SATELLITE AND SPACE COMMUNICATIONS

SSC

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IEEE COMMUNICATIONS SOCIETY

SSC Newsletter **Vol. 31, No. 2, December 2021**

CONTENTS

The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.

ONLINE MEETING URL:
https://zoom.us/j/94895030159

Time: Monday, Nov 22, 2021
08:00 AM - 9:00 AM EST (NEW YORK)

Future SSC Meetings
June 2022, Seoul, South Korea
December 2022, Rio de Janeiro, Brazil

GLOBECOM 2021 SSC Committee Activities:

Symposium on Selected Areas in Communications:

SAC-SSC1 *Wednesday, December 8, 11:00 - 12:30 Madrid, Madrid Time Zone*

SAC-SSC2 *Wednesday, December 8, 14:00 - 15:30 Madrid, Madrid Time Zone*

SAC-SSC3 *Thursday, December 9, 09:00 - 10:30 Madrid, Madrid Time Zone*

SAC-SSC4 *Thursday, December 9, 11:00 - 12:30 Madrid, Madrid Time Zone*

SAC-SSC5 *Friday, December 10, 09:00 - 10:30 Madrid, Madrid Time Zone*

SAC-SSC6 *Friday, December 10, 14:00 - 15:30 Madrid, Madrid Time Zone*

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
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MESSAGE FROM THE CHAIR

Dr. Song Guo

As pointed out in the messages provided in the previous SSC newsletter, the priority is given to initiatives that encourage our members to further explore the evolution of new satellite and space-based systems and the application of new and emerging technologies, at all layers of the network protocol suite.

In particular, we organized spotlight talks in our SSC technical committee meetings, delivered by world-class experts in the interested areas of our technical committee. The second talk "Integrated Satellite-Terrestrial Networks Towards 6G: Architectures, Applications, and Challenges" was held on 20 July 2021 by Prof. Chunxiao Jiang from the School of Information Science and Technology, Tsinghua University, China. He is the recipient of IEEE VTS Early Career Award 2020, IEEE ComSoc Asia-Pacific Best Young Researcher Award 2020, and IEEE VTS Distinguished Lecturer 2021.

To foster the development of emerging topics of satellite and space communications, SSCTC established the first Special Interest Group (SIG) on orthogonal time frequency space (OTFS). We look forward to receiving more proposals of SIGs which will promote technical publications, workshops, tutorials, student activities, standardizations, and other related activities in focused areas relevant to satellite and space communications. OTFS provides the possibility to embrace localized delay and Doppler impairments and converts time-frequency selective channels into an invariant channel in the DD domain. More importantly, OTFS enjoys the full time-frequency diversity of the channel, which is the key to provide reliable transmissions for high-mobility environments, such as vehicular networks, aircraft communications, and LEO satellite systems. The series of OTFS online seminars has been also launched. I'd like to take this opportunity to especially appreciate the services from OTFS-SIG Chair, Prof. Weijie Yuan, who has promoted initiatives and enhanced visibility for our TC. For more information about the aims, topics of interest, and seminars of OTFS, please visit its website at https://sites.google.com/view/otfs-sig/.

Last but not the least, my term as chair is going to conclude (Spring 2022) so that elections for the new officers (chair, vice-chair, and secretary) will start in early 2022 in order to have the new officers announced before ICC'22 and then start the activities right afterwards. I take this opportunity to thank all members of the SSC community for your great efforts and dedication especially during these difficult times. Let us sustain our commitment, professionalism, and solidarity.

Prof. Song Guo
Satellite and Space Communications TC

SCANNING THE WORLD

Pascal Lorenz

It took the U.S. Federal Communications Commission (FCC) four and a half years to rule on Boeing's satellite constellation project. The application filed in March 2017 was approved this month. As a result, the U.S. aircraft manufacturer has just been granted a license to build, deploy and operate a constellation of 147 satellites. It will be used to provide broadband Internet access to the general public as well as to businesses, institutions and governments. Boeing will first offer its services in the United States, Puerto Rico and the Virgin Islands, and then in the rest of the world.

The constellation will be a mix of highly inclined low earth orbits and geostationary orbits, with 132 satellites at an altitude of 1,056 kilometers and 15 others between 27,355 and 44,221 kilometers above the Earth. Those in low orbit will provide reduced latency, and the geostationary ones better coverage.

It will not be a huge constellation compared to other competing projects. As a reminder, SpaceX has already deployed 1,700 satellites out of a planned 12,000, OneWeb has launched 358 for a goal of 2,000, and Blue Origin (owned by Amazon founder Jeff Bezos) plans to launch 3,236 for its Kuiper constellation.

Boeing is allowed to transmit in some V-band channels, higher than the Ka-band typically used by satellite operators. This promises to establish faster links. This V-band is currently mainly considered for links with constellation ground stations rather than for direct links to terminals. SpaceX and OneWeb also intend to exploit this frequency band. The industry wanted to complete its portfolio with channels on the Ka band, but the FCC refused.

The clock is ticking as Boeing will be forced to launch half of its satellites by November 2, 2027, and all of them by 2030, although it had hoped to obtain a longer delay.

FORTHCOMING GLOBECOM AND ICC CONFERENCES

GLOBECOM 2022

December 4-8, 2022, Rio de Janeiro, Brazil

http://globecom2022.ieee-globecom.org/

IEEE GLOBECOM 2020 - IEEE Global Communications Conference (GLOBECOM) is one of the IEEE Communications Society's two flagship conferences dedicated to driving innovation in nearly every aspect of communications. Each year, more than 2,900 scientific researchers and their management submit proposals for program sessions to be held at the annual conference. After extensive peer review, the best of the proposals are selected for the conference program, which includes technical papers, tutorials, workshops and industry sessions designed specifically to advance technologies, systems and infrastructure that are continuing to reshape the world and provide all users with access to an unprecedented spectrum of high-speed, seamless and cost-effective global telecommunications services.

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

ICC 2022

May 16-20, 2022, Seoul, South Korea

http://icc2022.ieee-icc.org/

The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 - 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. IEEE ICC 2021 - Featuring the latest developments in telecommunications from a technical perspective.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
ITC 2022 34th International Teletraffic Congress	14-16 September 2022	https://itc34.itc-conference.org/
ICL-GNSS 2022 International Conference on Localization and GNSS	7-9 June 2022, Tampere, Finland	https://events.tuni.fi/icl-gnss2022/
VTC-Spring 2022 2022 IEEE Vehicular Technology Conference (VTC-Spring)	19-22 June 2022, Helsinki, Finland,	https://events.vtsociety.org/vtc2022-spring/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://committees.comsoc.org/ssc/.

PERSPECTIVE ARTICLE *December 2021*

Orthogonal Time Frequency Space Modulation for Satellite and Space Communications

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Abstract — **Sixth-generation (6G) wireless networks are envisioned to provide global coverage for the intelligent digital society of the near future, ranging from traditional terrestrial to non-terrestrial networks, including satellite and space communications. In such scenarios, the conventional orthogonal frequency division multiplexing (OFDM) modulation may fail to provide reliable communications due to the high Doppler shift. The recently proposed orthogonal time frequency space (OTFS) modulation has demonstrated superior performances over OFDM in high-mobility environments. This article will provide a brief introduction of the OTFS modulation for satellite and space communications. We first revisit the properties of the wireless channels and then introduce the fundementals of OTFS concept. Some critical challenges of OTFS are summarized and a range of promising research topics will be discussed.**

INTRODUCTION

Sixth-generation (6G) wireless networks are expected to support ubiquitous connectivity to a wide range of mobile terminals, spanning from autonomous cars to unmanned aerial vehicles (UAV), low-earth-orbit (LEO) satellites, and high speed-trains, etc. One of the critical challenges for these services is to provide reliable communications in high-mobility environments. In those scenarios, the conventional OFDM modulation may break down due to the severe Doppler spread introduced by the high mobility. To facilitate the design of B5G wireless networks, the recently proposed orthogonal time frequency space (OTFS) modulation has attracted substanial attention [1].

OTFS modulates information in the delay-Doppler (DD) domain rather than in the time-frequency (TF) domain of classic OFDM modulation, providing a strong delay-resilience and Doppler-resilience, while enjoying the potential of full diversity [2], which is the key for supporting reliable communications. Furthermore, OTFS modulation invokes the 2D symplectic finite Fourier transform (ISFFT) to transform the DD domain signal to the TF domain [3]. Thanks to the ISFFT, each DD domain symbol spreads onto the whole TF domain and thus, principally experiences the whole fluctuations of the TF channel response over an OTFS frame, where its attractive properties can be exploited. Given that most of the existing wireless system designs have been conceived for low-mobility and low-carrier scenarios, OTFS introduces new critical challenges in transceiver architecture and algorithmic designs.

This article aims to portray OTFS modulation conceived for communications in high-mobility satellite ans space communications by providing an easy-reading overview of its fundamental concepts, highlighting the challenges and potential solutions for future research.

FUNDEMANTALS OF OTFS CONCEPT

The success of OTFS modulation roots from the special data placement in the DD domain, which can explore the good properties of the DD domain representation of the wireless channel, such as sparsity, separability, and predictability. In the following, we will first study the DD domain properties of general wireless channels and then discuss the OTFS system model.

A. Underspread Wide-Sense Stationary Uncorrelated Scattering Channels

The underspread WSSUS channel model is commonly adopted for real-world wireless channels, whose stochastic properties match well with the actual channel measurement results [4]. For any given linear time-varying channel, its second-order statistics can in general be represented by four different variables that are time, frequency, delay, and Doppler, respectively. With the assumption of WSSUS, this complex statistical dependence can be reduced to only two variables. The rationale of the WSSUS assumption is that in practical wireless channels, the channel impairments are introduced by physical scatterers with different reflectivities and any two distinct scatterers generally have uncorrelated reflectivities. In specific, the US assumption implies that the different delay shifts associated with different resolvable paths are uncorrelated. On the other hand, the WSS assumption indicates that the different Doppler shifts associated with different resolvable paths are uncorrelated such that the time domain channel response is jointly WSS with respect to the time.

B. From TF to DD Domain Channels

Apart from the time-delay domain, LTV channels can be equivalently described in either the TF or DD domain [5]. Due to the limited coherence time and coherence bandwidth of LTV channels, channel acquisition in the TF domain would be challenging and would impose a significant signaling overhead. However, in DD domain, the channel characterizes the intensity of scatterers having a propagation delay and Doppler frequency shift, which directly captures the underlying physics of radio propagation in high-mobility environments. More importantly, the LTV channel in the DD domain exhibits benefi cial features of separability, stability, compactness, and possibly sparsity, which can be exploited to facilitate efficient channel estimation and data detection.

C. OTFS Characteristics

By performing ISFFT, each DD domain symbol is spread onto the whole TF domain, and then transferred to a pulse train in the time domain.Assuming that the wireless channel is noiseless and only has two paths with different delay and Doppler indices. The received time domain OTFS signal is then the superposition of the delayed, phase-rotated versions of the transmitted OTFS signal. After performing the FFT and the SFFT, we observe that the DD domain received symbols are the delay- and Doppler-shifted versions of the original DD domain information symbol corresponding to the channel coefficients and delay, Doppler shifts. By observing the connections between the transmitted and received OTFS signals in the DD and TF domains, it is obvious that the DD domain input-output relationship is much simpler compared to that of the TF domain. Specifically, this example demonstrates the sparsity, separability properties of the DD domain channel representation, thus validates the motivation of OTFS modulation. An interesting fact of OTFS signals is that each DD domain symbol corresponds to a delayed, phase-rotated pulse train in the time domain, where the location of the symbol on DD domain grids determines how the pulse train is delayed and phase-rotated in the time domain. In fact, the time domain OTFS signal behaves locally like time-division multiple access (TDMA) (localized pulses in the time domain), globally like OFDM (localized pulses in the Doppler domain) and spreading like code-division multiple access (CDMA) (2D spreading in the DD domain), thus inheriting their beneficial properties.

D. OTFS for Satellite and Space Communications

Alought OTFS was originally developed for addressing the high-mobility vehicular communications, its resilence to high Doppler makes it attractive in satellite and space communications cases. Satellite and space communications are capable of supporting the terrestrial 5G networks in the provision of global coverage and mobility, as well as ubiquitous connectivity and enhanced network reliability. Since the airborne and spaceborne vehicles usually move fast, the high Doppler spread experienced imposes new challenges on its air interface design. OTFS modulation has rich potential in the satellite and space communications owing to its prominent capability of handling the Doppler effect. Additionally, airborne and spaceborne vehicles have limited on-board power supply and computing capability, hence the low PAPR and low-complexity of OTFS are of pivotal importance. Moreover, the corresponding communication links spanning to the ground terminals usually exhibit spatial channel sparsity in the DD domain, which allows OTFS to strike an attractive performance vs. complexity trade-off.

CHALLENGES AND OPEN RESEARCH TOPICS

As a fledgling waveform, OTFS modulation unveils new opportunities but also has its own challenges. Moreover, several open facets are expected to stimulate new research.

A. Challenges

The channel envelope fl uctuates violently even in a short time period in high-mobility environments. Accurately estimating the CIR in OTFS systems is a challenging but vital requirement for reliable detection. Thanks to the DD domain channel sparsity and quasi-stationarity, channel acquisition in the DD domain is more convenient than that in the TF domain, even for a lower training overhead. However, the DD domain channel may not always be sparse, particularly in the presence of fractional Doppler. Due to this channel spreading, a much larger guard space is needed around the pilot symbols to avoid the interference caused by unknown data symbols for channel estimation, which imposes a signifi cant training overhead [6].

The output signal in the DD domain can be regarded as a 2D circular convolution of the input data symbols and the effective aggregate channel, which results in a rather specific interference pattern, where a pair of symbols far from each other in the DD domain may interfere with each other. Mitigating this peculiar interference requires a bespoke receiver. A potent solution is to adopt the variational framework of [7], which can adaptively construct the distributions of OTFS symbols according to their interference patterns. By appropriately constructing the distributions of OTFS symbols for variational purposes, we can design rapidly converging OTFS detection.

While OTFS has the potential of attaining the maximum achievable diversity gain, the channel codes have to be carefully designed for OTFS modulation. Moreover, perfect detection at near-capacity signal-to-noise ratios (SNRs) may not be attained for practical OTFS systems due to the associated poor channel conditions. Hence, the channel decoder has to cope with the OTFS detector's residual errors, which would require iterative OTFS receivers. However, how to design such a receiver and how to choose the coding parameters for near-capacity joint detection and decoding remains an interesting open issue.

B. New Research Topics

How to support a multiplicity of users in high-mobility satellite and space communications environments is a very challenging issue. OTFS offers the opportunity to accommodate multiple users in the DD domain, where employing carefully designed user scheduling and guard spaces has the potential of avoiding multi-user interference. However, how to scale the systems for accommodating a large number of users without a significant overhead is an interesting open research problem. The coexistence of promising multiple access schemes and OTFS, such as non-orthogonal multiple access, spatial-division multiple access, and interleave-division multiple access, is worth exploring further.

Moreover, the sensing capability is highly expected for the future non-terrestrial networks. Since the DD domain channel directly exploits the physics of propagation, relying on the distance, speed and scattering intensity, OTFS is eminently suitable for integrating sensing and communications solutions in a single platform. Efficient sensing algorithms to exploit the OTFS signal structure are still unknown. Finding the optimal trade-off between the sensing and communication performances remains an interesting open question. Moreover, as location and velocity can serve as beneficial side information for improving communication performance, sensing-based communications relying on OTFS is an exciting open topic to investigate.

Considering the multi antenna system equiptted on the airbone or spaceborn vehicles.Applying OTFS in multi-antenna systems provides additional hitherto unexploited spatial DoF for multiplexing. In contrast to TF domain channels, which may fluctuate dynamically for different antennas in different time slots and subcarriers, the DD domain channels tend to remain quasi-stationary both in the time and antenna domains, which may result in an efficient channel estimation and multi-input multiple-input multiple-output (MIMO) detection. How to design sophisticated beamforming/precoding to fully exploit all the available spatial DoFs and how to perform low-complexity detection for MIMO-OTFS constitute intriguing problems. Moreover, the analytical framework of MIMO-OTFS system performance versus the number of antennas is also unexplored in the open literature.

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