A Survey on MIMO Techniques for Indoor Visible Light Communication

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Abstract- The demand of bandwidth is growing as the numbers of users and applications are increasing day by day in wireless communication. But licensed spectrum and limited bandwidth present the limitations for the end user. Visible light communication (VLC) is a subdivision of wireless communication (WC) in which the light of the LED's is used for communication among the various devices in indoor environment .So it gives the advantage of both energy harvesting and license free communication. Also LEDs have many advantages, one of which is long life expectancy. The wireless communication system has gone through many creations i.e. from SISO to MIMO technologies. These techniques can be used in VLC to further improve the bandwidth. In this paper, MIMO techniques are discussed and compared on the behalf of spatial multiplexing for achieving high data rate and best bit error rate (BER).

Keywords- Radio Frequency, visible light communication, multiple input multiple output, Wireless Communication.

I. INTRODUCTION

From last few years, the wireless communication has been ubiquitous. All the multimedia transmission requires high data rate for web browsing, downloading, and transfer of file, paging and internet access. .VLC basically uses white LED light for the transmission of data [1]. LEDs are used because of its low cost, faster response, longer lifespan and generate less heat. Due to these advantages, LEDs are used for both illuminations as well as for communication [2].VLC has the potential to transmit and receive the data at high rate. The use of visible spectrum is due to the presence of high bandwidth and ease to transmit the data at high rates

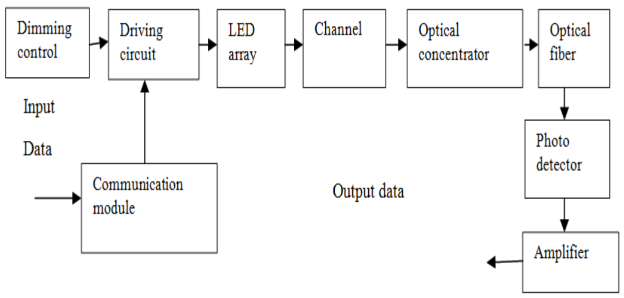

Fig.1: A block diagram of VLC

In figure 1, block diagram of VLC has been shown. The transmitter used in VLC is LED which gives us illumination and a driving circuit used which helps to control the flow of current through LEDs to control the brightness. All the performance of VLC is dependent on how the LED lightening is designed. At the receiver's side, photo-detector and image sensor is used. So VLC has much more advantages than a radio frequency (RF) as in RF there is a limited spectrum for the communication and there are so many nodes present that affect the performance of the transmission [3]. So VLC is the appropriate technique for the transmission of high data rate with low bit error rate (BER) [4] in indoor communication. In communication, we have basically four types of models that includes single input single output (SISO), single input multiple output (SIMO), multiple input single output (MISO) and multiple input multiple output (MIMO). MIMO system was proposed to overcome the drawbacks of the other three techniques. As MIMO have so many advantages like by using the multiple antennas, reliability of the system can be improved, spatial diversity, multiplexing [5] This paper aims to provide a comprehensive survey on existing MIMO techniques for indoor visible light communication. Section 2 briefly describes the optical MIMO techniques for VLC. Section 3 discusses the history timeline of MIMO VLC. Lastly conclusion and future scope has been discussed in section 4.

II. OPTICAL MIMO TECHNIQUES

MIMO techniques are broadly executed in many RF systems. The usage of the multiple transmitters and receivers gives high data rate by increasing the spectral efficiency [6]. As in Free space optical communication, a proper alignment of the transmitters and receivers are necessary for the outdoor transmission. Over last two decades, Free-space optical (FSO) communication has become more and more interesting as an adjunct or alternative to radio frequency (RF) communication. FSO links engaging transmission between two buildings, between ground station and satellite, between end users and fiber optic backbone and as a backup link for optical fiber. Adopting high order M-ary PPM modulation for FSO to boost the power and bandwidth efficiencies as compared to conventional PPM technique whereas in indoor optical wireless communication, it is not clear that at how much MIMO techniques can allocate gains. Due to the fact that in indoor atmosphere, there are no fading effects [7]. So there is less chance of the information loss in the MIMO VLC systems. Fig. 2 depicts the flow diagram of existing optical MIMO techniques available in the literature.

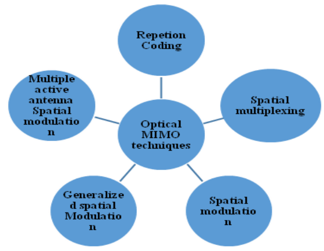

Fig.2: Block diagram of existing optical MIMO techniques

A. REPETITION CODING (RC)

The simplest MIMO technique is the RC technique which transfers the similar signal from all the transmitters. Due to the transmit diversity, RC is acknowledged to attain the better performance in free space OWC. It is observed that RC can do better than orthogonal space time block codes (OSTBCs) like SIMO setups and Alamouti scheme [8]. This is because IM/DD based relates the intensities coming from various transmitters that will be add up at the receiver. As RC transfers same signal from various transmitters, the optical power will be equally allocated to all the emitters. So the mean optical power that is emitted is steady without knowing the number of used transmitters. The transfer factor of the wireless optical links affects the BER of RC without knowing the received optical power. So we can say that RC can be taken as the SISO which gives the same received electrical energy. RC does not give SMP gains as it needs large signal constellation sizes to have the high spectral efficiencies but due to its diversity gain, RC is robust to different transmitters and receivers [9].

B. SPATIAL MULTIPLEXING (SMP)

Another MIMO technique is spatial modulation technique in which self-standing data streams are emitted separately from the optical transmitters so that space dimension will be reused and multiplexed for more than one time as a result of which it can give us high spectral efficiency. There is no bandwidth expansion in the spatial multiplexing. The use of space time equalization is required at the receiver so that the various numbers of receiver will be greater than or equal to the number of transmitters. The data streams in SMP can be set apart by using equalizer if the fading of the spatial channels are nearly independent. In MIMO channels, the capacity increases linearly by the increasing the number of antennas. One of the advantages of SMP is that it provides the data capacity and additional bandwidth. SMP is not planned to make the transmission more robust but it also increases the data rate. By exploiting the multiplexing gains, SMP enables the high data rate so to have these gains, low channel correlation is needed. In SMP there are two algorithms that are useful for the high rate transmission. These are vertical Bell-labs layered space time architecture (V-BLAST) and diagonal Bell-labs layered space time architecture (D-BLAST). These both are a part of the class of layered space time coding. In V-BLAST, output of the coders operate co-channel with synchronized symbol timing whereas in D-BLAST, the output of coder can be put to use by transmit antennas.

C. SPATIAL MODULATION (SM)

Spatial modulation is the collective MIMO and digital modulation technique that was suggested and then it was further investigated [10]. In SM, spatial dimension is designed by extending the signal constellation diagram to additional dimensions. A spatial dimension is used for the transmission of the additional bits. Each transmitter is given a different binary sequence which is called as spatial symbol. A transmitter is activated only when the random spatial symbol that is transmitted paired with the pre-allocated spatial symbol. There is a single transmitter which is active at any symbol duration. Due to this fact, inter channel interference (ICI) [11] is completely neglected. So SM has the least decoding complexity as compared to others. The spectral efficiency of SM- MIMO is greater than the single antenna and OSTBC-MIMO because of the 3-D constellation diagram and spatial-constellation [12]. It has simpler design of transmitter because of the single transmitter antenna transmission, MIMO can be carried out by using one active RF which is less expensive and easy to implement. So the use of multiple RF, expensive power amplifiers can be avoided. As single RF source gives us multiplexing gain so the use of total power used that is required for the RF output power is reduced. So the power that dissipates does not depend on the number of transmitter antennas as a result of which there will be the energy efficiency gains for the low and high spectral efficiency.

In SM-MIMO, the parameters of transmitter antenna changes at every channel by encoding mechanism. As an outcome, a sufficient fast RF switch operating is needed for the single RF implementation that introduces low switching losses. SM-MIMO gives the best application for the visible light spectrum that is namely called as visible light communication (VLC) or optical wireless communication (OWC). VLC offers the spectrum that is more as compared to RF spectrum. VLC is licensed free that is why it offers about 10,000 times higher spectrum compared to RF spectrum which is most helpful belonging of the VLC. The use of solid state lightening and LEDs for the light is considered for the high data rates in wireless communication. LEDs used in the VLC gives us non-coherent light for the illumination. So this shows that the most workable modulation technique for the VLC is Intensity Modulation (IM) in which the preferred waveform is applied on the arising power of an optical carrier by fluttering it. And the down conversion technique is Direct Detection (DD) in which a photo-detector generates a current that is proportional to the received arising power. The use of DD is easier to implement as compared to the coherent detection because it only identifies the intensity of the signal but phase and frequency of the carrier is destroyed. Most of the short range of indoor environment applications, IM/DD modulation is used for the transmission for achieving the low complexities and low cost. So we can say that SM-MIMO is a capable technique for the realizing of gains for VLC MIMO with the uncomplicated IM/DD. SM-MIMO principle is same as for RF applications [13]. The index of a single LED and a light intensity level are both being mapped on the information data. The performance is computed by the Monte Carlo simulations for the transmission of the MIMO channels. In case the transmitter and receiver locations are not found to be efficient then the result shows that the optical MIMO beams are highly mutually related, this results in a power penalty. By using the number of photo-detectors and using channel coding techniques, the power efficiency can be enhanced. On the other hand, by carefully aligning the photo-detectors and LEDs nearly uncorrelated channels paths can be created and therefore this results in an enhanced substantial system performance.

D. GENERALISED SPATIAL MODULATION

Generalized spatial modulation (GSM) is the variation of the spatial modulation which has multiple numbers of antennas that transmits same signal. So it is proposed to prevail the restrictions in the number of transmit antennas that are used in the spatial modulation. In GSM [14], same symbol is transmitted from the multiple active antennas that give the low computational complexity same as SM. There is a unique binary representation for each antenna combination from the multiple antennas that are active at a time in GSM. Even the number of bits is also more that are used for the representation of antenna position in GSM. This is because the possible antenna combination will be more than the number of antennas in an array. If the combination of antennas is used instead of the single antenna then the number of bits for index representation will increase as a result of which the total data rate with minimum number of antennas will improve.

E. MULTIPLE ACTIVE ANTENNAS SPATIAL MODULATION (MA-SM):

It is the modification of the GSM technique. As in GSM, multiple antennas that are active will transmit the same symbol at a time whereas in MA-SM multiple symbols are transmitted by the multiple antennas. So by allowing this, MA-SM achieves low complexity and high multiplexing gain. The transmitted symbols correspond to a high dimensional constellation space [15] which includes the spatial dimension. After the receiver decodes the transmitted signal it should detect the transmitted antenna. Since a part of data is transmitted as antenna index, detection of transmitted antenna becomes essential.

III. DISCUSSION

For the perfect transmission, the performance and the reliability of the system are very important so that we gain high data rate with low BER. So to increase the performance and reliability, space time codes (STC) are used which provide us the increase in the coverage area of optical wireless system. But they give a low coding gain as compared to repetition coding (RC) [16]. In RC, simultaneously same information is transferred from different transmitters. By the use of intensity modulation (IM), system can achieve high diversity gain from RC. So RC is the most proficient technique for the use of IM/DD. To enhance the channel capacity in indoor OWC scenarios, Spatial multiplexing (SMP) technique is used. In this technique, multiple LEDs are used for the transmission of the independent data streams all together. So there is less interference and there is a enhancement in the channel capacity. SMP causes ICI which needs complex interference elimination techniques. Spatial modulation (SM) [17] technique is used to increase the spectral efficiency by the use of multiple transmitters to transfer the data with the completely ignorance of ICI. There are two modifications of spatial modulation that are introduced are generalized spatial modulation and multiple active antenna spatial modulation [18]. The review of the MIMO VLC has been shown in the table 1.

Table.1. Review of VLC MIMO techniques

Author	Work done	No of Antenna	Methodology	Input Source	Results
Zeng et.al [19]	Designed imaging and non imaging systems that can use a compact receiver array for best optical MIMO system. It also overcome the challenge of limited bandwidth of sources.	4x4	Non-imaging and imaging diversity.	White LEDs	Minimum power level has been achieved at the receiver array to get the preferred BER using array of lens.
Fath et.al [20]	Compared the MIMO techniques at different transmitter spacing and at different position of receivers using RC, SMP and SM techniques. It proposed the SM techniques as it reduces the channel correlation by improving channel conditions.	4x4	Repetition coding (RC), Spatial Modulation (SM) and Spatial Multiplexing (SMP).	White LEDs	SM performs best BER with respect to SNR as compared to SMP and RC

Lu et.al [21]	Demonstrated a MIMO VLC system using VCSEL as transmitters and achieved a data rate of 10 Gbps over a 15-m free space link.	4x4	Spatial light modulators with 16-QAM OFDM modulating signal.	Vertical Cavity Surface Emitting Laser (VCSEL)	Due to employment of low noise amplifier and data comparators, low BER Operation is obtained.
Burton et.al [22]	Designed VLC MIMO using 4*4 LEDs and observed BER of 50Mb/s over the distance of 2m and gives luminance of 350 Lux.	4x4	Non-imaging, Zero forcing, zero forcing with pseudo inversion, minimum mean square error and vertical Bell labs layered space time.	White LEDs	Improvement in BER is observed when SNR is low.
Chen et.al [23]	Demonstrated high-spatial-diversity imaging receiver using Fisheye Lens for Indoor MIMO VLCs with the ultra-wide FOV for better quality of imaging	4x4	Spatial diversity.	White LEDs	----
Hong et.al [24]	Designed 4*4 MIMO indoor VLC using 2 scenario with tilted receivers at centre and corner	4x4	Angular diversity.	White LEDs	At center, BER can be improved from 4.97×10^{-3} to 1.66×10^{-5} and at corner it can be improved from 1.90×10^{-3} to 1.59×10^{-6}.
Mulyawan et.al [25]	Proposed a MIMO VLC system with fluorescent concentrator as a receiver. This receiver design allows a wide acceptance angle and a data rate of 32Mbps has been observed.	2x2	Spatial multiplexing employing a fluorescent concentrator based receiver.	White LEDs	3.8×10^{-3} BER has been observed with respect to data rate.

IV. CONCLUSION AND FUTURE SCOPE

The MIMO schemes including RC, SMP, and SM are compared in terms of diversity gain, RC is found robust to diverse transmitter to receiver alignments. But spatial multiplexing gains could not be provided by RC, as it requires large signal constellation sizes in order to provide high spectral efficiencies. On the other hand, high data rates at the cost of increased SNR requirements are enabled by spatial multiplexing. However, low correlation is required between the spatial channels to achieve diversity gains. As a result, SM is found to be not vulnerable to the correlation between various VLC paths in contrast to spatial multiplexing while providing a higher throughput than RC. On the other hand, comparing GSM with MA-SM, while achieving high transmit rate GSM requires more number of transmitted antennas which increases the system complexity while the GSM receiver complexity for high data rate becomes high. Therefore MA-SM scheme with low computational complexity is proposed. In MA-SM during each time slot, several antennas carrying different information are active. Information bits here are mapped into spatial and traditional dimension. Therefore more spectral and energy efficiency can be attained using same bandwidth. Difference also occurs when in GSM same symbol is transmitted while in MA-SM different antennas which are active at a time transmit different information, while some amount of information will be encoded as index of antenna combination. As a result, data rate of MA-SM is more than GSM. This is how a system which is spectrum and energy efficient is achieved. In its future scope, we can investigate about the communication via non line of sight (NLOS). Also by applying various modulation techniques with MIMO techniques, we can investigate about the high transmission rate with low bit error rate (BER).

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