Defence Science Journal, Vol. 69, No. 5, September 2019, pp. 458-463, DOI : 10.14429/dsj.69.14951

Reliable Integrated Satellite/Terrestrial Communications using MIMO for Mitigation of Microwave Absorption by Earth's Oxygen

Anurag Vijay Agrawal* and Meenakshi Rawat

Department of Electronics and Communication Engineering, Indian Institute of Technology, Roorkee - 247667, India

**E-mail: anurag.v.agrawal@gmail.com*

ABSTRACT

Microwaves are used to communicate with satellite and terrestrial communication networks. But as microwaves pass through the Earth's atmosphere, the oxygen gas absorbs microwave. In this 5G era, when the whole world is moving towards high data-rates and reliable communications, this absorption affects the data transmission in integrated satellite/terrestrial communication (ISTC) systems, which leads to degradation of the system performance. However, the superior data-rates and better transmission reliability requirements of modern and future (5G and beyond) practical wireless communication systems may easily be acquired by using the multiple input multiple output (MIMO) techniques. The authors investigate MIMO diversity results by considering the effect of varying signal-to-noise ratio (SNR) value on key performance indicators block error rate (BLER), throughput and error vector magnitude (EVM). The paper envisages that higher order MIMO configuration is capable of providing reliable signal transmission and higher data rates both. MIMO 8×1 provides 5, 20 and 42.5 times improved performance to BLER; 5.26 per cent, 25 per cent and 81.82 per cent in throughput; and 10.34 per cent, 23.07 per cent and 28 per cent in EVM calculations as comparable to MIMO 4×1, MIMO 2×1 and SISO 1×1, respectively at a moderate SNR value of 15 dB. The authors also give a new concept of multi-cellular layers based mobile communication network, useful for future smart cities.

Keywords: BLER; ISTC; Microwave absorption; MIMO; Satellite communication; Terrestrial communication

1. INTRODUCTION

Wireless communication makes use of microwave frequencies[1] due to its unique property of ionosphere penetration. But this type of communication is reliable only for Line-of-Sight (LoS) transmission as microwave frequencies face attenuation when researchers use them for surface- or ground-wave communications. Now-a-days, various standard regulators, researchers, and business stakeholders are very much interested to implement a single telecommunication network, i.e. a 'network of networks', which is the combination of one or more satellite communication system (s) and one or more terrestrial wireless or wireline communication system (s). This is called 'integrated' satellite / terrestrial communication network, which is suitable to deliver three type of satellite services: Fixed, broadcasting, and mobile[2].

The terrestrial and satellite parts are complementary to each other in integrated satellite/terrestrial communication (ISTC) network[3]. Both of them are allocated same frequency bands and are operated by the same network. Contrary to a standalone satellite communications system, the resulting combined network has several benefits: extension in coverage area, economical to both operators and users, broad range of services, enhanced quality of service (QoS). Moreover, when satellite has been used in combination with a terrestrial system, the benefits include the optimised recurring / overall investment cost if compared with a new service deployment expenditure and the optimised energy requirement for data transmission by making use of the solar power facility of the satellite infrastructure.

European Aviation Network (EAN) has been working to combine the satellite and terrestrial components to deliver reliable and high speed inflight broadband to airlines. The work is done by Deutsche Telekom and Inmarsat[4] having technological collaborations with Cobham, Nokia and Thales for MSS S-band frequencies and is the world's first dedicated aviation solution to the cause. Alcatel-Lucent has implemented an integrated 4G long term evolution (LTE) solution[5] that combines the advantages of the satellite network with the country-wide Air-to-ground LTE network, where both the networks are working in Europe with S-band frequencies. India too uses an S-band MSS with Indian National Satellite (INSAT) system for voice/data transmission during disasters[6]. A small portable satellite terminal is connected to the electronic private automatic branch exchange (EPABX) central ground station with location at Space Applications Centre (SAC) Ahmedabad (India) through satellite channel. The satellite terminal is used from any location in India for emergency communication.

The ISTC system makes use of microwave radio transmission to provide point-to-point communication on Earth's surface. But due to the same frequency band usage by the satellite and terrestrial components within the ISTC network, this point-to-point communication capability allows

Received : 01 December 2018, Revised : 05 March 2019
Accepted : 20 April 2019, Online published : 17 September 2019

nearby microwave equipments to use the same frequencies without interfering with each other. But the magnetic dipole transitions of the oxygen molecule available in Earth's atmosphere produce a non-resonant absorption that is effective at all frequencies below 60 GHz. Oxygen gas is about 21 per cent in the Earth's atmosphere and is electrically non-polar but absorbs microwave signals[7]. The reason is the interaction of electromagnetic fields and the magnetic moment of oxygen molecule. This interference affects the data transmission more when wavelengths are in the vicinity of 0.5 cm, where the interference exceeds 10 dB/km. A subsidiary resonance takes place near 0.25 cm and a non-resonant absorption at long wavelengths.

The interference caused by microwave absorption at the Earth's surface distorts the transmitted signal, which in turn, reduces the system reliability and affects the achievable data-rate in the ISTC system. Multiple-input-multiple-output (MIMO) is the emerging technique to fulfill the everyday growing high data-rates and enhanced signal transmission reliability demands for current and future (5G and beyond) wireless technologies. If the ISTC system makes use of the multiple antennas and if the same signal is send from all the antennas to the same destination at the same time, the signal transmitted from each antenna interfered in a different manner as to follow different paths to reach the destination. The receiver in turn decodes each stream of data into its original sequence. Therefore, MIMO[8-9] may effectively be used with LTE ISTC systems and helps in improving the data throughput and transmission reliability capabilities of the communication network.

The authors evaluate the block error rate (BLER), data throughput and error vector magnitude (EVM) parameters corresponding to varying signal-to-noise ratio (SNR) values with single-input-single-output (SISO) and various multiple antenna configurations for the LTE ISTC downlink transmission system. The transmission is done for a wireless MIMO downlink channel with 64-QAM mapping and the system supports S-band[10] frequencies for 20 MHz bandwidth for downlink transmission. An overview of MIMO-LTE technology and a version of future global mobile communication system is suggested in the paper.

2. FUTURE GLOBAL MOBILE COMMUNICATION SYSTEM AND MIMO-LTE

2.1 MIMO-LTE Technology

LTE[11] is a MIMO-OFDM (orthogonal frequency division multiplexing) technology; where multiple antennas, that is MIMO configurations, are combined with the OFDM multicarrier transmission scheme. Thus, MIMO-LTE uses multi-antenna multi-carrier transmission schemes in which modulated data symbols are mapped to multiple antenna ports. Diversity and multiplexing are two widely used MIMO schemes, using which MIMO configurations may take advantage of the multipath signal propagation that, otherwise, is providing interference in all terrestrial communications.

If the same information-carrying signals are transmitted across multiple antennas, they may pass through different paths. Thus, the receiver, in this case, may obtain multiple replicas of the independently faded data symbols. The aforesaid scheme is MIMO diversity, also called transmit/receive diversity. This scheme allures the diversity benefits of reflections during multipath propagation and provides more reliable reception.

On the other hand, if the incoming data is distributed into multiple bit-streams and if each information bit-stream is transmitted in parallel through a different antenna, the data-rates may be increased and the scheme is known as multiplexing.

2.2 Future Global Mobile Communication System

It was forecasted that the small cell concept will fulfill the everyday increasing demands of enhanced capacity and higher speed but the problems arising due to coverage gaps and frequent handovers outdates small cell structures very soon. Today, a layered cellular architecture is needed to cover discrete data-traffic densities areas with different-sized overlapping cells. This concept of overlapping cells may be utilised by future smart cities.

A satellite-based communication system covers more area than that of a terrestrial-based communication system and it is a known fact that a geostationary satellite having single antenna covers about quarter of the Earth. Mobile satellite systems and cellular terrestrial networks have already started to converge towards a future ISTC mobile network, which may unload the fixed part responsibility of the mobile network. The future mobile communication system, as shown in Fig. 1, is said to be an extended version of ISTC system. It suggests that several cellular layer-based satellite/terrestrial structures will exist in the Future Global Mobile Communication System to cover the whole Earth, which may include nano- and pico-cellular structures for indoor areas, micro-cellular structures for urban environments, macro-cellular structures for data communications to suburban and rural locations, and satellite based systems for covering the complete Earth.

3. SYSTEM DESCRIPTION

A detailed block diagram model for the simulation of a modern ISTC system is as shown in Fig. 2. The satellite terminal prefers using OFDM scheme for single-carrier transmission to communicate data information bits. The ISTC system also provides the facility of using sparse transmitters that can broadcast at the same time, through synchronisation, exactly the same data at the same frequency and, therefore, there is not any significant effect of signal interference on the receiver.

The ISTC system simulation is split in two stages: Stage 1 is the channel coding and code rate matching stage, which includes the processes of turbo-encoding/ decoding, code rate matching and retransmission processes like hybrid automatic repeat request (HARQ). Stage 2 is termed as the LTE physical layer simulation that includes the broadband OFDM modulation / demodulation, power amplification / low-noise amplification and the MIMO downlink channel. All the simulated OFDM subcarriers are received at the Stage 1 output, which is a set of log-likelihood ratios (LLRs) of the received encoded data in bits. The output is then filtered by Stage 2 and extracts the LLRs of the physical resource blocks. Thus the time-frequency correlations of the channel

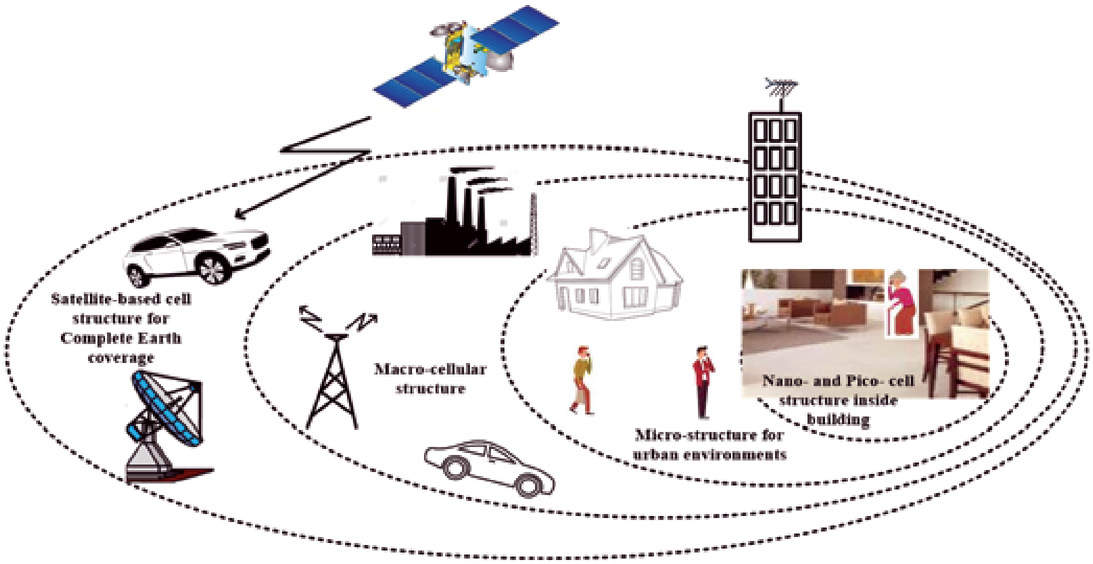

Figure 1. A reliable high-speed future mobile communication system.

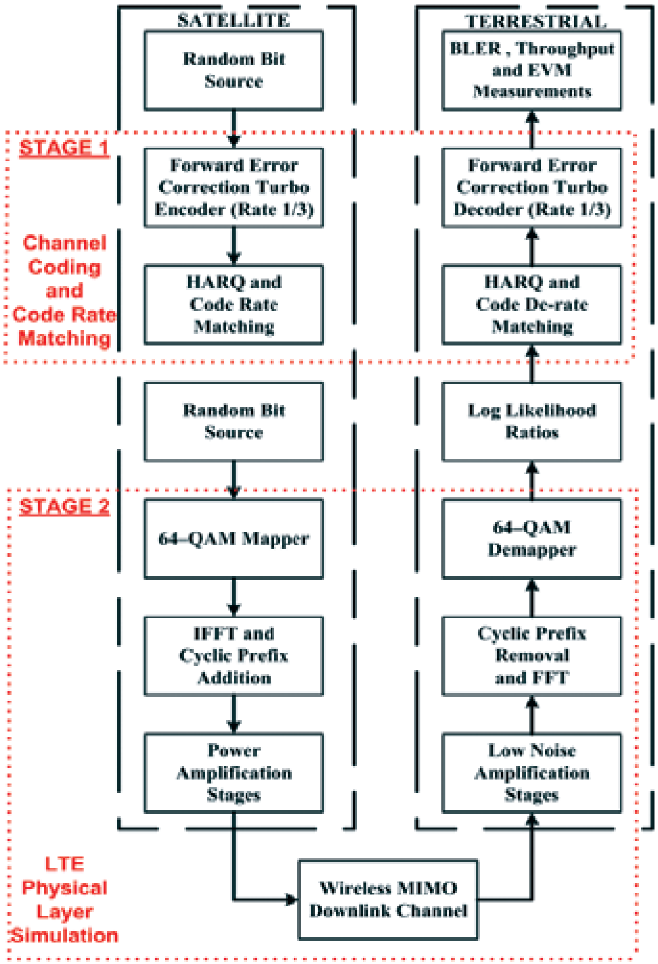

Figure 2. Block Diagram Model for the simulation of a modern ISTC system.

responses have been analysed at the terrestrial terminal. The authors make use of time windowing spectrum shaping type. The raised-cosine window type is chosen due to its ability to minimise intersymbol interference (ISI).

The low-noise amplifier (LNA) stages take weaker and uncertain signals from the antenna. These signals are of the order of microvolts or are under -100 dBm range. The amplification is then done by LNA stages, which amplify the signal to an appropriate level of about 0.5-1 volt. In contrast to the LNA's difficult signal-capture challenge, the power amplifier stage takes a relatively strong signal having moderate SNR value. The signal is taken from the system and then the power amplification stages provide amplification to boost its power.

The channel coding scheme used at the satellite terminal for LTE transport channels is forward error correction (FEC) turbo-coding with a coding rate of 1/3. The terrestrial terminal inverts the processing of code rate matching, turbo-coding and HARQ processes. The turbo-decoder uses maximum likelihood detection (MLD) algorithm whereas the HARQ process uses the acknowledgement (ACK) / non-acknowledgement (NACK) signalling to provide reliable wireless transmission.

The simulation is done with value considerations as in Table 1. The BLER, throughput and EVM[12] are the most widely used performance indicators to perform MIMO diversity analysis for the mitigation of microwave absorption in an ISTC system for a line of sight (LOS) fading channel.

The BLER analysis has been done to test the signal transmission reliability for any modern ISTC system. The signal transmission is reliable if the ISTC system is capable in efficiently decoding the transmitted transport block. This is possible only if the receiver cyclic redundancy check (CRC) matches with the transmitted transport block CRC. The BLER value is set as 0.1 for having successful data signal transmission over radio link. This target BLER value is the same as of attaining 90 per cent reliable data transmission.

BLER is calculated as

$$BLER = \frac{\sum_{SU\ Start}^{SU\ Stop}\left(1 - CRC\ Check\right)}{\sum_{SU\ Start}^{SU\ Stop}\left(1\right)} \qquad (1)$$

Table 1. System parameters

Name	Value (s)
Communication system type	Downlink ISTC
Channel type	Line of sight, microwave absorbing
Channel estimation scheme	Minimum mean square error
Traffic type	Full buffer model
Bandwidth	20 MHz
Carrier frequency	2 GHz
Antenna arrangement	SISO, MIMO
MIMO detection scheme	Maximum likelihood detection
Diversity mode	Transmit diversity
Frame structure	FDD
FFT size	2048
Radio frames	200 (in number)
Sub-frames	2000 (in number)
Frame duration	10 ms
Sampling frequency	30.72 MHz
Coding scheme	turbo, forward error correction
Modulation mapping scheme	64-QAM
Resource block	12 tones over 1 ms
Sub-carrier spacing	15 kHz

The Throughput Fraction is the percentage of averaged throughput to its maximum possible value for the specified total number of subframes and is calculated as

$$Throughput\ Fraction\ = \frac{\sum_{SU\ Start}^{SU\ Stop} TBLS * CRC\ Check}{\sum_{SU\ Start}^{SU\ Stop} TBLS} \tag{2}$$

where *SU* is the acronym for sub-frame, *TBLS* is the sub-frame transport block size and *CRC Check* shows CRC result for each sub-frame. If *CRC Check* is '1', it reflects successful CRC comparison, whereas '0' reflects failure of CRC comparison. The authors, in this paper, place an assumption that the receiver is delayed by one sub-frame of 1 millisecond duration for the sake of transceiver synchronization. This represents that the throughput should be calculated at least after the completion of the transmission of first sub-frame, i.e. *SU Start* >=1.

EVM is another standard parameter used to measure the modulation scheme quality and to quantify the communication system error performance. It is usually denoted in dB and computes the vector difference between the corrupted received symbol voltage during multipath propagation and a clean reference symbol voltage value regenerated at the receiver. EVM is mathematically calculated as the square root of the error vector power (P_{EV}), which is defined as the normalised mean square error (MSE), where the normalisation takes place by the mean square signal power.

$$P_{EV} = \frac{\sum_{n=1}^{N_u} \left| M_n - P_{0,n} \right|^2}{\sum_{n=1}^{N_u} \left| P_{0,n} \right|^2} = \frac{P_E}{P_S} = \frac{1}{SNR_E} \tag{3}$$

where M_n is the normalised nth symbol within the measured symbols, and $P_{0,n}$ is the nth normalised symbol within the ideal constellation and N_u is the total number of unique constellation symbols. SNR_E is the signal-to-inband error ratio and is calculated as

$$SNR_E = \frac{P_S}{P_E} \tag{4}$$

The LTE standard requires that the EVM for 64-QAM modulation mapping scheme shall be better than -22 dB[13]. It should hold true for all types of antenna arrangements.

Moreover, 15 dB is the acceptable SNR value[14] for having meaningful data transmission in all modern LTE practical wireless communications, where the 15-25 dB SNR range represents low signal strength, and the 25-40 dB range represents good strength signals.

4. RESULTS

The MIMO diversity effect is analysed for BLER, throughput and EVM performances with SNR values ranging from 0 to 30 dB. The curves for these performance metrics are plotted for SISO and different MIMO configurations, as shown in Fig. 3, Fig. 4 and Fig. 5, respectively.

Larger BLER values can cause low downlink throughput. The authors maintain the target BLER at 10 per cent of the maximum value. Figure 3 reports that MIMO 8×1 configuration is capable to reach this target BLER value of 0.1 with an SNR of only 12 dB. This is the least SNR required by any MIMO configuration in the given ISTC system to have reliable signal transmission. This also shows that MIMO 8×1 transmit diversity mode offers least signal power. It is remarkable that the 8×1 configuration achieves 99 per cent throughput at BLER value 0.1 for microwave absorbing channels, as in Fig. 4.

Figure 3 reveals that other antenna configurations, viz. MIMO 4×1, MIMO 2×1 and SISO may also achieve the required 10% BLER but at comparatively higher SNR values equal to 13.5 dB, 17 dB and 19.5 dB respectively. It implies that lower MIMO transmission modes need more signal power to have reliable transmission. Figure 4 also shows that at 0.1 BLER value, all other antenna arrangements, lower to MIMO 8×1, achieve the same 90 per cent throughput, which is considerably lower than that of MIMO 8×1 configuration.

The system is analysed further with the assumption that the SNR value is fixed at 15 dB. With this target SNR value, from Fig. 4, MIMO 8×1 configuration achieves the maximum 100 per cent throughput; whereas MIMO 4×1, MIMO 2×1 and SISO transmission modes are capable to achieve only 95 per cent, 80 per cent and 55 per cent throughput values, respectively. The BLER values achieved for the target 15 dB SNR are 0.425, 0.2, 0.05 and 0.01. These BLER values are attained for 1×1, 2×1, 4×1 and 8×1 antenna diversity modes respectively. It is seen from Fig. 3 and Fig. 4 that 8×1 configuration gives superior throughput performance with low power usage and achieves the target of 0.1 BLER.

This also indicates that the higher order MIMO transmission mode 8×1 provides the minimum BLER and maximum throughput values, which took place at an SNR of 16 dB. The lower MIMO configurations have inferior BLER

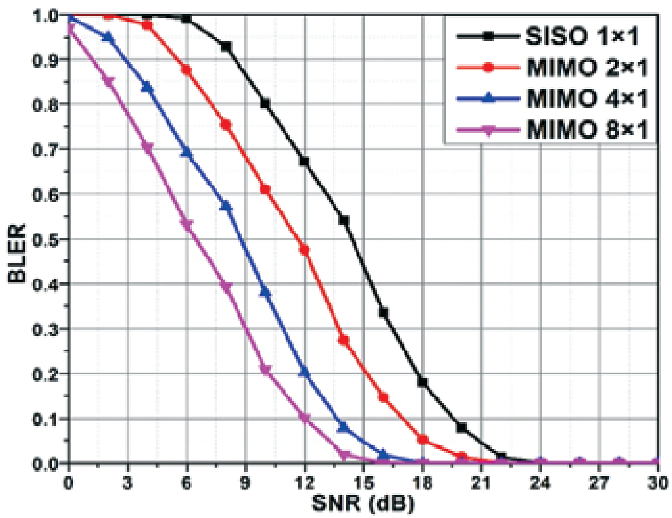

Figure 3. BLER vs SNR with different antenna configurations.

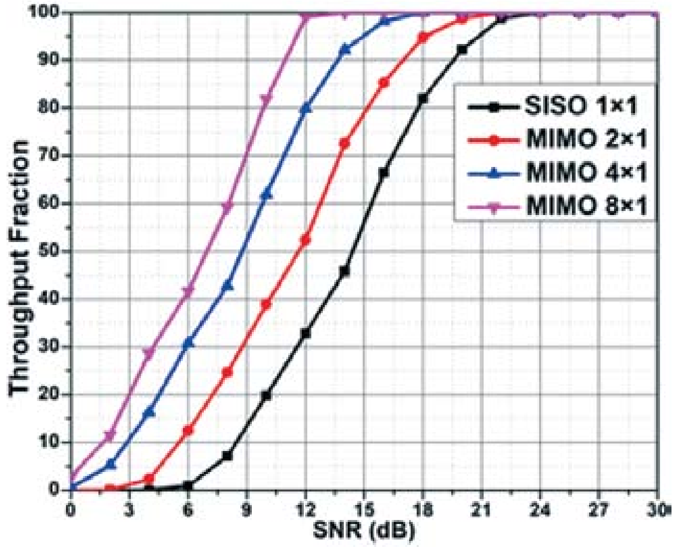

Figure 4. Throughput vs SNR with different antenna configurations.

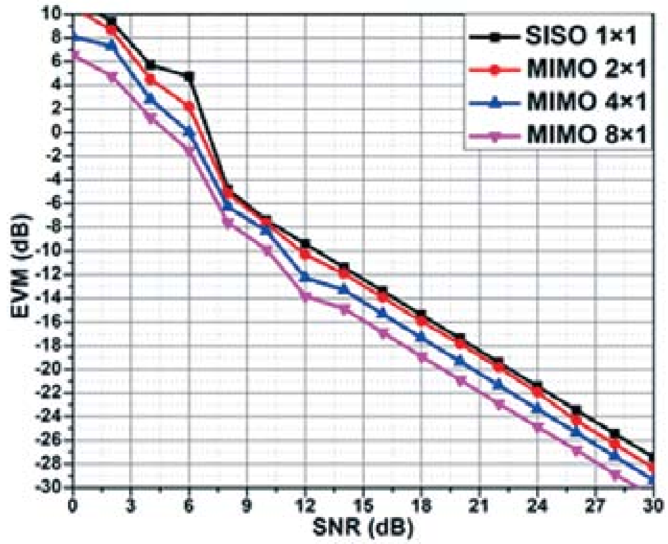

Figure 5. EVM performance curves with different antenna configurations.

and throughput performances. It establishes that the use of higher MIMO diversity configurations enhances the achieved data-rates and makes the practical wireless communication system more reliable.

It is envisaged from Fig. 5 that for moderate signal strengths, the system EVM is always below the target EVM value, which should be atleast -22 dB for complex 64-QAM modulation mapping scheme, used by the authors to study MIMO diversity for mitigation of microwave absorption by Earth's Oxygen. This holds true for all the antenna configurations taken in this paper. But the ISTC system under study shows poor EVM performances for low air link SNRs (< 22 dB). This poor performance is for the complete received signal power range with all the antenna modes used in the paper.

5. CONCLUSIONS

The effect of the absorption of microwaves by the oxygen gas available on the Earth's surface is studied for an ISTC system. A new concept for reliable and high speed global mobile communications suitable for future smart cities is designed. The BLER, throughput and EVM parameters calculated for various SISO and MIMO configurations establish that MIMO 8×1 has improved performance as compared to MIMO 4×1, MIMO 2×1 and SISO 1×1. The ISTC system shows superior performance with MIMO 8×1 configuration corresponding to 15 dB SNR with 64-QAM modulation mapping scheme. When compared with MIMO 4×1, MIMO 2×1 and SISO, the MIMO 8×1 has improved its BLER performance by 5 times, 20 times and 42.5 times respectively; the throughput performance by 5.26 per cent , 25 per cent and 81.82 per cent respectively; and the EVM performance by 10.34 per cent , 23.07 per cent and 28 per cent, respectively. Therefore, MIMO technology is a perfect choice to address the demands of all the end-users for future data communications and to materialise this vision, 5G needs to support and exploit the facilities of ISTC network.

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CONTRIBUTORS

Mr Anurag Vijay Agrawal received the BE in Electronics and Communication Engineering from MJP Rohilkhand University, Bareilly, Uttar Pradesh, India and ME in Electronics and Communication Engineering from Panjab University, Chandigarh, India in 2000 and 2010 respectively. He is currently pursuing the PhD at the Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee, Roorkee, India.

In the current study, he has modelled and integrated the modern integrated satellite / terrestrial communication system, completed simulation, acquired data and validated the results.

Dr Meenakshi Rawat received the MSc and PhD in electrical and computer engineering from the University of Calgary, Calgary, AB, Canada, in 2012. She is currently an Assistant Professor with IIT Roorkee, India. She was the Workshop Co-Chair for the Automatic RF Techniques Group (ARFTG)-82 and the Session Co-Chair for millimeter-wave and terahertz designs for iMARC 2014, Bangalore, India. She was part of the Calgary Group that won the Overall Championship and Best Design Prize of the Third Annual Smart Radio Challenge, Wireless Innovation Forum. She was also the three-time recipient of the Research Production Award of the University of Calgary and Best Poster Award of the 82nd ARFTG Conference, Columbus, OH, USA, in 2013. Recently, she was listed as a Featured Engineer on EEWeb.com (Electrical Engineer Community).

In the current study, she has contributed in technical discussions and conception of idea.