially poor uplink performance. On the other hand, amplitude control (denoted as amplitude tapering in the antenna theory literature) is necessary at the base-station end with many antennas for side-lobe management and mitigating out-of-band emissions. Further, given that the base-station is a network resource, simultaneous amplitude and phase control of the individual antennas across RF chains is feasible at millimetre wave base-stations at a low-complexity and cost [18]. The millimetre wave experimental prototype demonstrated in allows simultaneous amplitude and phase control.

**Table 1.** Summarization of notable review papers.

Methods	Years	Advantages	Disadvantages
Network feedback based IOT	2014	1. connect, control and monitor more than one appliance together through IoT.	1. Constant monitoring and services are required.
Wired Building Automation	2015	1. pilot models with the wired network. 2. Web-based instrument.	1. Maintenance required. 2. Automatic nodal updates not possible.
Network-based FDS via CAN	2004	1. Very short response time. 2. Direct data accusation for accuracy.	1. Data received directly from the fire detectors any interruption means system loss.
FPGA based smart system.	2016	1. Smart system. 2. Auto update.	1. Use for a stand-alone system.
BACnet-based FDS	2014	1. Monitoring system using MS/TP protocol. 2. reference model is operated by wireless-BACnet for flexibility.	1. Signal is directly dependent upon the traffic load. 2. Inter-operability of different vendors' field devices makes problems.
Addressable FACS	2015	1. Broad range of device connecting capabilities.	1. Standard capacity of maximum 127 points.
Dedicated Computer Controlled system	2016	1. Added power, Internet connectivity, and remote service capabilities	1. Failure of dedicated computer or connection problem can fail the system. 2. Required maintenance.
Address-able VAD (Visual Alarm Device)	2010	1. Visual Alarm Device.	1. For a small plant. 2. Extension not possible.

Pattern matching process	2015	1. Use predefined pattern matching process. 2. Signature-based traffic.	1. The performance depends on detection engine.
Mechatronic approach	2016	1. Autonomous fire-suppression module was used. 2. Versatile device addable.	1. The autonomous system used is expensive.
Optical fibre sensors	2014	1. Long durability. 2. Long distance detection.	1. The problem of hot air.

## 2. Research Method

The proposed system is a combination of successive interference cancellation (SIC) and Minimum Mean Square Error (MMSE) or can be written as SIC-MMSE. In this process, initially, the raw data is sampled and prepared for sub-band packaging according to users' data symbol. The coder is joined along with MMSE detection system, which will depend upon user or operator. The MMSE detection process will continue to do channel pilot sensing, testing signal quality, estimate the Signal to Noise Ratio (SNR), arrange Channel Matrix (CM) formation, Channel selection & estimation. The MMSE processed data will be filtered for maximum correlation detection, which is the part of SIC method. This method is used to detect the sequentially processed data according to the users' symbols and regenerate the data to transfer it through the new channel. While MMSE will

constantly monitor the signal quality to realter the channel coefficient, the SIC will help MMSE to improve its performance by processing sequential data so that MMSE can reselect any parameters at any moment to reduce interruption and data loss. At the end of transmission process, the RF modulation will modulate the data then filter with Spectrum Shaping Filter (SSF) and transmit through the channel. A synchronizer is used in transmission process to synchronize any disrupted operation. On the receiver side the signal will be demodulated and reshaped with SSF. After demodulation the same concept of proposed MMSE will be used to decode the data. The synchronizer on the receiver side and transmitter side will be synchronized together through MMSE. Finally, the decoded data will be reframed using same SIC method. This combination (SIC-MMSE) can reduce the channel shortage and performance losses.

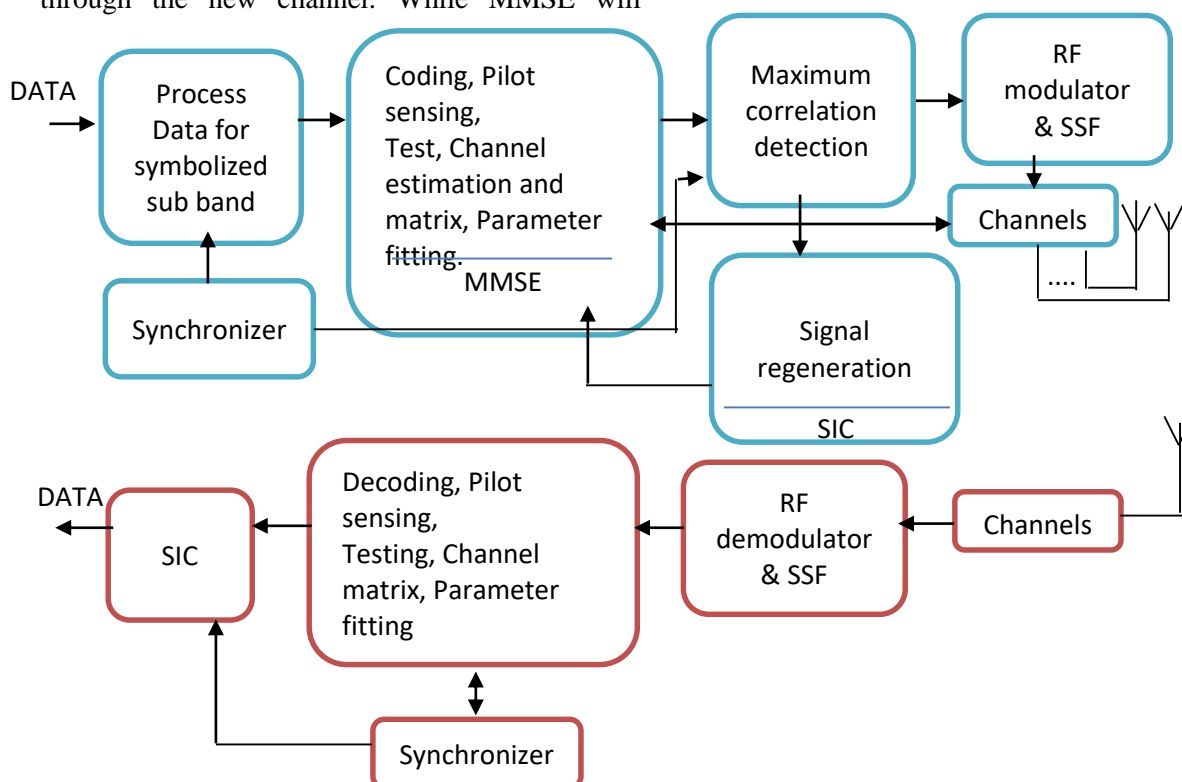


Figure 1. Proposed system approximation for transmission and receiver.

## 2.1. Symbolize error vector:

A multiple user with multiple nodes for base station (BS) was considered based on time division duplex (TDD) method where upload and download channel data links consider within coherence interval in a point to point MIMO system. Considering the system have N numbers of nodes on a base station per cells having M number of total antennas per cells and K number of single antennae known as user terminal (UT) in each cell. For K antenna user terminal to base station J can be expressed as:

$$H_{jk} = B_{jk} G_{jk};$$

Where,  $H_{jk}$  is the fading's on J station for K number of single antennae.  $B_{jk}$  is the fading coefficient of large scale and  $G_{jk}$  is the fading coefficient of small scale [7]. Here,  $B_{jk}$  represent path loss and shadow fading of the channel. The matrix was denoted by upper case and bold uppercase used for vector identifications. The  $G_{jk}$  is the total nodal fading effect induced in per cell's capacity can be represented by [7],

$$G_{jk} = CM(0, I_m)$$

Where, C and M are the capacity sum rate & number of BS antennas respectively and  $I_m$  is the indication function of M. So,

$$H = G\sqrt{B}$$

Here, H is channel fading, B represents the large-scale diagonal matrix and G represents the small-scale matrix each column represents a channel from UT to BS [8]. When the number of BS antennas increase the channel, the approximates orthogonal matrix will be  $\lim_{n \rightarrow \infty} HH^H = B$ . Each terminal is assigned with a pilot sensing for k number of single antennas, the sensing pilot  $s_k$  with power equal to,  $s_k, t = [s_{k1}; s_{k2} \dots s_{kt}]^T$  and at each BS station,  $\|s_k s_j^H\|_2 = 0$ , if  $j \neq k$  and the transmitted power is equal for all pilots. For the conventional detection the receiver vector matrix y can be denoted by,

$$y \in C^{M \times 1} [8] \text{ or } y = Hx + n \quad (1)$$

Where, C is channel matrix and complex additive white gaussian noise (AWGN) vector,  $H \in C^{M \times K}$ , x is the symbol vector sent by K user can be denote by  $x \in C^{K \times 1}$  and number of nodes n. If the symbol error vector e then,

$$e = x - \hat{x} \quad (2)$$

here,  $\hat{x}$  is the receiving signal. Assuming correlation parameter  $\sigma$  is known perfectly at the base stations

and  $h[n]$  be the channel vector between a UT and a BS at time t. Then [9],

$$h[t] = \sigma h[t-1] + e_v[t] \quad (3)$$

Here, t is time index and  $e[t]$  is white noise with zero mean and temporal correlation parameter  $\sigma^2 = ((1-2))$  obtained through the Yule-Walker equation [7]. The channel model above is known as the stationary ergodic Gauss-Markov block fading channel model [8].

## 2.2. MMSE detection process:

For the MIMO model equation according to reference no [7], where receiving signal vector  $\hat{y}$  from receiver signal y and the fibrinous norm  $\|y\|_2$  to limit sphere of validity of general norm.

$$\hat{y} = y - H\hat{x} = H(e + x), \quad (3)$$

Where, x is transmitted symbol messages and  $\hat{x}$  is the received symbol messages. Error vector e should be zero for ideal communication system. So, that the error detection should be overcome from receiver signal vector. Some researcher expresses the compressing sensing methods, where they proposed to naturally consider the symbol error vector e [7]. In compressing sensing methods M should be less than K, but if M becomes more than equal to K, this system will be impractical. For MIMO multi-antenna mode, the M is generally greater than equal K, the receiver signal vector later filter by matrix  $W_{MMSE}$  is given by the equation,

$$W_{MMSE} = \frac{H^H}{H H^H + I_m} \quad (4)$$

Where, W is a predefine filter matrix,  $W_{MMSE}$  is the filter matrix for MMSE matrix for and AWGN (Gaussian noise) vector  $n \in CM(0, I_m)$  [8]. By Maximum A Posterior (MAP) detection known as detection system detection method the optimal detection  $\hat{e}$  can be found from the reference paper no [10].

$$\hat{e} \cong \arg \max_{e \in \hat{A}^K} (1/\sqrt{2\pi\sigma^2}) \exp \left[ \frac{-0.707}{\sigma^2} ((\|\hat{y} - H\hat{e}\|_2)^2) \right] \Pr(e) \quad (5)$$

According to the paper the approximation is because of e and n dependency and may omit while SNR increases and can be precise at high SNRs [10].  $\Pr(e)$  is probability of priority error symbol. When BPKS values are +1 & -1,  $\hat{A}$  is the finite alphabet having the values -2, 0 & +2 and for the nonzero value of  $\hat{A}$  detection error becomes -2 & 2. If transmitted symbols are from -1 to 1, then the possibility of the e will be no zeroes from +2 to -2 and possible probability can be  $0.5P$ . when  $\lambda$  is the degree of sparsity,  $\|e\| = 0.25\|e\|^2$ . If, e is the

element of  $\hat{A}^K$  and  $e^\circ$  is the symbol error vector for initial iteration, by solving the equation no (5)

$$e^\circ = \frac{H^H \hat{y}}{H^H H + 0.5 \lambda}$$

$$e^\circ = M \hat{y} ; [\text{if, } \hat{A}^K \text{ is finite and initially } \hat{e} = e^\circ] \quad (6)$$

Here,  $M$  is MMSE detection method with tuneable degree of spares  $\lambda$ , where,  $\lambda$  is the replacement of noise. If,  $Q\theta(*)$  is vector dividing function and  $\theta$  optimal threshold then, optimal detection,  $\hat{e} = Q\theta(e^\circ)$  for discrete function [10]. So, we can rewrite the equation

$$\hat{e} = Q\theta(e^\circ) = 2\sin(e^\circ)I ; [\|e^\circ\| > \theta] \quad (7)$$

Where,  $I$  is a indication function. If, the optimal threshold,  $\theta = \{\theta_1, \theta_2, \theta_3, \dots, \theta_n\}$  and for the non-zero components,  $e = \{0, \pm 2\}$ ; [i.e.  $\|e\| < \theta$ ]. Similarly, QPSK detection the equivalent transform with real (R) and imaginary (I), where  $I(e)$  and  $R(e)$  parts of  $x$ ,

$$\hat{e} = 2\sin[\{R(e) + I(e)\}T]; [\text{Where, } e^\circ \in \hat{A}] \quad (8)$$

Here,  $y^\circ$  initial receiver signals,  $n$  is the Gaussian noise,  $e(l)$  is the  $l^{\text{th}}$  symbol error vector. The equation (8) is the prior probability detection of  $e$ . If,  $e(l)$  is non-zero, for the  $n^{\text{th}}$  entry,  $x_n^{l-1}$  is of  $x^{l-1}$ , the  $y^\circ$  for  $n^{\text{th}}$  entry of  $l^{\text{th}}$  symbol,

$$y_n^l = W(l-1) e_n^l + \sum_{i \neq j} w_{nj}^{1-l} e_j^l + x_n^{l-1} \quad (9)$$

So, Gaussian approximates with following variance  $\sigma$ ,

$$(\sigma_n^{l-1})^2 = \sum_{n \neq j} 4(\omega_{jn}^{1-l})^2 p^{l-1} + \{\sum_n (l-1)\} \quad (10)$$

The error probability for  $n^{\text{th}}$  entry can be solve in same way from the optimal detection equation no 5. If the operator for MMSE is  $Q$  for the sensing pilot  $s_k$  is given by the equation,

$$s_{ki} = Q(y_{ki}) = Q(g_{ki} r_i) \quad (11)$$

Here,  $y_k$  is the output of  $k$  antenna, the chosen vector  $g_k$  and  $r$  is the degree of freedom. The operator  $Q$  can be used to give instruction where the sampling should stop for a transmission. The ideal analysed threshold can minimize the probability of error by  $\frac{d}{dx} p_n^l = 0$ . If, the optimal threshold  $\theta$  for  $n^{\text{th}}$  entry of  $\hat{e}$  is can be found from the equation no 11,

$$\theta_n^l = w_{nn}^{1-l} + \frac{1}{2} \left\{ \frac{\lambda}{\omega_{nn}^{1-l}} \right\}^{l-1} \cdot (\sigma_n^{l-1})^2 \quad (12)$$

From the above equations, the proposed MMSE detector can be iteratively exploited to improve the detection performance. To minimize the errors, it is possible to refit the tuneable parameters like degree

of sparsity ( $\lambda$ ), selection of different channel based on lower SNR or MSE and availability of CM [7].

### 2.3. SIC algorithm:

Considering the mm-wave MIMO system with Distributed Antenna System (DAS) configuration, where, number of base antenna  $M_B$  having  $k$  number of single antenna and  $N$  number remote radio heads. If the  $Q$  user also equipped with  $M_U$  antenna, the receiving antennas,  $M_R = M_B + Nk \geq QM_U$  [20]-[26]. For  $Q$  user  $M_U$  number flat fading channels, the MMSE pilot  $s_k$  was considered before now can be rewritten as vectoral form,  $s_k \in \mathbb{C}^{M_U \times 1}$ . From the model as Gauss-Markov block fading channel shown above in equation no.3, the data vector  $s_k$  have zero mean.

The SIC algorithm relies on sequential detection receiver signals, where it is required to equalize the channel matrices  $W_{\text{MMSE}}$  given in equation no. 4, then carrier channels can get the higher Signal to Interference Noise Ratio (SINR). From the reference no [27] the SINR per symbol for  $l^{\text{th}}$  iteration for the  $j^{\text{th}}$  number of symbols is thus can be expressed as,

$$\text{SINR}_j^l = (\sigma^l)^{-2} (a^l)^2 (|s_{kl}|)^2 \quad (13)$$

Where,  $a^l$  is the amplitude, Gaussian approximates variance  $\sigma$ , pilot  $s_k$  for  $l^{\text{th}}$  iteration. The fading matrix  $H_k$  for  $k$  user, having  $N+1$  submatrix in each remote radio head, then,  $H_k = [H_{k1}, H_{k2}, \dots, H_{k(N+1)}]^T$ . When the symbol is decides according a decision will be made depends on MMSE operator given in equation no. 11. Instead of executing don't care sign decision, it is possible to use operator  $Q$  as soft switch through the hyperbolic tangent non-linear detector whose argument is weighted by an estimation of the SINR [27]. So the expression for  $s_k$  for  $l^{\text{th}}$  iteration can be given in QPSK constellation as,

$$s_{ki} = 0.707 [\tanh\{R(y_{ki})/(\sigma_{ki}^2)\} + j \tanh\{I(y_{ki})/(\sigma_{ki}^2)\}] \quad (14)$$

Finally, for the decoded case in receiver end, while all symbols are retrieved, the don't care decision will perform for the resulting output  $y = (y_1, y_2, \dots, y_n)^T$ .

### 3. Measurement and Simulations

For MATLAB simulation we used Gaussian noise as reference with different SNR levels to analyse



the performance of the proposed SIC-MMSE system. In this simulation process we have compared results with conventional mm-wave MIMO system and MMSE system. For the simulation process we first considered the number of antennae per cells  $M=1000$ . For the process, initially we detected symbol vector  $\mathbf{j}$  using conventional MIMO system and proposed MMSE. For the output SNRs priority probability for conventional and MMSE we followed equations from the reference papers [7]-[10] shown below.

$$\lim_{SNR \rightarrow \infty} \frac{\log P_c(SNR)}{\log SNR} = -d;$$

$$\lim_{SNR \rightarrow \infty} \frac{\log P_{SIC-MMSE}(SNR)}{\log SNR} = -d \quad (15)$$

Then, the degree of sparsity  $\lambda$ , can be obtained from  $\lambda = \ln\left[\frac{2(1-p)}{p}\right]$ ; Considering the MMSE linear detection, for the  $l^{th}$  iteration the error probability  $\epsilon$  for SIC-MMSE based MIMO was obtained from equation no. 8, where optimal threshold  $\theta_n^l$  was obtained by solving the equation no. 7. This proposed research was conduct on Time Division Duplex (TDD) method. So, to determine the Spectral Efficiency (SE) for SIC-MMSE is expressed [27]:

$$\eta_{hMMSE} = \frac{(T_f - T_p - T_t)N_i}{T_i N_s} \quad (16)$$

Where,  $T_p$  = preamble period,  $T_t$  = trailer time period,  $T_f$  = frame duration and  $N_s$  = number of symbols in a  $t$  time slot,  $N_i$  = number of information bits. By resolving the equations in MATLAB finally we got SE for the SIC-MMSE.

Simulating the proposed system in MATLAB the performance of SIC-MMSE was achieved. For the comparison and benchmarking we also simulated the conventional mm-Wave. Where the simulation was done by Spectral Efficiency (SE) [bit/s/Hz/cell] vs Number of BS Antennas (M).

The Figure 2. shows the comparison of the Spectral Efficiency (SE) with the increase number of BS antenna at base station for conventional or single millimetre-Wave system. Where it is depicted that spectral efficiency increases from 0 to maximum 136 bits/s/Hz/cell with the increase of base antennas from 0 to 1000. Where, the parameters are optimized for the better performance, the maximum SE was recorded to 157 bits/s/Hz/cell for the 1000 number of antennas.

The SIC- MMSE simulation in Figure 3 shows more better performance than conventional mm-Wave MIMO system after optimization. Before optimization the maximum SE was found to

133~132 bits/s/Hz/cell while number of antennas was maximum. Where, after optimization the value crossed 195 bits/s/Hz/cell. Every system requires optimization, where without optimization this proposed system performed almost the equal to the optimized conventional mm-wave MIMO system, but after optimization it increased rapidly. Figure 4. Shows the performance comparison simulation block for the both methods having same parameters, spectral efficiency according to increase number of antennas.

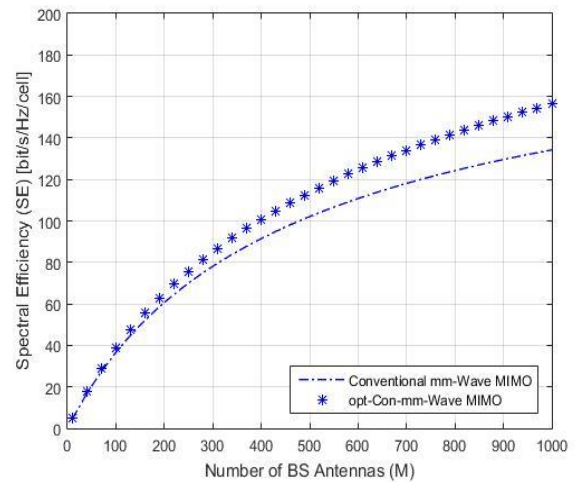


Figure2 Conventional mm-waves MIMO and optimized mm-waves MIMO spectral efficiency performance with the increase number of Antennas.

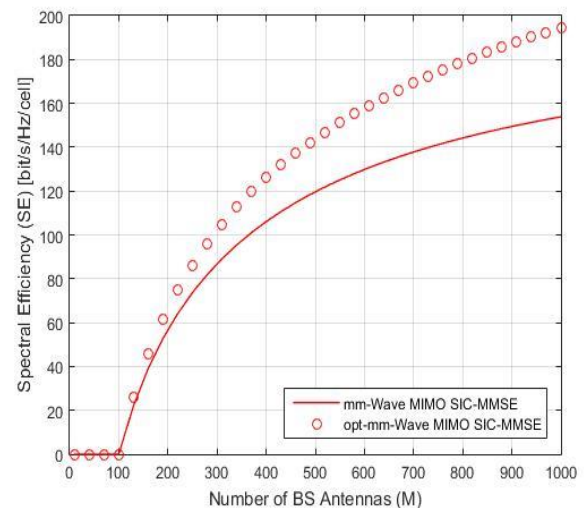


Figure 3. proposed SIC-MMSE and optimized SIC-MMSE spectral efficiency performance according to increase number of Antennas.

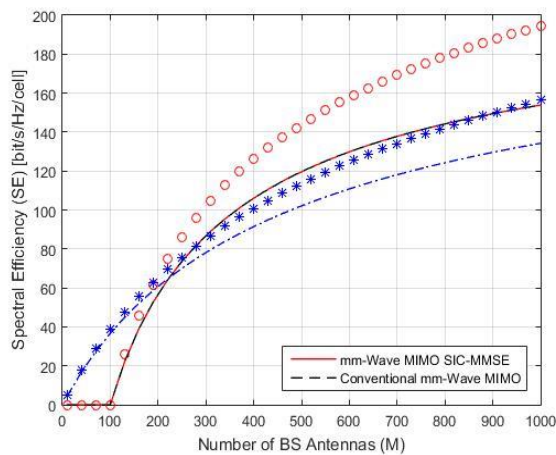


Figure 4. The performance of both methods' spectral efficiency according to increase number of antennas.

#### 4. Conclusion and Future Work

This paper has presented a communication method which is the combined methodology of MMSE and SIC technique for mm-Wave MIMO based wireless communication system. The combined method was proposed to reduce the relative orthogonal coordination and multiple node detection problem while transmitter or receiver moves. The development of the equations was done by comparing, reading and reoptimizing the existed several concepts. From the simulation it can be found that, the proposed combined technique for wireless power communication is better than conventional mm-wave MIMO. Though, the Proposed SIC-MMSE require optimization for better performance more combined technique with better optimization can lead a better performance then single one. In future we would like to improve this research by adding more system together for optimal performance and compare with recent research.

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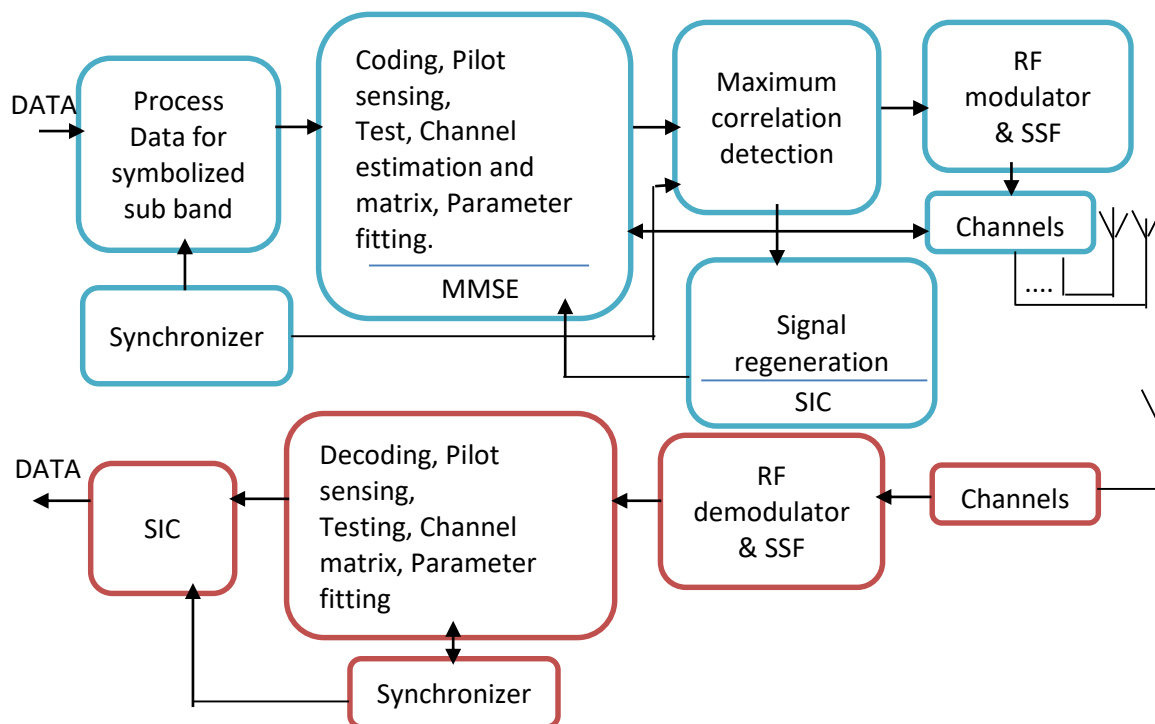
**FIGURES:**

Figure 1. Proposed system approximation for transmission and receiver.

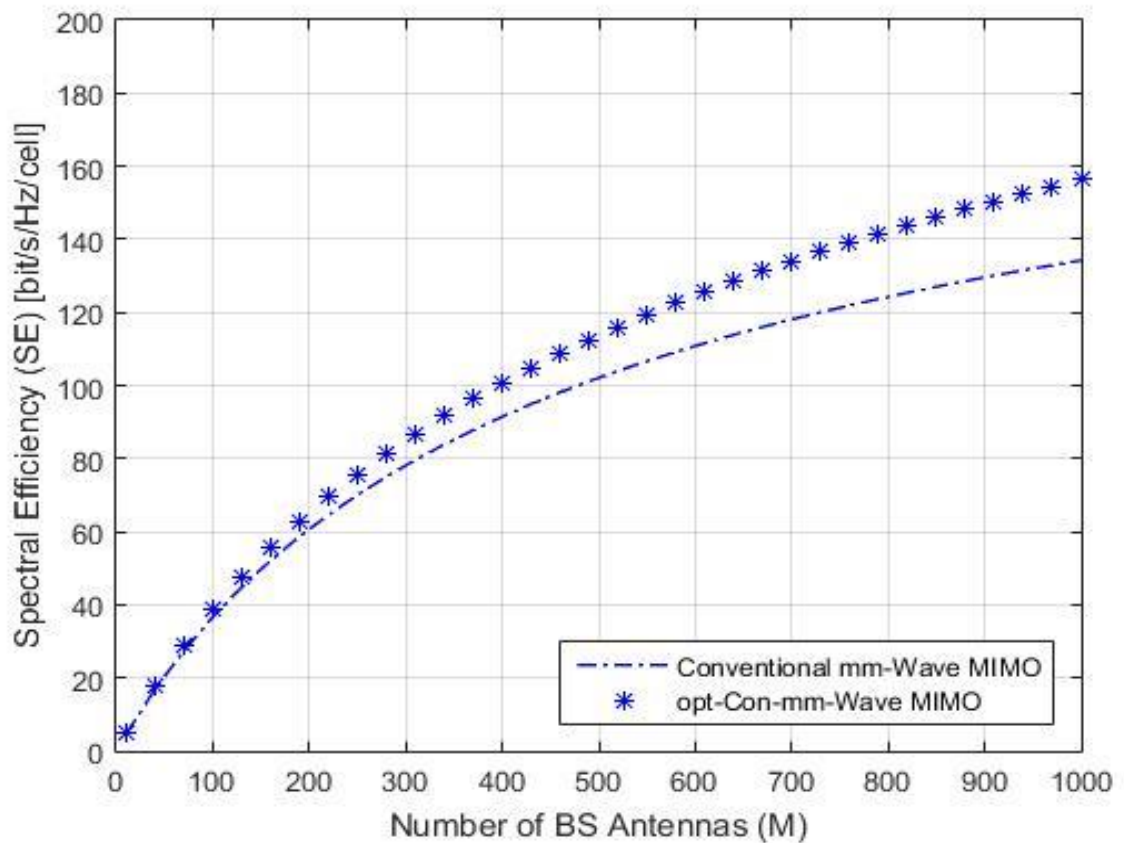


Figure2 Conventional mm-waves MIMO and optimized mm-waves MIMO spectral efficiency performance with the increase number of Antennas.

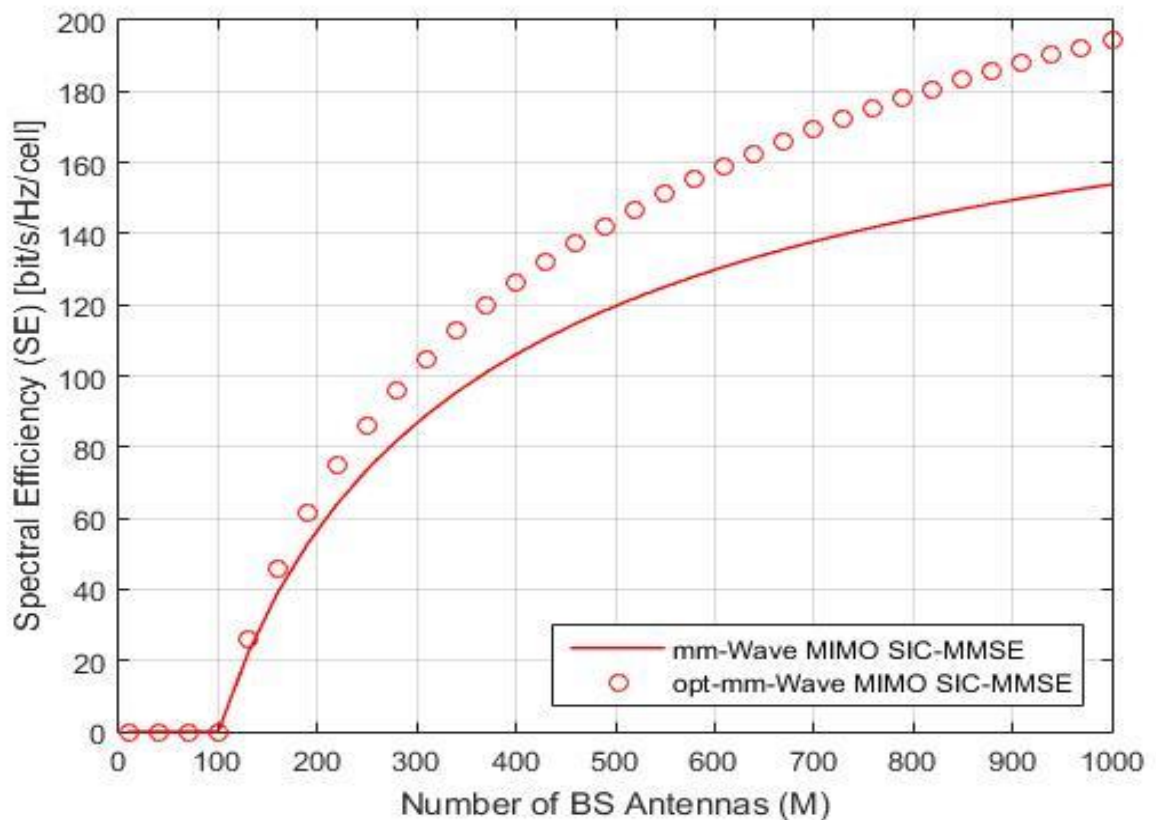


Figure 3. proposed SIC-MMSE and optimized SIC-MMSE spectral efficiency performance according to increase number of Antennas.

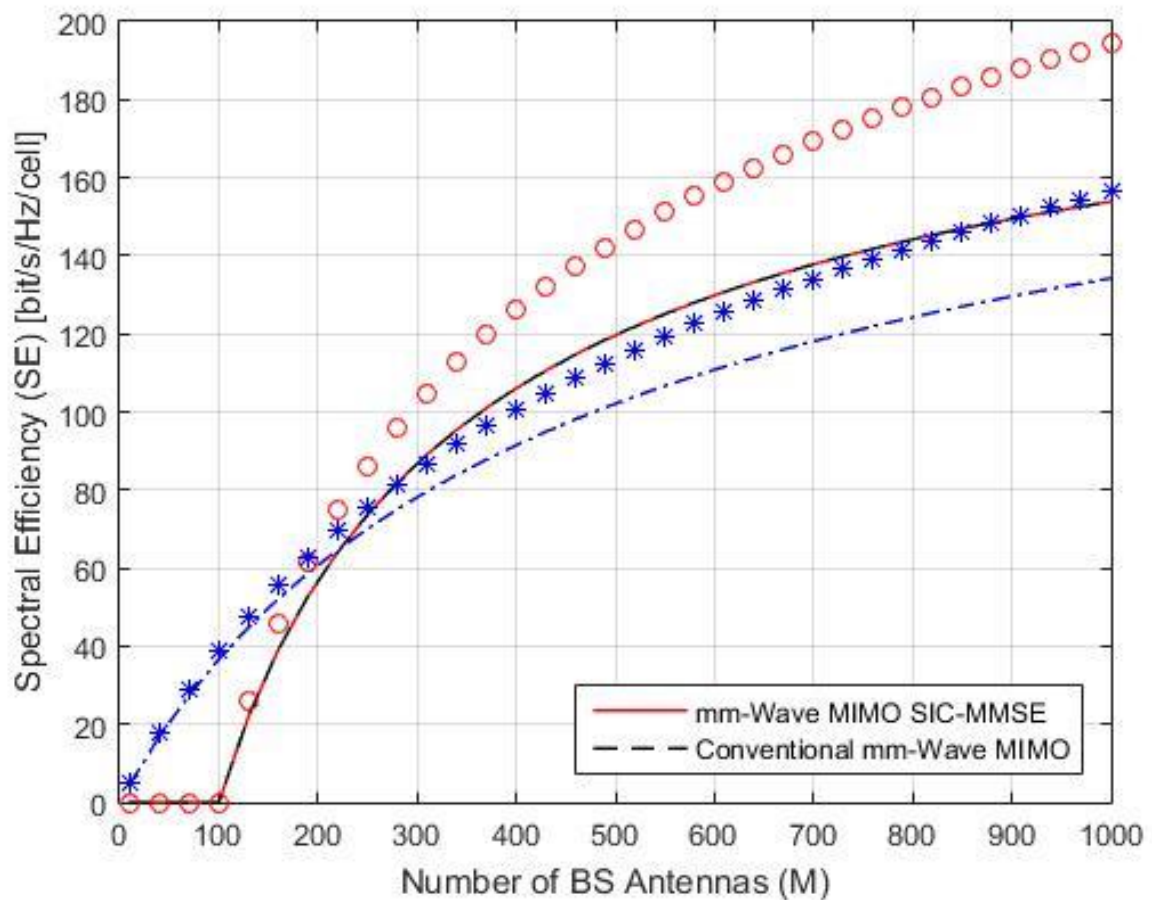


Figure 4. The performance of both methods' spectral efficiency according to increase number of antennas.

#### TABLES:

Methods	Years	Advantages	Disadvantages
Network feedback based IOT	2014	1. connect, control and monitor more than one appliances together through IoT.	1. Constant monitoring and services are required.
Wired Building Automation	2015	1. pilot models with the wired network. 2. Web-based instrument.	1. Maintenance required. 2. Automatic nodal updates not possible.
Network-based FDS via CAN	2004	1. Very short response time. 2. Direct data accusation for accuracy.	1. Data received directly from the fire detectors any interruption means system loss.
FPGA based smart system.	2016	1. Smart system. 2. Auto update.	1. Use for a stand-alone system.
BACnet-based FDS	2014	1. Monitoring system using MS/TP protocol.	1. Signal is directly dependent upon the traffic load.

		2. reference model is operated by wireless-BACnet for flexibility.	2. Inter-operability of different vendors' field devices makes problems.
Addressable FACS	2015	1. Broad range of device connecting capabilities.	1. Standard capacity of maximum 127 points.
Dedicated Computer Controlled system	2016	1. Added power, Internet connectivity, and remote service capabilities	1. Failure of dedicated computer or connection problem can fail the system. 2. Required maintenance.
Address-able VAD (Visual Alarm Device)	2010	1. Visual Alarm Device.	1. For a small plant. 2. Extension not possible.
Pattern matching process	2015	1. Use predefined pattern matching process. 2. Signature-based traffic.	1. The performance depends on detection engine.
Mechatronic approach	2016	1. Autonomous fire-suppression module was used. 2. Versatile device addable.	1. The autonomous system used is expensive.
Optical fibre sensors	2014	1. Long durability. 2. Long distance detection.	1. The problem of hot air.