DHT-OFDM Based Spatial Modulation for Optical Wireless Communication

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***Abstract*—The combination of orthogonal frequency division multiplexing (OFDM) and spatial modulation (SM) can enhance the capacity of optical wireless communication (OWC) systems with low complexity. In this paper, we propose a novel SM scheme for intensity modulation/direct detection (IM/DD) OWC systems by employing discrete Hartley transform based OFDM (DHT-OFDM). Due to the use of DHT with one-dimensional constellations, the Hermitian symmetry constraint, which is generally imposed in conventional discrete Fourier transform based OFDM (DFT-OFDM) to obtain a real-valued output signal, is not required in DHT-OFDM. As a result, DHT-OFDM based SM can achieve much higher spectral efficiency than that of DFT-OFDM based SM in OWC systems. Simulation results show that, for an indoor 4 × 4 SM-OWC system with a spectral efficiency of 6 bits/s/Hz, DHT-OFDM achieves a remarkable 4.5-dB transmit signal-to-noise ratio reduction for an overall bit error rate of 10^{-5} in comparison to conventional DFT-OFDM.**

Keywords-Spatial modulation, orthogonal frequency division multiplexing, optical wireless communication.

I. INTRODUCTION

Due to the rapid growth of smart mobile devices which demand high definition video streaming, low-latency gaming and virtual/augmented reality in our daily life, the mobile data traffic is exponentially increased in recent years. However, the existing radio frequency (RF) spectrum will be saturated in the near future. In order to support the ever-increasing mobile data traffic, it might be necessary to exploit the higher frequency of the electromagnetic spectrum, i.e., the optical spectrum including visible light, infrared and ultra-violet [1]. As a very promising candidate to satisfy the demand of heavy mobile data traffic for mobile users, optical wireless communication (OWC) has attracted great attention lately [2]. Typical OWC systems use laser diodes (LDs) or light-emitting diodes (LEDs) as transmitters and photo-diodes (PDs) as receivers, which generally adopt intensity modulation with direct detection (IM/DD) for signal transmission [3].

Commercial off-the-shelf optical elements usually have very limited electrical bandwidth, and hence various capacity-enhancement techniques have been applied in OWC systems to achieve high capacity. Among them, orthogonal frequency division multiplexing (OFDM) modulation using high-order quadrature amplitude modulation (QAM) constellations and multiple-input multiple-output (MIMO) transmission are two most popular techniques [4]–[8]. Due to the IM/DD nature of OWC systems, the Hermitian symmetry constraint is usually imposed in OFDM modulation so as to obtain a real-valued signal and a direct current (DC) bias is usually added to convert the bipolar signal into a non-negative unipolar signal for intensity modulation in LD/LED transmitters. Moreover, mainly three types of MIMO transmission schemes can be applied in OWC systems, including repetition coding (RC), spatial multiplexing (SMP) and spatial modulation (SM) [6]. RC is the simplest MIMO scheme which can provide transmit diversity for OWC systems, but with the lowest spectral efficiency. SMP can provide high spectral efficiency, but suffers from severe inter-channel interference (ICI) due to channel correlation and high detection complexity. As a digitized MIMO scheme, SM has the advantages of reduced ICI, increased power efficiency and low detection complexity compared with SMP [9]. Nevertheless, the spectral efficiency of SM is relatively lower than SMP.

The combination of OFDM and SM has been shown as an efficient way to enhance the capacity of bandlimited OWC systems with low complexity, where SM can be implemented in the frequency domain or in the time domain [10], [11]. Although OFDM with time-domain SM can achieve higher spectral efficiency than that with frequency-domain SM, it requires a secondary DC bias to avoid zero samples after zero clipping, which might reduce the power efficiency of the system [12]. To improve the spectral efficiency of bandlimited OWC systems employing OFDM with frequency-domain SM, in this paper, we propose a novel SM scheme based on discrete Hartley transform based OFDM (DHT-OFDM). By utilizing DHT with one-dimensional constellations, the Hermitian symmetry constraint in discrete Fourier transform based OFDM (DFT-OFDM) can be eliminated [13], and hence the spectral efficiency can be greatly increased in bandlimited OWC systems. The superiority of DHT-OFDM over DFT-OFDM has been verified in a typical indoor 4 × 4 SM-OWC system via numerical simulations.

II. SYSTEM MODEL

In this section, we introduce the model of a general IM/DD SM-OWC system using OFDM modulation. The model of a typical MIMO OWC channel is first described and then two different IM/DD SM-OWC systems based on DFT-OFDM and DHT-OFDM are respectively discussed.

Wireless Communication Ieee Paper

Rehmani, Mubashir Husain,Faheem, Yasir

Wireless Communication Ieee Paper:

Physical Layer Security Khoa N. Le,2021-01-24 This book studies the vulnerability of wireless communications under line of sight LoS and non LoS correlated fading environments The authors theoretically and practically provide physical layer security analyses for several technologies and networks such as Fifth Generation 5G networks Internet of Things IoT applications and Non orthogonal multiple access NOMA The authors have provided these under various practical scenarios and developed theoretical aspects to validate their proposed applications Presents physical layer security PLS under correlated fading environments 5G wireless networks and NOMA networks Provides end to end analyses combination of channel correlation and outdated CSI and their effects on PL Includes contributions of PLS research written by global experts in academia and industry Implementing Data Analytics and Architectures for Next Generation Wireless Communications Bhatt, Chintan,Kumar, Neeraj,Bashir, Ali Kashif,Alazab, Mamoun,2021-08-13 Wireless communication is continuously evolving to improve and be a part of our daily communication This leads to improved quality of services and applications supported by networking technologies We are now able to use LTE LTE Advanced and other emerging technologies due to the enormous efforts that are made to improve the quality of service in cellular networks As the future of networking is uncertain the use of deep learning and big data analytics is a point of focus as it can work in many capacities at a variety of levels for wireless communications Implementing Data Analytics and Architectures for Next Generation Wireless Communications addresses the existing and emerging theoretical and practical challenges in the design development and implementation of big data algorithms protocols architectures and applications for next generation wireless communications and their applications in smart cities The chapters of this book bring together academics and industrial practitioners to exchange discuss and implement the latest innovations and applications of data analytics in advanced networks Specific topics covered include key encryption techniques smart home appliances fog communication networks and security in the internet of things This book is valuable for technologists data analysts networking experts practitioners researchers academicians and students **Driving 5G Mobile Communications with Artificial Intelligence towards 6G** Dragorad A. Milovanovic,Zoran S. Bojkovic,Tulsi Pawan Fowdur,2023-04-06 Driving 5G Mobile Communications with Artificial Intelligence towards 6G presents current work and directions of continuous innovation and development in multimedia communications with a focus on services and users The fifth generation of mobile wireless networks achieved the first deployment by 2020 completed the first phase of evolution in 2022 and started transition phase of 5G Advanced toward the sixth generation Perhaps one of the most important innovations brought by 5G is the platform approach to connectivity i e a single standard that can adapt to the heterogeneous connectivity requirements of vastly different use cases 5G networks contain a list of different requirements standardized technical specifications and a range of implementation options with spectral efficiency latency and reliability as primary performance metrics Towards 6G machine learning ML and artificial

intelligence AI methods have recently proposed new approaches to modeling designing optimizing and implementing systems They are now matured technologies that improve many research fields significantly The area of wireless multimedia communications has developed immensely generating a large number of concepts ideas technical specifications mobile standards patents and articles Identifying the basic ideas and their complex interconnections becomes increasingly important The book is divided into three major parts with each part containing four or five chapters Advanced 5G communication Machine learning based communication and network automation Artificial Intelligence towards 6G The first part discusses three main scenarios and standard specification of 5G use cases eMBB URLLC mMTC vehicular systems beyond 5G and efficient edge architecture on NFV infrastructure In the second part different AI ML based methodologies and open research challenges are presented in introducing 5G AIoT artificial intelligence of things scheduling in 5G 6G communication systems application of DL techniques to modulation detection and channel coding as well as 5G Open Source tools for experimentations and testing The third part paved the way to deployment scenarios for different innovative services including technologies and applications of 5G 6G intelligent connectivity AI assisted eXtended Reality integrated 5G IoT architecture in next generation Smart Grid privacy requirements in a hyper connected world and evaluation of representative 6G use cases and technology trends The book is written by field experts from Europe and Mauritius who introduce a blend of scientific and engineering concepts covering this emerging wireless communication era It is a very good reference book for telecom professionals engineers and practitioner in various 5G vertical domains and finally a basis for student courses in 5G 6G wireless systems **Cellular Communication Networks and Standards** Wei Jiang,Bin Han,2024-07-12 This textbook provides a comprehensive review of the evolution of mobile communications and networking from the birth of cellular networks to the forthcoming sixth generation mobile communications which is envisioned to be commercially deployed first in 2030 New students who are coming to wireless communications electrical engineering computer networking telecommunications and network engineering can benefit from this book by quickly grasping the whole history of cellular networks understanding its trends This tutorial styled textbook provides a comprehensive overview but also provides details of the system design aspects of the various cellular generations up to 6G and how they build on each other The book also gives the student an overview of different cellular generations motivations core technologies architecture key performance indicators killer applications market drivers and the general main features of each The authors capture the big picture and fundamental drivers of wireless communication technologies and then motivate students to understand the importance of learning related subjects such as electromagnetics theory antenna design analog and digital circuits signal processing Internet protocols artificial intelligence etc The book features homework questions and case studies throughout

5G-Enabled Internet of Things Yulei Wu,Haojun Huang,Cheng-Xiang Wang,Yi Pan,2019-05-29 How the enabling technologies in 5G as an integral or as a part can seamlessly fuel the IoT revolution is still very challenging This book

presents the state of the art solutions to the theoretical and practical challenges stemming from the integration of 5G enabling technologies into IoTs in support of a smart 5G enabled IoT paradigm in terms of network design operation management optimization privacy and security and applications In particular the technical focus covers a comprehensive understanding of 5G enabled IoT architectures converged access networks privacy and security and emerging applications of 5G eabled IoT *Realizing the Metaverse* Wei Yang Bryan Lim,Zehui Xiong,Dusit Niyato,Junshan Zhang,Xuemin Shen,2024-11-19 A guide to the challenges in making virtual reality reality The Metaverse a version of the internet in which online interactions take place in real time within fully realized virtual spaces has been promised as the next frontier in wireless communication It has drawn huge investment from Silicon Valley and widespread media attention However the technologies required to make the Metaverse a reality are still in their infancy and significant barriers must be overcome if this massive step is to be taken Realizing the Metaverse provides a systematic overview of these challenges and their likely solutions Focusing on five key areas infrastructure access intelligence security and future developments it offers one of the first comprehensive formalized treatments of the Metaverse as a nascent reality It promises to be an integral contribution to the future development of Metaverse technologies Realizing the Metaverse readers will also find An editorial team with extensive research experience in the field Detailed discussion of topics such as augmented reality AR adaptation haptic feedback artificial intelligence and more Enlightening discussion of open questions and future prospects for research Realizing the Metaverse is ideal for graduate and advanced undergraduate students in wireless technology network communications and related fields as well as for researchers and industry professionals involved with the Metaverse or adjacent technologies The Current Trends of Optics and Photonics Cheng-Chung Lee,2014-11-25 Optics and photonics offer new and vibrant approaches to meeting the challenges of the 21st century concerning energy conservation education agriculture personal health and the environment One of the most effective ways to address these global problems is to provide updated and reliable content on light based technologies Optical thin films and meta materials lasers optical communications light emitting diodes solar cells liquid crystal technology nanophotonics and biophotonics all play vital roles in enriching our lives We hope to raise readers awareness of how optical technologies are now promoting sustainable development and providing reliable solutions to basic human needs Furthermore in order to broaden new research fields we hope to inspire them to pursue further cutting edge breakthroughs on the basis of the accomplishments that have already been made *Cognitive Radio Sensor Networks: Applications, Architectures, and Challenges* Rehmani, Mubashir Husain,Faheem, Yasir,2014-06-30 This book examines how wireless sensor nodes with cognitive radio capabilities can address these network challenges and improve the spectrum utilization presenting a broader picture on the applications architecture challenges and open research directions in the area of WSN research Provided by publisher **The Internet of Things** Ricardo Armentano,Robin Singh Bhadoria,Parag Chatterjee,Ganesh Chandra Deka,2017-10-16 This book provides

a dual perspective on the Internet of Things and ubiquitous computing along with their applications in healthcare and smart cities It also covers other interdisciplinary aspects of the Internet of Things like big data embedded Systems and wireless Sensor Networks Detailed coverage of the underlying architecture framework and state of the art methodologies form the core of the book Networks of the Future Mahmoud Elkhodr,Qusay F. Hassan,Seyed Shahrestani,2017-10-16 With the ubiquitous diffusion of the IoT Cloud Computing 5G and other evolved wireless technologies into our daily lives the world will see the Internet of the future expand ever more quickly Driving the progress of communications and connectivity are mobile and wireless technologies including traditional WLANs technologies and low ultra power short and long range technologies These technologies facilitate the communication among the growing number of connected devices leading to the generation of huge volumes of data Processing and analysis of such big data brings about many opportunities as well as many challenges such as those relating to efficient power consumptions security privacy management and quality of service This book is about the technologies opportunities and challenges that can drive and shape the networks of the future Written by established international researchers and experts Networks of the Future answers fundamental and pressing research challenges in the field including architectural shifts concepts mitigation solutions and techniques and key technologies in the areas of networking The book starts with a discussion on Cognitive Radio CR technologies as promising solutions for improving spectrum utilization and also highlights the advances in CR spectrum sensing techniques and resource management methods The second part of the book presents the latest developments and research in the areas of 5G technologies and Software Defined Networks SDN Solutions to the most pressing challenges facing the adoption of 5G technologies are also covered and the new paradigm known as Fog Computing is examined in the context of 5G networks The focus next shifts to efficient solutions for future heterogeneous networks It consists of a collection of chapters that discuss self healing solutions dealing with Network Virtualization QoS in heterogeneous networks and energy efficient techniques for Passive Optical Networks and Wireless Sensor Networks Finally the areas of IoT and Big Data are discussed including the latest developments and future perspectives of Big Data and the IoT paradigms **Channel Characterization and Modeling for Vehicular Communications** Xiang Cheng,Ziwei Huang,Lu Bai,2023-12-04 This book presents and develops comprehensive knowledge of vehicular channel characteristics and proper vehicular channel models The studied topics contain the propagation characteristics of vehicular communications such as a time frequency non stationary single input single output SISO vehicle to vehicle V2V non geometry stochastic model NGSM a space time non stationary massive multiple input multiple output MIMO V2V regular shaped geometry based stochastic model RS GBSM and a space time non stationary massive MIMO V2V irregular shaped geometry based stochastic model IS GBSM Each is introduced with characteristics then discussed in detail Finally this book discusses future research directions to inspire further investigation in the field of vehicular channels from three different perspectives *Physical Layer Security in Wireless Communications* Xiangyun Zhou,Lingyang Song,Yan

Zhang,2013-11-15 Physical layer security has recently become an emerging technique to complement and significantly improve the communication security of wireless networks Compared to cryptographic approaches physical layer security is a fundamentally different paradigm where secrecy is achieved by exploiting the physical layer properties of the communication system such as thermal noise interference and the time varying nature of fading channels Written by pioneering researchers Physical Layer Security in Wireless Communications supplies a systematic overview of the basic concepts recent advancements and open issues in providing communication security at the physical layer It introduces the key concepts design issues and solutions to physical layer security in single user and multi user communication systems as well as large scale wireless networks The book starts with a brief introduction to physical layer security The rest of the book is organized into four parts based on the different approaches used for the design and analysis of physical layer security techniques Information Theoretic Approaches introduces capacity achieving methods and coding schemes for secure communication as well as secret key generation and agreement over wireless channels Signal Processing Approaches covers recent progress in applying signal processing techniques to design physical layer security enhancements Game Theoretic Approaches discusses the applications of game theory to analyze and design wireless networks with physical layer security considerations Graph Theoretic Approaches presents the use of tools from graph theory and stochastic geometry to analyze and design large scale wireless networks with physical layer security constraints Presenting high level discussions along with specific examples illustrations and references to conference and journal articles this is an ideal reference for postgraduate students researchers and engineers that need to obtain a macro level understanding of physical layer security and its role in future wireless communication systems *Adaptive Antennas for Wireless Communications* George V. Tsoulos,2001-01-15 Electrical Engineering Adaptive Antennas for Wireless Communications In the past decade the wireless communications community recognized adaptive antennas as a core technology that would help existing systems overcome problems related to spectrum efficiency and provide a vehicle to achieve the ambitious requirements of next generation networks The communications industry has already begun to develop adaptive antenna systems for commercial use and at the same time is working with standardization institutes around the world to produce adaptive antenna friendly standards Adaptive Antennas for Wireless Communications is a concise detailed resource of information for all critical issues related to this technology and is compiled from the original published work of experts in the field The extensive literature covers Historical and background aspects Radio channel simulation techniques and characteristics Adaptive algorithm performance under a variety of conditions Adaptive antenna performance in different operational environments Design and implementation issues Experimental results Other issues such as network planning and recent novel techniques Adaptive Antennas for Wireless Communications is a valuable reference for helping consultants researchers communications professionals academics and students gain an in depth understanding of adaptive antenna technology **Machine Learning for Wireless**

Communications and Networking Kwang-Cheng Chen,2023-02-01 Machine Learning for Wireless Communications and Networking An Introduction gives an easy to understand introduction to machine learning methods and techniques and their application to wireless communications The book covers a wide range of machine learning techniques starting with concepts related to statistical signal processing i e decision detection and estimation taking advantage of the commonality of knowledge between statistical learning and statistical communication theory that the electronic engineer will be familiar with Each chapter focuses on a class of machine learning techniques clearly explaining the principles with a supporting range of examples in general wireless communications wireless networks sensor networks and signal processing Every chapter also has a dedicated section applying machine learning techniques to specific state of the art wireless network applications Machine Learning for Wireless Communications and Networking An Introduction is ideal for graduate and senior undergraduate students in wireless communications and networking who need to understand and apply machine learning techniques researchers in wireless communications signal processing and wireless networks who need background knowledge in machine learning for wireless systems and networks and engineers and professionals in the wireless communications and networking industry seeking to learn this important new technology which is having a major impact in the field **Compressive Sensing for Wireless Networks** Zhu Han,Husheng Li,Wotao Yin,2013-06-06 This comprehensive reference delivers the understanding and skills needed to take advantage of compressive sensing in wireless networks **Proceedings of the IEEE.** Institute of Electrical and Electronics Engineers,1927 Vols 34 include section Waves and electrons **Index of Conference Proceedings** British Library. Document Supply Centre,2003 Smart Antenna and Non-feedback IF Equalization Techniques for LEO Satellite Communications in a Complex Interference Environment Mehdi Haghdad,2003 **Wireless Device-to-Device Communications and Networks** Lingyang Song,Dusit Niyato,Zhu Han,Ekram Hossain,2015-03-12 Enables engineers and researchers to understand the fundamentals and applications of device to device communications and its optimization in wireless networking *Wiley Encyclopedia of Telecommunications* John G. Proakis,2003

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