

**DESIGN AND PERFORMANCE EVALUATION
OF FSO SYSTEM WITH
OSSK MODULATION SCHEME**

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DESIGN AND PERFORMANCE EVALUATION OF FSO SYSTEM WITH OSSK MODULATION SCHEME

by

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Certificate

This is to certify that the thesis entitled "**Design and performance evaluation of FSO system with OSSK modulation scheme**" being submitted by **Mr. Anshul Jaiswal** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is the record of the bona-fide research work carried out by him under our supervision. In our opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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Abstract

Improving spectral efficiency, without increasing design complexity, is the prime motivation to manage the high data traffic of future wireless transmission technologies. Optical spatial modulation (OSM) scheme is one of the possible viable options when employed with multiple-input multiple-output (MIMO)-free-space optical (FSO) communication system. OSM is a modulation scheme which conveys information over both spatial and signal constellation simultaneously. In other words, a part of the information bits is used to choose one of the optical antennas/sources (LASERs/LEDs) while the remaining bits are transmitted by a traditional modulation scheme through the selected optical antenna. Therefore, by encoding information in the index of the optical antenna, spectral efficiency of the system can be improved. In addition to increasing spectral efficiency, other challenges of MIMO systems such as inter-channel interface, inter-antenna synchronization, complex decoding, etc. are completely eliminated by OSM scheme since it uses a single optical antenna at a time. A special case of OSM is optical space shift keying (OSSK) where only antenna indices are used to transfer the information; this makes the overall system even simpler as compared to OSM. These inherent benefits make OSM/OSSK a suitable modulation scheme to achieve high spectral efficiency for future FSO systems.

In this dissertation, a detailed performance analysis of OSSK scheme over different FSO channel models is presented. The analysis starts with a multiple-input single-output (MISO) system employing OSSK scheme (MISO-OSSK system). The closed-form expressions of different performance metrics such as average bit error rate (BER), diversity order, and coding gain are obtained for MISO-OSSK system under Gamma-Gamma fading channel model. The effect of different transmit power weights on the

error performance of OSSK scheme is also investigated. For a more realistic study of the OSSK scheme, the effect of pointing errors along with the atmospheric turbulence is included. Subsequently, the analysis is extended to MIMO-FSO system employing OSSK scheme (MIMO-OSSK system) over three different channel models which cover the entire turbulence regime. The mathematical expressions of the average BER and the finite constellation based channel capacity of MIMO-OSSK system are derived. MIMO-OSSK system is then compared with the same rate MIMO-FSO system employing repetition coding (MIMO-RC) in terms of error performance and channel capacity.

After a detailed study of the traditional OSSK schemes, a novel partially informed transmitter based OSSK (PIT-OSSK) scheme is proposed wherein the transmitter has a partial knowledge of the channel condition. The partial knowledge of the channel state is used to reorder the mapping of symbols onto the optical sources along with power allocation. This modification reduces the number of bits in error between two consecutive constellation points and hence reduces the system BER. A framework to obtain the mathematical expression of BER of the proposed PIT-OSSK scheme is provided. A comparison of PIT-OSSK scheme with conventional OSSK scheme over different channel models is also performed. At last, a novel differential OSM/OSSK (DOSM/DOSSK) is designed and intensively studied. The proposed DOSM/DOSSK scheme overcomes the necessity of channel state information at receiver side which is required in traditional OSM/OSSK scheme. In short, this dissertation presents a fundamental analytical framework to investigate the OSSK scheme over the FSO system along with some new variants of OSM/OSSK.

डिजाइन की जटिलता को बढ़ाए बिना वर्णक्रमीय दक्षता में सुधार, भविष्य की वायरलेस ट्रांसमिशन प्रौद्योगिकियों के उच्च डेटा ट्रैफ़िक का प्रबंधन करने की मुख्य प्रेरणा है। ऑप्टिकल स्पेसियल मॉड्यूलेशन (OSM) स्कीम संभावित व्यवहार्य विकल्पों में से एक है जब इसे मल्टीपल-इनपुट मल्टीपल-आउटपुट (MIMO) फ्री-स्पेस ऑप्टिकल (FSO) संचार प्रणाली के साथ नियोजित किया जाता है। OSM एक ऐसी मॉड्यूलेशन स्कीम है जो स्थानिक और संकेत नक्षत्र का उपयोग एक साथ करके जानकारी भेजती है। दूसरे शब्दों में, सूचना बिट्स के एक हिस्से का उपयोग ऑप्टिकल एंटेना/स्रोतों (LASER/LED) में से एक को चुनने के लिए किया जाता है, जबकि शेष बिट्स चयनित ऑप्टिकल एंटीना के माध्यम से एक पारंपरिक मॉड्यूलन योजना द्वारा प्रेषित होते हैं। इसलिए, ऑप्टिकल एंटीना के सूचकांक में जानकारी को एन्कोडिंग करके, प्रणाली की वर्णक्रमीय दक्षता में सुधार होता है। वर्णक्रमीय दक्षता बढ़ाने के अलावा, MIMO सिस्टम की अन्य चुनौतियाँ जैसे इंटर-चैनल इंटरफ़ेस, इंटर-एन्टेना सिंक्रोनाइज़ेशन, कॉम्प्लेक्स डिकोडिंग इत्यादि को OSM योजना द्वारा पूरी तरह से समाप्त हो जाता है क्योंकि यह एक समय में एक ही ऑप्टिकल एंटीना का उपयोग करता है। OSM का एक विशेष प्रकार ऑप्टिकल स्पेस शिफ्ट कींग (OSSK) है जहां केवल एंटीना सूचकांक का उपयोग करके सूचना को स्थानांतरित किया जाता है; यह OSM की तुलना में समग्र प्रणाली को और भी सरल बनाता है। OSM/OSSK के ये सभी अंतर्निहित लाभ इन्हें भविष्य के FSO सिस्टम के लिए उच्च वर्णक्रमीय दक्षता प्राप्त करने के लिए एक उपयुक्त मॉड्यूलन योजना बनाते हैं।

इस शोध प्रबंध में, विभिन्न FSO चैनल मॉडल पर OSSK योजना का एक विस्तृत प्रदर्शन विश्लेषण प्रस्तुत किया गया है। विश्लेषण OSSK योजना को नियोजित करने वाले मल्टीपल-इनपुट-सिंगल-आउटपुट (MISO-OSSK) सिस्टम से शुरू होता है। गामा-गामा चैनल मॉडल के तहत, MISO-OSSK प्रणाली के लिए औसत बिट त्रुटि दर (BER), विविधता क्रम और कोडिंग लाभ जैसे विभिन्न प्रदर्शन मैट्रिक्स के अभिव्यक्तियाँ प्राप्त की जाती हैं। OSSK स्कीम के त्रुटि प्रदर्शन पर अलग-अलग ट्रांसमिशन शक्ति भार के प्रभाव की भी जांच की जाती है। ओएसएसके योजना के अधिक यथार्थवादी अध्ययन के लिए, वायुमंडलीय अशांति के साथ-साथ पॉइंटिंग त्रुटियों का प्रभाव भी शामिल किया गया है। इसके बाद, विश्लेषण को MIMO-FSO प्रणाली के लिए विस्तारित किया गया है जो OSSK योजना (MIMO-OSSK प्रणाली) को तीन अलग-अलग चैनल मॉडल पर जाँच करता है जिससे संपूर्ण अशांति शासन कवर होता है। MIMO-OSSK प्रणाली का औसत BER और परिमित नक्षत्र आधारित चैनल क्षमता की गणितीय अभिव्यक्तियाँ को निकाला गया है। त्रुटि प्रदर्शन और चैनल क्षमता के संदर्भ में, MIMO-OSSK प्रणाली की तुलना सामान्य दर वाले MIMO-FSO प्रणाली जो पुनरावृत्ति कोडिंग (MIMO-RC) को नियोजित करता है के साथ की गयी है।

पारंपरिक OSSK योजनाओं के विस्तृत अध्ययन के बाद, एक नया आंशिक रूप से सूचित ट्रांसमीटर आधारित OSSK (PIT-OSSK) योजना प्रस्तावित किया गया है, जिसमें ट्रांसमीटर को चैनल की स्थिति का आंशिक ज्ञान है। चैनल राज्य का आंशिक ज्ञान शक्ति आवंटन के साथ-साथ ऑप्टिकल स्रोतों पर प्रतीकों के मानचित्रण को फिर से व्यवस्थित करने के लिए उपयोग किया जाता है। यह संशोधन दो लगातार नक्षत्र बिंदुओं के बीच त्रुटि में बिट्स की संख्या को कम करता है और इसलिए सिस्टम बीईआर को कम होता है। प्रस्तावित पीआईटी-ओएसएसके योजना के बीईआर की गणितीय अभिव्यक्ति प्राप्त करने के लिए एक रूपरेखा प्रदान की गई है। विभिन्न चैनल मॉडल पर पारंपरिक OSSK योजना के साथ PIT-OSSK योजना की तुलना भी की गयी है। अंत में, एक नया डिफरेंशियल OSM/OSSK (DOSM/DOSSK) का डिजाइन और गहन अध्ययन किया गया है। प्रस्तावित DOSM/DOSSK योजना रिसीवर की तरफ चैनल की जानकारी की आवश्यकता को खत्म करता है जो पारंपरिक OSM/OSSK योजना में आवश्यक है। संक्षेप में, यह शोध प्रबंध OSSK योजना की जांच करने के लिए एक मौलिक विश्लेषणात्मक ढांचा प्रस्तुत करने के साथ साथ OSM/OSSK के कुछ नए प्रकार भी प्रस्तुत करता है।

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Abbreviations

ABER	Average Bit Error Rate
APEP	Average Pair-wise Error Probability
AWGN	Additive White Gaussian Noise
AT	Atmospheric Turbulence
BER	Bit Error Rate
CSI	Channel State Information
CSIT	Channel State Information at the Transmitter
FSO	Free Space Optical
G-G	Gamma-Gamma
IAI	Inter-antenna Synchronization
ICI	Inter-channel Interface
i.i.d.	independent identically distributed
IM/DD	Intensity-Modulation/Direct-Detection
MGF	Moment Generating Function
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
PAM	Pulse Amplitude Modulation
PPM	Pulse Position Modulation
OSM	Optical Spatial Modulation
OOK	On-Off Keying
OSSK	Optical Space Shift Keying
OWC	Optical Wireless Communication
PEP	Pair-wise Error Probability

PDF	Probability Density Function
PE	Pointing Error
RC	Repetition Coding
RF	Radio-Frequency
RV	Random Variable
SER	Symbol Error Rate
SM	Spatial Modulation
SMuX	Spatial Multiplexing
SNR	Signal-to-Noise Ratio