OTFS Enabled NOMA for MMTC Systems over LEO Satellite

MA Yiyan[1], MA Guoyu[1], WANG Ning[2], ZHONG Zhangdui[1], AI Bo[1,3]

(1. Beijing Jiaotong University, Beijing 100044, China;
2. Zhengzhou University, Zhengzhou 450001, China;
3. Peng Cheng Laboratory, Shenzhen 518000, China)

Abstract: As a complement of terrestrial networks, non-terrestrial networks (NTN) have advantages of wide-area coverage and service continuity. The NTN is potential to play an important role in the 5G new radio (NR) and beyond. To enable the massive machine type communications (mMTC), the low earth orbit (LEO) satellite is preferred due to its lower transmission delay and path loss. However, the LEO satellite may generate notable Doppler shifts to degrade the system performance. Recently, orthogonal time frequency space (OTFS) modulation has been proposed. It provides the opportunity to allocate delay Doppler (DD) domain resources, which is promising for mitigating the effect of high mobility. Besides, as the LEO satellite constellation systems such as Starlink are thriving, the space spectrum resources have become increasingly scarce. Therefore, non-orthogonal multiple access (NOMA) is considered as a candidate technology to realize mMTC with limited spectrum resources. In this paper, the application of OTFS enabled NOMA for mMTC over the LEO satellite is investigated. The LEO satellite based mMTC system and the OTFS-NOMA schemes are described. Subsequently, the challenges of applying OTFS and NOMA into LEO satellite mMTC systems are discussed. Finally, the potential technologies for the systems are investigated.

Keywords: mMTC; LEO satellite; OTFS; NOMA

DOI: 10.12142/ZTECOM.202104007

https://kns.cnki.net/kcms/detail/34.1294.TN.20211126.0933.002.html, published online November 26, 2021

Manuscript received: 2021-10-09

Citation (IEEE Format): Y. Y. Ma, G. Y. Ma, N. Wang, et al., "OTFS enabled NOMA for mMTC systems over LEO satellite," *ZTE Communications*, vol. 19, no. 4, pp. 63–70, Dec. 2021. doi: 10.12142/ZTECOM.202104007.

1 Introduction

1.1 Non-Terrestrial Networks

Nowadays, non-terrestrial networks (NTN) are playing an important role in human society, especially in navigation, ground monitoring and communications services. It regains attention recently in both academia and industry, advertised by several companies' plans of launching thousands of satellites in the low earth orbit (LEO), such as OneWeb and SpaceX. The NTN refers to the segment of network that uses air-borne or space-borne vehicles as relay nodes or base stations (BS) for transmission[1]. In a typical NTN, it features the following elements: the satellite-gateway that connects the NTN to the public network, satellites or unmanned aerial systems (UAS), and user equipment.

There are kinds of available orbits for space-borne vehicles, including the high elliptical orbit (HEO) (400 – 50 000 km), geostationary earth orbit (GEO) (35 786 km), medium earth orbit (MEO) (7 000 – 25 000 km), and LEO (300 – 1 500 km). Different orbits exhibit different coverage and transmission characteristics, which determine the types of services on them.

This work is supported by the Fundamental Research Funds for the Central Universities under Grant Nos. 2021YJS202, 2020JBZD005 and 2021RC205, the National Key Research and Development Program under Grant Nos. 2016YFE0200900 and 2016YFB1200102-04, NSFC under Grant Nos 61725101 and U1834210, the Royal Society Newton Advanced Fellowship under Grant Nos. 61961130391 and NA191006, Beijing Natural Haidian Joint Fund under Grant No. L172020, Major Projects of Beijing Municipal Science and Technology Commission under Grant No. Z181100003218010, State Key Lab of Rail Traffic Control and Safety under Grant Nos. RCS2021ZQ002, RCS2018ZZ007 and RCS2020ZT010, Teaching Reform Project under Grant No. 134496522, the Open Research Fund from Shenzhen Research Institute of Big Data under Grant No. 2019ORF01006, and the PCL Future Greater-Bay Area Network Facilities for Large-scale Experiments and Applications Project under Grant No. LZ0019.

The non-GEO (NGSO) satellites refer to LEO and MEO satellites, whose orbital periods vary between 1.5 and 10 h. The UAS has an altitude range of 8 – 50 km and keeps a fixed position in terms of elevation with respect to a given earth point[1].

1.2 MMTC System over LEO Satellite

In the 5G new radio (NR) system, massive machine type communications (mMTC) are introduced for Internet of Things (IoT). 5G NR considers the IoT communications with low energy consumption, low data rate, burst transmissions and massive connections. In the beyond 5G (B5G) and 6G networks, IoT communications will take a larger proportion[2]. However, it is unavoidable that the required large-scale deployment of 5G or 6G BSs in the future could generate greater overhead compared with short-term revenue. Furthermore, terrestrial networks (TN) are hard to be deployed due to the geographical environment and cost in unmanned areas whereas IoT communication services are required. However, the NTN is not restricted by geographical environment and can still work in unmanned and geological disaster areas. Therefore, the NTN is considered to be involved as a complement of TN to construct an air-space-ground integrated network for the sake of the superiority of cost, coverage and massive connections[1 – 3]. Ref. [3] demonstrates that Release 17 will study the feasibility of adapting narrowband NB-IoT to support NTN. Additionally, potential modifications of NB-IoT at physical and higher layer aspects to support NTN are investigated[3]. For example, the transmission bandwidth can be reduced to improve uplink signal to noise ratio (SNR) and to realize transmission under limited power of devices, based on which it is possible to support low data rate GEO satellite communication using the 23 dBm device power class. Besides, directional antenna can also be equipped by mMTC devices to obtain transmission gain. Among the candidate orbits, path loss and transmission delay of LEO communications are smaller than those of MEO and GEO, so LEO is more competitive for connection of terrestrial power-constrained mMTC devices.

The 3GPP[4] suggests that the connectivity of mMTC is 10^6 devices/km^2. Since the typical beam footprint size of an LEO satellite is 100 – 1 000 km[1], there could be 10^8 – 10^9 devices inside. Though the TN could coordinate with NTN for mMTC connection, heavy control signal overhead in the grant-based multiple access (MA) technologies will be generated due to the massive concurrent devices. Besides, the scarce frequency resources are different to be allocated to the massive IoT devices orthogonally[5]. Researchers have tried to introduce non-orthogonal multiple access (NOMA) into satellite framework[6 – 8]. The related works focus on improving system spectrum efficiency and show the feasibility of applying NOMA into NTN. Moreover, the reliable access of massive devices affected by power limitation and Doppler shift remains to be a challenging topic.

On the other hand, the LEO satellite rotates at a high speed and the Doppler shift effect is obvious. The Doppler characterization of LEO satellites was investigated in Ref. [9], as a function of the maximum elevation angular and satellite position. For instance, the normalized Doppler of the satellite with circular orbit altitude 1 000 km and inclination 53° is around 10^{-5} for a terminal located at (39° N, 77° W), which varies at the rate 0.1 ppm/s approximately. Since the severe Doppler shift could introduce inter carrier interference (ICI) to degrade the transmission performance, various Doppler estimation schemes have been proposed[10 – 14]. In general, the Doppler estimators are based on either geometric information or preamble data. For the device capable of tracking satellites based on ephemeris, such as the ground gateway, the Doppler shift can be estimated and compensated according to the obtained Doppler shift curve and its own position information. However, Doppler estimation at mMTC devices could raise complexity and consume extra energy[15]. Thus, the coexistence of Doppler shift at the user side needs to be considered, which could be handled at the gateway.

1.3 Combining OTFS and NOMA for MMTC System over LEO Satellite

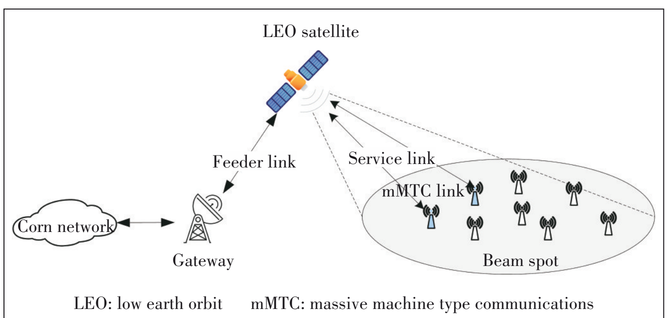
Taking the effect of scarce spectrum and notable Doppler shift into account, the mMTC over LEO satellite prefers the NOMA technologies which are robust to multiple Doppler shift. Under such vision, the classic orthogonal frequency division multiple (OFDM) framework is no longer suitable for the system due to the vulnerability to Doppler shift. In Ref. [15], the adaptability of NB-IoT technologies for NTN communications was investigated, which mitigated the effect of Doppler shift by user grouping geographically. Then the maximum differential Doppler shift of users in the same group is limited to a tolerable range of NB-IoT, which is 950 Hz. Subsequently, the gateway compensates the common Doppler shift component of users in each user group. By doing so, NB-IoT is practical for IoT communications over the LEO satellite. However, this scheme is not general for the NOMA technologies, since the inter carrier interference (ICI) remains to be unprocessed. It will limit the system user capacity and improves the complexity of the ground gateway, especially for the schemes where concurrency is larger than NB-IoT. Recently, orthogonal time frequency space (OTFS) modulation has been proposed. OTFS is a chance to utilize the Doppler diversity to realize the NOMA system robustness against multiple users' Doppler shift. In what follows, the application of OTFS enabled NOMA for mMTC over LEO satellite is investigated. Specifically, the system architecture is described. Adaptability research of OTFS-NOMA for mMTC over LEO satellite is discussed. Moreover, the potential technologies for the system are listed.

2 System Description

According to the 3GPP NTN standard[1], there are three parts in the mMTC system over the LEO satellite, including ground massive devices, the satellite and the ground gateway (Fig. 1). The link between the LEO satellite and mMTC devices refers to the service link while that between the LEO satellite and ground gateway refers to feeder link. In the system, the satellite could work in a transparent or regenerative mode. In the transparent mode, the satellite performs frequency carrier changing, filtering and amplifying merely. For the regenerative payload, the satellite performs signal digital processing additionally, including demodulation/re-modulation, decoding/re-encoding, etc. Due to the difficulty of air interface protocol application on the satellite, the transparent mode of the satellite is supposed in this paper. Besides, this paper concentrates on the uplink access procedure, which refers to the link from the devices to the ground gateway. The interaction between the LEO satellite and mMTC devices during uplink access depends on the utilized MA technologies. For example, four-step random access channel (RACH) enhancements for NTN are investigated in Ref. [1] considering the long transmission delay. After receiving mMTC devices' data, the LEO satellite would forward it to the ground gateway, where user identification and data recovery are performed.

As introduced before, LEO could generate a notable Doppler shift to degrade the symbol performance. In the feeder link, it is assumed that the link is available all the time. Thus, the gateway could always track the satellite and compensate the Doppler shift inside. In the service link, the Doppler shift is determined by the LEO satellite altitude, the maximum and minimum elevation angles of the devices, etc. Hence, the OTFS enabled NOMA for mMTC over the LEO satellite could be designed based on devices' geographic locations.

Current MA technologies for NTN enabled communications can be divided into the grant-based and grant-free. The grant-based MA technologies include time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), physical random access channel (PRACH) in 5G-NR, etc. For example, FDMA and TDMA are applied in the Thuraya, AceS and Iridium satellite systems; CDMA is adopted by the Odyssey and Glonass systems. In the 3GPP 5G NR-NTN R16, PRACH formats and preamble sequences in Rel-15 are reused for random access[1]. Besides,



▲**Figure 1. MMTC system over LEO satellite**

several options are provided for pre-compensating the timing and frequency offset at the device side. In general, the grant-based MA have several rounds of interactions before data transmission between devices and the satellite, which are designed for device access and contention resolution. In addition, each device occupies certain specific resources independently. In the grant-free category, there are ALOHA, contention resolution diversity slotted ALOHA (CRDSA), etc. Devices in such grant-free MA systems do not require the satellite to perform dynamic scheduling authorization, but transmit data independently and obtain resources by competition. To reduce the control signal overhead, this paper adopts the grant-free access mode for the mMTC over LEO satellite.

3 OTFS-NOMA for LEO Satellite MMTC System

3.1 NOMA Schemes for LEO Satellite MMTC System

Up to now, multiple NOMA schemes have been proposed for the mMTC system over the LEO satellite[6, 7, 16]. Simulation results demonstrate that the satellite communication systems can benefit from the application of non-orthogonal transmission schemes in terms of capacity and user fairness. However, the related studies rarely considered the Doppler effect and directly assumed perfect/imperfect channel satellite information (CSI) in the system. As introduced before, the coexistence of multiple Doppler shifts during the uplink transmission needs to be considered in the system due to the users' power limitation. Thus, OTFS is considered to be involved in such systems.

OTFS-NOMA was first proposed in Ref. [17], which considered a scenario where there was only one user with high mobility. In the mMTC system over the LEO satellite, the model in Ref. [17] could suffer more severe interference and the corresponding performance need to be evaluated. Meanwhile, there are OTFS enabled code or space domain NOMA schemes, such as OTFS-SCMA in Ref. [18] and OTFS-tandem spreading multiple access (TSMA) in Ref. [19]. The applicability and improvement of different OTFS-NOMA schemes in the LEO satellite system requires further research.

3.2 OTFS Modulation

OTFS modulation designs the transceiver in the delay Doppler (DD) domain[20]. Note that the channel impulse response (CIR) of the double-selective channel is time varying in the time frequency (TF) domain. In the DD domain, the CIR reflects the scattering environment, which can be regarded as time-invariant during a transmission frame. Besides, CIR in the DD domain is sparse due to the limited number of scatters. The channel equalization is simplified as a result. In the TF domain, different Doppler shifts of users occupying the same TF resource block are difficult to be equalized in the grant-free NOMA mode. Meanwhile, the effect of Doppler shifts is considered as interference in the TF domain, and its information entropy is not utilized. Now in the OTFS, transmission can be scheduled considering the users' Doppler shift characteristic, and the Doppler diversity could bring additional performance gain. In the DD domain, the transceiver input-output relationship depends on the DD resource granularity and adopted waveform types[21]. If the waveforms ideally satisfy the bio-orthogonal property and the DD resource granularity is able to locate the CIR exactly, the output will be expressed as:

$$y[k,l] = \sum_{i=1}^{P} h_i e^{-j2\pi\nu_i\tau_i} x\left[\left[k - k_{\nu_i}\right]_N, \left[l - l_{\tau_i}\right]_M\right], \quad (1)$$

where x and y refer to the input and output in the DD domain respectively, P denotes the number of multipath, h_i refers to the channel fading, τ_i and ν_i are the values of delay and Doppler shift of the i-th path, $[\bullet]_N = \mathrm{mod}(\bullet, N)$. In the TF domain, it is assumed that the system occupies the time domain resource with NT and the frequency domain resource with $M\Delta f$, where N denotes the number of time intervals T and M denotes the number of subcarrier intervals $\Delta f = 1/T$. Then the scattered Doppler domain resource is obtained as $\frac{l}{M\Delta f} \in \left[0, \frac{M-1}{M\Delta f}\right], l = 0,1,\ldots,M-1$, and the scattered delay domain resource is $\frac{k}{NT} \in \left[0, \frac{N-1}{NT}\right], k = 0,1,\ldots,N-1$[20]. Therein, the maximum Doppler and delay values are assumed to be less than Δf and T respectively. Additionally, suppose that τ_i and ν_i are dividable by $\frac{1}{NT}$ and $\frac{1}{M\Delta f}$, then $k_{\nu_i} = \nu_i NT$ and $l_{\tau_i} = \tau_i M\Delta f$ are obtained. Eq. (1) illustrates that based on the bio-orthogonal transceiver waveforms, y is the superposition of the faded x, which is two-dimension cyclically shifted by the corresponding DD CIR. Under the non-delicate DD resource granularity or the practical waveforms such as the rectangular waveform, there are additional ICI and inter symbol interference (ISI) in the output.

As for the OTFS receiver, the data detection and channel estimation scheme should be able to reverse the two-dimensional cyclic shift in Eq. (2). In terms of data detection, a bespoke optimal maximum a posteriori (MAP) detector was proposed in Ref. [21]. Such kind of detector is designed based on the sparsity of the DD domain channel matrix $\boldsymbol{H} \in \mathbb{C}^{NM \times NM}$, and is with excessive complexity. Therefore, researchers have focused on complexity reduction of the MAP detector[22]. A variational Bayes (VB) OTFS detector was proposed in Ref. [23]. In such a detector, the distributions of OTFS symbols are constructed adaptively according to corresponding interference patterns to make the OTFS detection converge rapidly. Besides, Ref. [24] proposed a detector named cross-domain iterative detection (CDID). In this detector, a linear minimum mean squared error (L-MMSE) estimator is adopted for equalization in the time domain and low-complexity symbol-by-symbol detection is utilized in the DD domain. Both VB and CDID based detectors are shown to be with close-to-optimal performance, where the computational complexity is reduced[22]. There are other potent schemes such as the combination of hybrid MAP and PIC detection proposed in Ref. [25].

In terms of channel estimation, OTFS modulation outperforms the schemes designed in the TF domain, due to the DD domain channel sparsity and quasi-stationarity[22]. When the channel sparsity is damaged (e.g., there are fractional Doppler shifts), the requirement of larger guard space would result in heavy training overhead. The solution to enhancing the channel sparsity has been proposed by TF domain window designing[26]. Specifically, a Dolph-Chebyshev (DC) window is applied in the transceiver of OTFS to suppress the channel spreading. It is demonstrated that better channel estimation accuracy is obtained by the DC windowing compared with the conventional rectangular window. Moreover, coded OTFS can be used to improve the system performance[27].

In the mMTC system over the LEO satellite, the satellite-land channel is different from that in terrestrial communications. In terms of large-scale fading, there are obvious atmospheric absorption, rain attenuation, cloud attenuation and scintillation in the satellite-land channel, which should be considered in the link budget. In terms of the small-scale fading, the LOS probability of the satellite-land channel is higher in the urban, suburban and rural scenarios[1]. Additionally, the additive white Gaussian noise (AWGN) channel can be assumed in the open area, such as the devices on boats or aircrafts. Therefore, the DD domain CIR is sparser than that in the terrestrial communication, and the DD domain input/output relationship under the ideal pulses is written as:

$$y[k,l] = he^{-j2\pi\nu\tau} x\left[\left[k - k_\nu\right]_N, \left[l - l_\tau\right]_M\right]. \quad (2)$$

It should be noted that k_ν and l_τ are mainly related to the devices' geographical position. Thus, the unique Doppler shift and delay values of difficult users can be regarded as a novel orthogonal space. It provides opportunity to schedule the system transmission from the perspective of devices' geography to mitigate multi-user interference (MUI). As a result, the precompensation of Doppler shift at devices could be omitted.

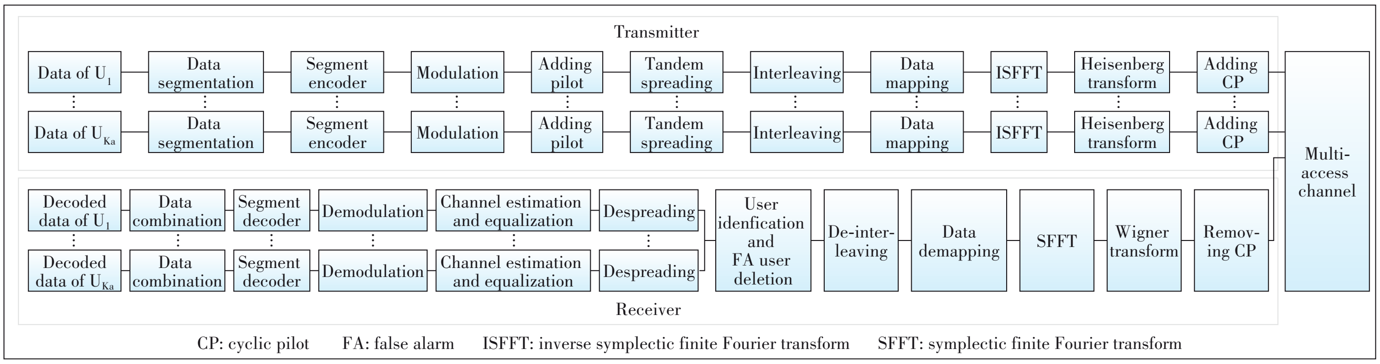
3.3 Combining NOMA with OTFS for MMTC over LEO Satellite

To embed NOMA into OTFS framework for mMTC over the LEO satellite, a novel transceiver could be designed. In terms of the transmitter, the main concern is to design the resource allocation scheme adapting to the DD domain channel characteristics. In terms of the receiver, equalization technologies need to be considered for the grant-free transmission. Furthermore, strategies to scale up the system capacity, such as massive multiple input multiple output (MIMO) and access point

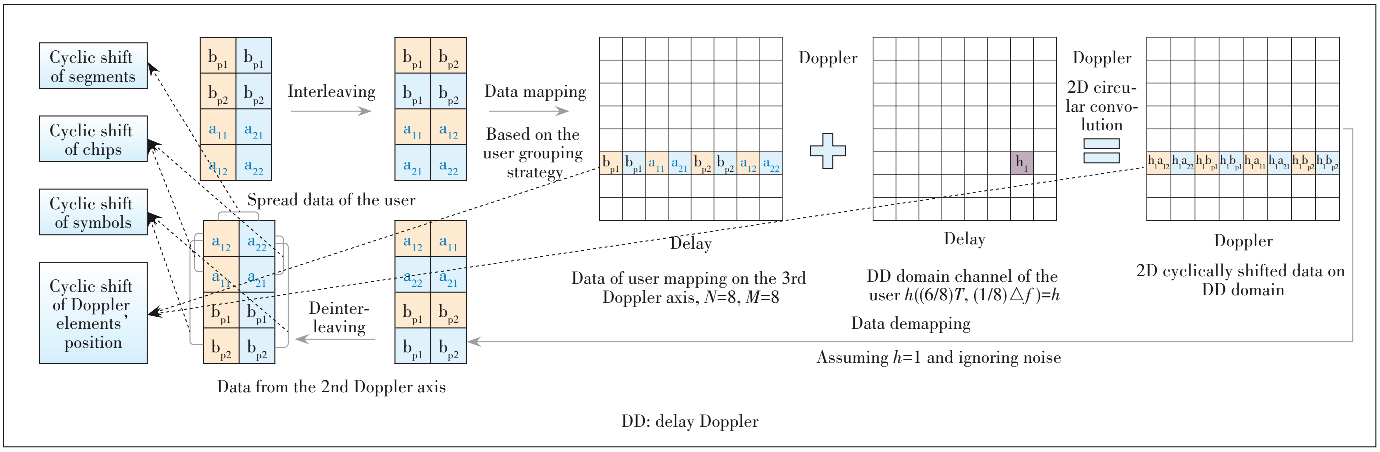
(AP) assistant communications, could be involved in. For the code domain grant-free OTFS-NOMA schemes, data spreading and interleaving are able to reverse two-dimension cyclic shift of the DD domain, like those shown in OTFS-TSMA[19].

TSMA is a code domain NOMA scheme, which innovates on transceiver design and data settings. At the TSMA transmitter, users' data are segmented and encoded to generate redundant segments. Subsequently, each user is allocated with a unique tandem spreading codeword, considering the indexes of the spreading sequences utilized by each segment. Then the segments are tandemly spread according to the codeword. Therein, the tandem spreading codebook C is designed according to the maximum distance separable (MDS) code, which maximizes the user capacity under the limitation of the number of colliding segments. At the TSMA receiver, the superposition of active users' data is separated by orthogonal correlation detection on each segment according to C. Then the active users set and corresponding data are obtained. Subsequently, the colliding segments inside are deleted and the redundant segments are used for segment decoding. Therefore, TSMA scales up the user capacity by tandem spreading, ensures transmission reliability by orthogonal spreading sequences and sacrifices data rate.

As shown in Fig. 2, novel data interleaving and corresponding data recovery strategies are proposed for OTFS-TSMA. The chip-level data interleaving/de-interleaving procedures are demonstrated in Fig. 3. It shows that based on the interleaving/de-interleaving strategies, the two-dimension cyclic shift of DD domain resources is transformed into cyclic shifts of Doppler domain elements, segments, systems and chips. Additionally, OTFS-TSMA adopts the cyclic orthogonal spreading sequences, namely discrete Fourier transform (DFT) sequences, whose orthogonality is maintained by the interleaving/de-interleaving strategies. At the OTFS-TSMA receiver, the segment-level cyclic shift is recovered during user identification, the symbol-level cyclic shift is recovered after despreading, phase rotation caused by the chip level cyclic shift is recovered before channel equalization, and Doppler diversity brought by the Doppler elements level cyclic shift is utilized during data combination. Therefore, two-dimension cyclic convolution of the DD domain is de-solved from the perspective of data design. Besides, OTFS-TSMA cleverly combines the multiple access characteristics of TSMA and the robustness of OTFS to dual selective channels. It could be involved into OTFS-NOMA enabled mMTC over the LEO satellite and inspire other OTFS-NOMA schemes of the code domain. Additionally, to make full use of DD domain resources, the schemes need to consider users' geometry positions.



▲**Figure 2. Orthogonal time frequency space (OTFS)-tandem spreading multiple access (TSMA) transmission diagram in Ref. [19]**



▲**Figure 3. Resource allocation and data interleaving demonstration of orthogonal time frequency space (OTFS)-tandem spreading multiple access (TSMA) in Ref. [19]**

Therefore, users with certain longitude and latitude values are scheduled to transmit during certain time slots according to their DD domain CIR characteristics.

For the power domain OTFS-NOMA, MUI brought by the DD domain channel could be mitigated by resource, rate and power allocation policies. In Ref. [17], users with high mobility are served in the DD domain and those with low mobility are serviced in the TF domain. Inspired by Ref. [17], both the TF and DD domains could be utilized for mMTC over the LEO satellite. For example, two users with the same Doppler shift and delay values (symmetrical with the sub satellite trajectory) could be serviced in two domains respectively. Besides, the users could be scheduled according to the channel conditions, whereas adaptive-rate transmission or fixed-rate transmission could be considered depending on the NOMA users' ability. Furthermore, power allocation schemes could be designed to facilitate the implementation of successful success interference cancellation (SIC), according to the users' QoS requirements and channel conditions. Note that the power domain OTFS-NOMA schemes rarely consider the uplink channel estimation, which always assume perfect CSI at transceiver. They perform better in system design in terms of communication capacity and transmission fairness. On the fast-varying satellite-ground channel, the performance of power domain OTFS-NOMA under imperfect CSI remains to be studied. Furthermore, in terms of the grant-free OTFS-NOMA design for mMTC systems over the LEO satellite, data colliding caused by non-cooperative transmission would effect user identification and data recovery. A classic grant-free OTFS-NOMA scheme utilizes the sparsity of devices[28], which is the idea from compressive sensing based multi-user detection (CSMUD). Therein, each user is provided with a preamble sequence known to the receiver, and the sequences are used for user identification and channel equalization based on compressed sensing. Nextly, the data could be divided by SIC. There is also another way to design the grant-free OTFS-NOMA in the time domain using the idea of ALOHA. Overall, the performance degradation brought by non-cooperative transmission in the grant-free OTFS-NOMA mode can be compensated by additional design in space, code, power, time or frequency domains.

3.4 Challenges of Combining OTFS and NOMA for MMTC over LEO Satellite

Firstly, the effect of a notable Doppler shift and heterogeneous delay is challenging for the system design. In the OTFS modulation, the DD domain resource plane requires that the subcarrier interval should be larger than the maximum Doppler shift, and the time interval should be larger than the maximum delay. Therefore, the required time and frequency resources are dozens of times that of similar services on ground communications, due to the normalized Doppler shift at 24 ppm and the propagation delay at 25.77 ms. It seems difficult to realize the system design with the rare space spectrum at sub-6G which is preferred for mMTC. Therefore, the Doppler and delay processing schemes need to be designed for OTFS-NOMA in the grant-free mode. For example, the system could concentrate on the differential values of the Doppler shift and delay, rather than the absolute values. In addition, the flexible configuration and mobility of the satellite system will bring different delay and Doppler characteristics. It also puts forward requirements for the flexibility of Doppler and delay processing schemes.

Secondly, the performance of OTFS-NOMA under rectangular pulses and fractional Doppler shift needs to be investigated. The DD domain input/output relationship in this scenario is written as:

$$y[k,l] \approx \sum_{q=-N'}^{N'} h e^{j2\pi\left(\frac{l-l_\tau}{M}\right)\left(\frac{k_\nu+\kappa_\nu}{N}\right)} \alpha(k,l,q) x\left[\left[k-k_\nu+q\right]_N, \left[l-l_\tau\right]_M\right], \tag{3}$$

where

$$\alpha(k,l,q) = \begin{cases} \frac{1}{N}\beta(q) & l_\tau \leqslant l < M \\ \frac{1}{N}\left(\beta(q)-1\right) e^{-j2\pi\frac{\left[k-k_\nu+q\right]_N}{N}} & 0 \leqslant l < l_\tau \end{cases}, \tag{4}$$

and

$$\beta(q) = \frac{e^{-j2\pi\left(-q-\kappa_\nu\right)} - 1}{e^{-j\frac{2\pi}{N}\left(-q-\kappa_\nu\right)} - 1}. \tag{5}$$

Eqs. (3) – (5) illustrate that ICI and ISI are introduced. Therefore, the system capacity and transmission reliability performance of OTFS-NOMA remain to be investigated. Besides, the OTFS-NOMA transmitter can be re-designed considering the geometry position of signal x and the LEO satellite, which determines k_ν and l_τ, where the unknown quantity is only h. The novel resource allocation scheme can be proposed correspondingly.

Thirdly, the retransmission, beamforming and handover strategies remain to be studied. Due to propagation fading, the retransmission strategy for massive devices needs to be designed. It is constrained by the short transmission window, limited devices power and overall throughput. In addition, since the massive terrestrial devices need to be served by the earth-fixed beams, beamforming of the LEO satellite should be investigated. It could expand the system user capacity in the meantime. Besides, owing to the high mobility of the LEO satellite, a handover proposal for reliable communications is required.

3.5 Potential Technologies for OTFS Enabled NOMA for MMTC over LEO Satellite

In addition to the technologies for OTFS modulation and NOMA, some additional technologies are still needed by the mMTC over LEO satellite to achieve reliable access and communications.

Since the cost of cyclic pilot (CP) could be huge under the large delay and the Doppler shift is notable, frequency and time advance at devices can be adopted. Therein, the propagation delay and Doppler shift could be formulated by the location information and the LEO ephemeris. If the devices do not support such kind of calculation, certain value of Doppler shift and time advance could be initialized in the devices. Thereafter, the LEO satellite concentrates on the differential Doppler shift and delay, which is much smaller than the absolute value.

To tackle with the differential Doppler shift and delay, user grouping based on geography is a potential solution. It is able to limit the differential values of the users' Doppler shift and delay in a certain interval. Subsequently, the interference could be mitigated and the resources required by the OTFS could be reduced. Besides, resource allocation and data mapping schemes of OTFS could be designed correspondingly. In order to realize grouping and seamless convergence of the massive devices in the earth-fixed beams, beamforming strategies are required. They can also be combined with spectrum sharing technologies, such as the cognitive radio, to increase the spectrum resources efficiency.

In the wide area application of mMTC over the LEO satellite, handover strategies need to be considered to enable the constant service. Firstly, the spot beam handover, which switches the connection to a difficult spot-beam, could be researched to achieve the maximum system throughput. Secondly, fast inter-satellite handover could be investigated to connect the worldwide mMTC devices, under the high mobility of the LEO satellite. Therein, the design of LEO satellite cancellations is required.

In addition to mMTC over the LEO satellite, the air network consisting of the high-altitude platforms (HAPs) and unmanned aerial vehicles (UAVs) could complement the NTN. In detail, the HAPs are with lower mobility and smaller communication coverage properties. Therefore, heterogeneous architecture can be adopted according to the service requirement. Additionally, the mobility management and routing algorithms need to be considered.

4 Conclusions

In this paper, we investigate the OTFS enabled NOMA for mMTC systems over the LEO satellite. The architecture and scenarios of the LEO satellite enabled mMTC systems are described. The MA schemes in the current NTN are also listed. Under the contradiction between the massive access and scarce spectrum, the NOMA technology is introduced in the system. Moreover, in the grant-free access system, OTFS is introduced to tackle with the notable Doppler shift by Doppler diversity, rather than pre-compensation. The designs and challenges of applying OTFS and NOMA into mMTC systems over the LEO satellite are then analyzed. In the end, the potential technologies and further studies of the system are suggested.

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Biographies

MA Yiyan received the B.S. degree in applied physics from Beijing Jiaotong University, China in 2019, and is currently working toward the Ph.D. degree at the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University. His current research interests include the field of Internet of Things and massive machine type communications.

MA Guoyu (magy@bjtu.edu.cn) received the B.S. and Ph.D. degrees in electrical engineering from Beijing Jiaotong University, China in 2012 and 2019, respectively. Currently he is an associate professor at the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University. His current research interests include machine-type communications and random access.

WANG Ning received the B. E. degree in communication engineering from Tianjin University, China in 2004, the M.A.Sc. degree in electrical engineering from The University of British Columbia, Canada in 2010, and the Ph.D. degree in electrical engineering from the University of Victoria, Canada in 2013. He was on the Finalist of the Governor General's Gold Medal for Outstanding Graduating Doctoral Student with the University of Victoria in 2013. From 2004 to 2008, he was with the China Information Technology Design and Consulting Institute as a mobile communication system engineer, specializing in planning and design of commercial mobile communication networks, network traffic analysis, and radio network optimization. He was a postdoctoral research fellow with the Department of Electrical and Computer Engineering, The University of British Columbia, from 2013 to 2015. Since 2015, he has been with the School of Information Engineering, Zhengzhou University, China, where he is currently an associate professor. He also holds adjunct appointments with the Department of Electrical and Computer Engineering, McMaster University, Canada, and the Department of Electrical and Computer Engineering, University of Victoria. He has served on the technical program committees of international conferences, including the IEEE GLOBECOM, IEEE ICC, IEEE WCNC, and CyberC. His research interests include resource allocation and security designs of future cellular networks, channel modeling for wireless communications, statistical signal processing, and cooperative wireless communications.

ZHONG Zhangdui is currently a professor and advisor of Ph.D. candidates with Beijing Jiaotong University, China. He is also a chief scientist with the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University. He is a director of the Innovative Research Team of Ministry of Education and a chief scientist of Ministry of Railways in China. He is an executive council member of Radio Association of China and a deputy director of Radio Association of Beijing. He has authored/coauthored seven books, five invention patents, and more than 200 scientific research papers in his research area. His interests include wireless communications for railways, control theory and techniques for railways, and GSM-R system. His research results have been widely used in railway engineering, including the Qinghai-Xizang railway, Datong-Qinhuangdao heavy haul railway and many high-speed railway lines in China. Prof. ZHONG was the recipient of a Maoyisheng Scientific Award of China, Zhantianyou Railway Honorary Award of China, and Top Ten Science/Technology Achievements Award of Chinese Universities. He is a fellow of IEEE.

AI Bo (boai@bjtu.edu.cn) graduated from Tsinghua University, China, with the honor of Excellent Postdoctoral Research Fellow in 2007. He received the master's and Ph.D. degrees from Xidian University, China in 2002 and 2004, respectively. He is currently working as a full professor and a Ph.D. advisor with Beijing Jiaotong University, China, where he is also the deputy director of the State Key Laboratory of Rail Traffic Control and Safety and the International Joint Research Center. He has authored or coauthored eight books and published over 300 academic research papers in his research area. He holds 26 invention patents. He has been the research team leader for 26 national projects and has won some important scientific research prizes. Five of his papers have been the ESI highly cited papers. He has been notified by the Council of Canadian Academies (CCA) that, based on Scopus database, he has been listed as one of the Top 1% authors in his field all over the world. His research interests include the research and applications of channel measurement and channel modeling and dedicated mobile communications for rail traffic systems. He is a fellow of IEEE and IET.