TELKOMNIKA, Vol.17, No.6, December 2019, pp.2782~2789
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i6.12802

A wireless precoding technique for millimetre-wave MIMO system based on SIC-MMSE

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Abstract

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. 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 problems while rapid movement of nodes (transmitter and receiver) occur. 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. MATLAB was used to validate the proposed system performance.

Keywords: *channel matrix, millimetre-wave, minimum mean square error, quantized system, successive interference-cancellation*

1. Introduction

The communications in the millimetre wave band suffers from increased path loss exponents, higher shadow fading, blockage and penetration losses, etc., where sub-6 GHz systems leading to a poorer link margin than legacy systems [1-3]. Spatial sparsity of the channel along with the use of large antenna arrays motivates a subset of physical layer beamforming schemes based on directional transmissions for signalling. In this context, there have been a few studies on the design and performance analysis of directional beamforming/ precoding structures for single-user multi-input multi-output (MIMO) systems [4-7]. However, by restricting attention to small cell coverage and by reaping the increased array gains from the use of large antenna arrays at both the base-station and user ends, significant rate improvements can be realized in practice. These works show that directional schemes are not only good from an implementation standpoint but are also 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]. Several recent works have addressed hybrid beamforming for millimetre wave systems. The problem of finding the optimal precoder and combiner with a hybrid architecture is posed as a sparse reconstruction problem in [12], leading to algorithms and solutions based on basis pursuit methods. While the solutions achieve good performance in certain cases, to address the performance gap between the solution proposed in [12] and the unconstrained beamformer structure, an iterative scheme is proposed in [13, 14] relying on a hierarchical training codebook for adaptive estimation of millimetre wave channels.

Received December 20, 2018; Revised May 25, 2019; Accepted July 2, 2019

The authors in [13, 14] show that a few iterations of the scheme are enough to achieve near-optimal performance. In [15], it is established that a hybrid architecture can approach the performance of a digital architecture if the number of RF chains is twice that of the data-streams. 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/analog 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 shows the summary of the related review papers.

Table 1. Summarization of notable review papers.

Methods	Years	Advantages	Disadvantages
Conventional mmWave	2016-17	1. High frequency 6GHz.	1. High path loss exponents, 2. higher shadow fading, 3. blockage and penetration losses, etc.
Single user MIMO	2013-16	1. Robust to phase changes across clusters and allow a smooth trade-off between peak beamforming gains. Initial user discovery latency.	1. Large antenna arrays motivate a subset of physical layer beamforming.
Multi-user MIMO	2014-17	1. Generalizing such directional constructions for multi-user.	1. Switching mode decrease efficiency. 2. Certain data loss.
Pursuit methods-based Hybrid architecture.	2014	1. Increased performance by addressing the performance gap between the channel switching.	1. Assumed phase control in the RF/analog domain, only possible in small number of antennae.
Digital hybrid architecture.	2016-17	1. Hybrid beamforming. 2. A heuristic algorithm used for better performance.	1. Number of RF chains is twice that of the data-streams. 2. Substantially poor uplink performance.
SAPC mmWave	2017	1. Simultaneous amplitude and phase control of the individual antennas across RF chains. 2. Low-complexity and cost.	1. Standard capacity of maximum 127 points.
Hybrid precoding single-user mmWave	2017	1. Hybrid precoding/combining is capable. 2. Same performance of the fully digital.	1. Failure of dedicated computer or connection problem can fail the system. 2. Required maintenance.
Hybrid precoding for multi-user mmWave	2015	1. Combination of RF combiner and RF beamformer to maximize the channel gain. 2. Derived as a zero-forcing (ZF) precoder.	1. For a small plant. 2. Extension not possible.
Mean-squared error (MSE) hybrid precoder	2011	1. Maximum likelihood (ML) decoder and a minimum mean square error (MMSE) decoder. 2. Window coefficients used to generate the quantized values.	1. The performance depends on detection engine.

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 fastly 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. The total process of proposed system for transmission unit and process of receiver unit are shown in Figure 1.

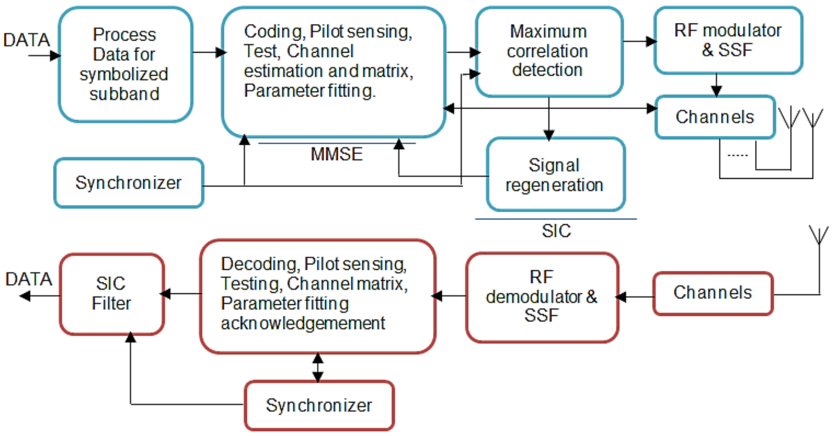

Figure 1. Proposed system approximation for transmission and receiver

2.1. Symbolize Sampling

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],

$$G_{jk} = CM\ (0, Im)$$

where, C and M are the capacity sum rate & number of BS antennas respectively and Im 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. When the number of BS antennas increase the channel, the approximates orthogonal matrix will be $\lim_{n\to\infty} HH^H$ = B. Each terminal is assigned with a pilot sensing for k number of single antennas, the sensing pilot sk with power equal to, $s_{k,t}$ = [s_{k1}; s_{k2}….s_{kt}]T and at each BS station, $\|s_k\, s_j^H\|$2 = 0, if j ≠ k and the transmitted power is equal for all pilots. For the conventional detection the receiver vector matrix y can be denoted by

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

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,

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

here, ẋ is the receiving signal. Assuming correlation parameter σ 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],

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

here, t is time index and e[t] is white noise with zero mean and temporal correlation parameter σ^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 ŷ from receiver signal y and the fibrinous norm $\|y\|^2$ to limit sphere of validity of general norm.

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

where, x is transmitted symbol massages and ẋ is the received symbol massages. 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 then K, but if M becomes more then equal to K, this system will be impractical. For MIMO multi-antenna mode, the M is generally greater then equal K, the receiver signal vector later filter by matrix WMMSE is given by:

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

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

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

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]. $P_{r(e)}$ is probability of priority error symbol. When BPKS values are +1 & -1, ˆA is the finite alphabet having the values -2, 0 & +2 and for the nonzero value of 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 0.5*P*. When λ is the degree of sparsity, $||e||= 0.25||e||^2$. If, e is the element of $\hat{A}^K$ and e° is the symbol error vector for initial iteration, by solving (5):

$$e° = \frac{H^H \hat{y}}{HH^H + 0.5\,\lambda}$$
$$e° = M\hat{y};\ [\text{if, } \hat{A}^K \text{is finite and initially é= e°}] \quad (6)$$

here, M is MMSE detection method with tuneable degree of sparesλ, where, λ is the replacement of noise. If, Qθ(*) is vector dividing function and θ optimal threshold then, optimal detection, é=Qθ(e°) for discrete function [10]. So, we can rewrite:

$$é = Q\theta(e°) = 2\sin(e°)I\ ;\ [||e°||>\theta] \quad (7)$$

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

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

here, y° initial receiver signals, n is the Gaussian noise, e(*l*) is the l^{th} symbol error vector. (8) is the prior probability detection of e. If, e(*l*) is non-zero, for the n^{th} entry, x_n^{l-1} is of x^{l-1}, the $y°$ for n^{th} entry of l^{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 varianceσ,

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

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, $M_R = M_B + Nk \geq QM_U$ [19-26]. For Q user M_U number flat fading channels, the MMSE pilot s_k was considered before now can be rewritten as vectoral form, $s_k \in C^{M_U \times 1}$. From the model as Gauss-Markov block fading channel shown above in (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_{MMSE} given in (4), then carrier channels can get the higher Signal to Interference Noise Ratio (SINR). From the reference no [26] the SINR per symbol for l^{th} iteration for the j^{th} number of symbols is thus can be expressed as,

$$SINR_j^i = (\sigma^i)^{-2}(a^i)^2(|s_{ki}|)^2 \quad (13)$$

where, a^i is the amplitude, Gaussian approximates varianceσ, pilot s_k for l^{th} iteration. The fading matrix H_k for k user, having N+1 submatrix in each remote radio head, then, $H_k = [H_{k1}, H_{k2}, \ldots, H_{k(N+1)}]^T$. When the symbol is decides according a decision will be made depends on MMSE operator given in (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 [26]. So, the expression for s_k for l^{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 $y = (y_1, y_2, \ldots, y_n)^T$.

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 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 in (15):

$$\lim_{SNR\to\infty} \frac{\log P_c\,(SNR)}{\log SNR} = -d;\ \lim_{SNR\to\infty} \frac{\log P_{SIC-MMSE}\,(SNR)}{\log SNR} = -d \quad (15)$$

Then, the degree of sparsity λ, can be obtained from $\lambda=\ln[\frac{2(1-p)}{p}]$; Considering the MMSE linear detection, for the l^{th} iteration the error probability é for SIC-MMSE based MIMO was obtained from (8), where optimal threshold θ_n^l was obtained by solving the (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]:

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

where Tp = preamble period, T_t = trailer time period, Tf = frame duration and Ns = number of symbols in a t time slot, Ni = number of information bits. By resoliving 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). 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.

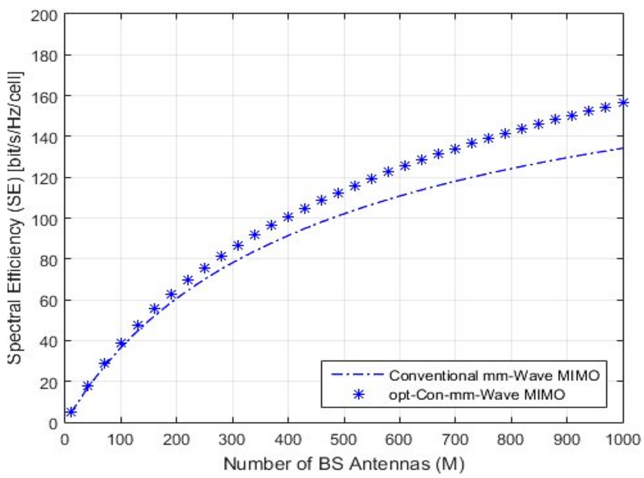

Figure 2. Conventional mm-waves MIMO and optimized mm-waves MIMO spectral efficiency performance with the increase number of Antennas.

The SIC-MMSE simulation in Figure 3 shows 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 this proposed system performed almost the equal to optimized conventional mm-wave MIMO system, but after optimization it rapidly increased. Figure 4 shows the performance comparison simulation block for the both methods having same parameters, spectral efficiency according to increase number of antennas.

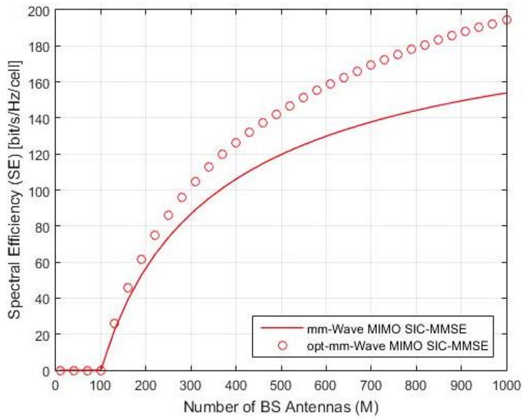

Figure 3. Proposed SIC-MMSE and optimized SIC-MMSE spectral efficiency performance according to increase number of antennas

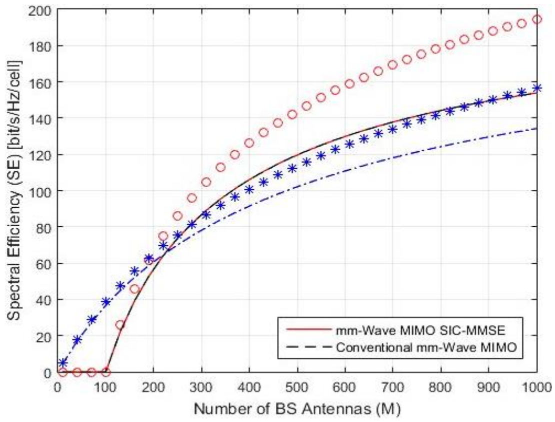

Figure 4. The performance of both methods' spectral efficiency according to increase number of antennas

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 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.

5. Acknowledgements

This paper was part of works conducted under the IIUM Research Initiative Grant Scheme (RIGS16-334-0498 & RIGS17-031-0606). The authors would also like to acknowledge all supports given by the IIUM Research Management Centre through the grant and RAY R&D for their research support.

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