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CODE DIVISION OFDM JOINT COMMUNICATION AND SENSING SYSTEM FOR WIRELESS COMMUNICATION

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Abstract—

The joint communication and sensing (JCS) system can provide higher spectrum efficiency and load-saving for 6G machine-type communication (MTC) applications by merging necessary communication and sensing abilities with unified spectrum and transceivers. In order to suppress the mutual interference between the communication and radar sensing signals to improve the communication reliability and radar sensing accuracy, we propose a novel code-division orthogonal frequency division multiplex (CD-OFDM) JCS MTC system, where MTC users can simultaneously and continuously conduct communication and sensing with each other. We propose a novel CD-OFDM JCS signal and corresponding successive-interference-cancellation (SIC) based signal processing technique that obtains code-division multiplex (CDM) gain, which is compatible with the prevalent orthogonal frequency division multiplex (OFDM) communication system. To model the unified JCS signal transmission and reception process, we propose a novel unified JCS channel model. Finally, the simulation and numerical results are shown to verify the feasibility of the CD-OFDM JCS MTC system and the error propagation performance. We show that the CD-OFDM JCS MTC system can achieve not only more reliable communication but also comparably robust radar sensing compared with the precedent OFDM JCS system, especially in low signal-to-interference-and-noise ratio (SINR) regime.

division OFDM, interference cancellation.

I. INTRODUCTION

A. *Background and Motivations*

The number of Internet of Things (IoT) devices is predicted to grow three-fold, from 11 billion in 2019 to 30 billion in 2030 [1], [2]. By 2030, the 6G MTC system intends to fulfill tremendous IoT connections for intelligent precise control applications to support the future IoT, such as advanced driving automation (from L4 to L5) and accurate vehicle swarm control in the industrial scenarios [2]. These applications aim to conduct customized and precise control missions in mixed sensing/actuation/haptics scenarios, and require sensing accuracy of 0.1 m indoors or 1 m outdoors and communication reliability of 99.9999% for the critical applications [2]. The tremendous connections and high function requirements will result in great spectrum congestion, and demand high spectrum and energy utilization efficiency [3]–[6], which can not be fully addressed in 5G cellular MTC scenarios [7].

The state-of-the-art joint communication and sensing (JCS) technique is a promising technique to confront the aforementioned challenges. The JCS system can share the unified transceiver, the same spectrum and digital signal processing hardware to exploit the reflected echo of communication beam to achieve additional radar efficiency, compared with the conventional communication system where the echo signal is not well used for sensing [9]. The JCS system also benefits from mutual sharing of sensing information for improved reliability performance, e.g.,using the range and Doppler knowledge to assist beamforming and channel prediction [10].

Related Works

The early researches about JCS systems concentrated on the JCS waveform design based on MIMO and beamforming techniques used in communications [8]. In [11], [12], Sturm *et al.* proposed an orthogonal frequency division multiplexing (OFDM) symbol-based JCS signal processing method, which overcomes the typical drawbacks of correlation-based radar signal processing and satisfies both the radar ranging and communication requirements. In [13], the authors proposed a reconfigurable and unified multifunctional receiver for data- fusion services of radar sensing and radio communication based on time-division platform. In each time slot assigned for radar sensing or radio communication modes, the system can achieve localization function or data communication, respectively.

Other researches on the JCS system focused on designing the JCS transmitting and receiving system architectures toexploit time and spectrum resources effectively. Kumari *et al.*
[14] proposed an IEEE 802.11ad-based OFDM JCS vehicle- to-vehicle (V2V) system exploiting the preamble of a single- carrier physical layr frame to achieve V2V communication and full-duplex radar at the 60 GHz band, which benefits from the great development of the sufficient isolation and self-interference cancellation. In [15], the authors proposed an OFDM JCS system based on the IEEE 802.11 standards for range and speed detection, which can achieve full-duplex operation through canceling the self-interference by estimating the self-interference channel between the transmitting and receiving antennas. In [10], Zhang *et al.* proposed a practical OFDM time-division-duplex (TDD) multi-beam scheme to achieve JCS, which complies with the prevalent terrestrial packet communication system. This work utilizes multi-beam forming scheme to generate several orthogonal beams, and as- signs to each beam either communication or sensing function. Based on the evolved mobile broadband (eMBB) scenario, Liu *et al.* further proposed the concept of JCS base station that operates in mmWave band with TDD protocol adopting single- array transceivers [9]. The authors considered that the targets of interests can also be scatterers, and proposed the concept of successive interference cancellation (SIC) based method to suppress the mutual interference between communication and radar sensing signal reception.

However, there are some challenges that the aforementioned state-of-the-art work cannot completely handle. The features of massive and dense users of 6G MTC scenarios lead to close range between MTC users and severe mutual interference [1]. The close range problem makes the single-array JCS transceiv- er designed for eMBB users vulnerable to the minimum range problem, i.e., if the target of interest is too close to the JCS user, then the target may be ignored because the transceiver may not be in receiving mode when radar echo returns, which is disastrous for mobile MTC applications [16]. In [10], Zhang *et al.* adopted double-array transceivers, which can make the receiver work constantly and thus handle the minimum range problem. The severe mutual interference problem makes the conventional OFDM JCS system hard to ensure the high- reliability requirements in low signal-to-interference-and-noiseratio (SINR) regime [2].

C.Our Contributions

In this paper, we propose a code-division OFDM (CD- OFDM) JCS system, which can conduct communication and radar sensing simultaneously and constantly with the unified spectrum and transceivers. Here, we consider the MTC scenarios of low speed movement. To suppress the mutual interference between communication and radar echo signals, we propose a novel CD-OFDM JCS signal and correspond- ing SIC based processing method, which is compatible with OFDM JCS signal processing. In order to overcome the aforementioned problem of minimum detection range, we adopt double-array transceiver design to make the JCS MTC devices able to conduct constant radar sensing and communication simultaneously.

The main contributions of this paper are summarized as follows.

1. We propose a novel CD-OFDM JCS MTC system that is compatible with both CD-OFDM and OFDM JCS signal processing. This system can achieve radar sensing and communication between MTC devices simultaneously and constantly with the unified spectrum and transceivers.
2. We propose a novel SIC-based CD-OFDM and OFDM JCS signal processing method for the CD-OFDM JCS MTC system that can achieve the code-division gain to suppress the multiple access interference for communi- cation, including the radar echo signal and co-channel interference of other radio users.
3. We propose a novel unified JCS channel model based on the MIMO communication and radar channel models, presenting comprehensive quantitative relation among the fading coefficients, average power, delay and Doppler of communication and radar echo channels.

Outline of This Paper

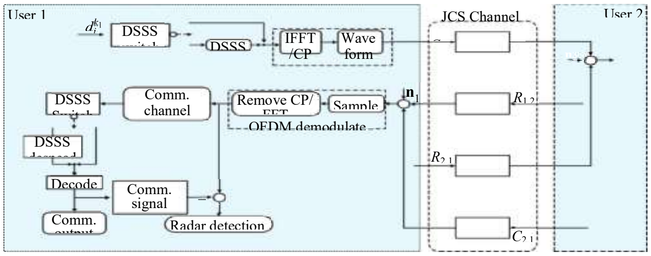
The remaining parts of this paper are organized as follows. In Section II, we describe the CD-OFDM JCS MTC system model and propose the JCS MIMO channel model. Section III proposes the SIC-based CD-OFDM JCS signal processing method. In section IV, the simulation results are presented. Section V concludes this paper.

Without particular claim, we adopt the following notations. Bold uppercase letters denote matrices (i.e., **M**); bold lower- case letters denote column vectors (i.e., **v**); scalers are denoted by normal font (i.e., γ); the entries of vectors or matrices are referred to with parenthesis, for instance, the qth entry of vector **v** is $\mathbf{v}(q)$, and the entry of the matrix **M** at the mth row and qth column is $\mathbf{M}(m, q)$; $\mathbf{I}_Q$ is the identity matrix with dimension Q Q; matrix superscripts $(\ )^H$, $(\ )^*$ and $(\ )^T$ denote Hermitian transpose, complex conjugate and transpose, respectively; Re ( ) and Im ( ) are the real and imaginary parts of complex number, E ( ) represents the expectation of random variable, denotes the floor function, and δ (t t_0) is the unit pulse function, Besides, we use $(\ )^{-1}$ to denote inverse of matrix, $(\ )^{\dagger}$ to denote the pseudo-inverse of the matrix, and *diag* (**v**) to denote a diagonal matrix with the entries of **v** on the diagonal.

II.SYSTEM MODEL

A. The CD-OFDM JCS MTC System Model

We consider a CD-OFDM JCS MTC system of low speed movement, where MTC devices conduct simultaneous and constant radar sensing and communication with the unified spectrum and transceiver[1]. s llustrated in Fig. 1, MTC users 1 and 2 conduct simultaneous bi-directional communication and radar sensing through line-of-sight (LoS) links. Each user is equipped with a double-array JCS transceiver composed of a transmitting array (TxA) and a receiving array (RxA) to generate the transmitting beams (TxBs) and receiving beams (RxBs), respectively. We assume that the transmit power for users 1 and 2 on each subcarrier is P_1 and P_2, respectively, and the antenna arrays are all uniform linear arrays (ULAs).



The isotropic antenna numbers of TxA and RxA are denoted by M and N , respectively. In order to solve the aforementioned minimum range problem, in-band full-duplex (IBFD) operation is required to make RxA work constantly [16]. In this case, the self-interference from TxA is large enough to ruin the communication and echo receiving. Thus, an isolation shield- ing plate and leakage cancellation module between TxA and RxA are required to alleviate or even cancel the self-leakage interference[2] [16]. Compared with the double-array transceiver design in [10] that adopts separate spectra for communication in TDD mode and constant radar detection, respectively, our proposed CD-OFDM JCS transceiver uses the same spectrum for both communication and sensing simultaneously and can achieve IBFD JCS operation.

In the JCS MTC system, users 1 and 2 both generate TxB and RxB pointed to each other to establish communication links (CLs), i.e., $C_{1,2}$ and $C_{2,1}$, and radar echo links (RELs), i.e., $R_{1,2}$ and $R_{2,1}$, as illustrated in Fig. 1. We assume that the perfect communication channel state information (CSI) is obtained at both users 1 and 2, i.e., the CSI matrices $\mathbf{H}_{C,12}$ and $\mathbf{H}_{C,21}$ for $C_{1,2}$ and $C_{2,1}$ can be well estimated, respec- tively, and the directions of arrival (DoA) is also detected for beamforming through multiple signal classification algorithm (MUSIC) or other angle detection methods. We also assume that the communication channel reciprocity holds as the users exploit the same spectrum and conduct communication simultaneously [17].

As illustrated in Fig. 1, user 1 transmits the JCS signal to user 2 through the CL $C_{1,2}$, and receives the reflected signals through the REL $R_{1,2}$. Once user 2 receives the JCS signal of user 1, user 2 transmits the JCS signal to user 1 through the CL $C_{2,1}$ and receives reflected signals through the REL $R_{2,1}$. The received signals at user 1 are composed of the communication signal from user 2 and the radar echo signal, while the received signals at user 2 consist of the communication signal from user 1 and the radar echo signal. It is noted that the radar echo signal is weaker than the communication signal because the radar echo transmits twice the distance as the communication signal. Thus, the radar echo signal can be regarded as small interference imposed on the communication signal, and can only be obtained after the communication signal is canceled. Fig. 2 illustrates the diagram of signal processing of the CD- OFDM JCS system. Note that user 2 has the same JCS signal

Fig. 2: The diagram of CD-OFDM JCS signal processing. DSSS switch decides whether CD-OFDM signal or OFDM signal is used. In high SINR regime, the DSSS switch turns to the void, and only the OFDM modulator is used. Otherwise, in low SINR regime, the switch turns to the DSSS module, and the original symbols are spread by DSSS to generate CD-OFDM signal.processing system as user 1. An SINR threshold is assumed at the direct-sequence-spectrum-spread (DSSS) switch module. By comparing the SINR threshold with the SINR obtained in the communication channel estimation, the DSSS switch decides whether CD-OFDM signal or OFDM signal is used. In low SINR regime, the switch turns to the DSSS module, and then the original symbols are first spread by the DSSS code book matrix and then modulated by the OFDM modulator to generate CD-OFDM signals, which enjoys code-division- multiplex (CDM) gain to enhance processing SINR and re- liability at the cost of high computation complexity. In high SINR regime, the DSSS switch turns to the void, i.e., the DSSS code book matrix is set as identity matrix, and therefore the original symbols are

directly modulated by OFDM modulator, as OFDM signal can satisfy the reliability constraints in the high SINR regime without additional computation complexity.

Note that the CD-OFDM JCS system can be achieved by modifying the frequency domain symbol processing modules of the MIMO OFDM communication system, the advanced DoA detection algorithms that are used in the MIMO OFDM system, such as MUSIC algorithm, can be applied to the CD- OFDM JCS system. Therefore, the angle detection is not our key innovation interest in this paper.

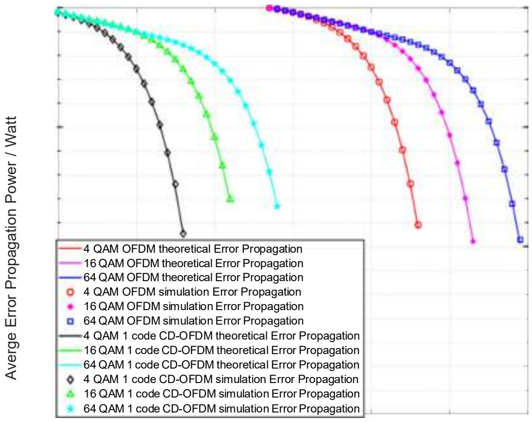


Fig. 6: Normalized AEPP of the 1-code CD-OFDM and OFDM JCS processing under 4, 16 and 64 QAM.

After the superposed signal is received, composed of com- munication, radar echo and interference-and-noise signals, it is first processed by OFDM demodulator, and then the super- posed JCS symbols with interference-plus-noise are obtained. Regarding the radar echo as the small interference imposed on communication signal, communication demodulation is first conducted. DSSS switch module decides whether DSSS despreading is used or not. After decoding the communica- tion symbols as shown in Section III-A, the communication signal can be restored and then canceled from the superposed received signal, which generates the radar signal plus noise. At last, radar detection can be conducted as shown in Section III-B.

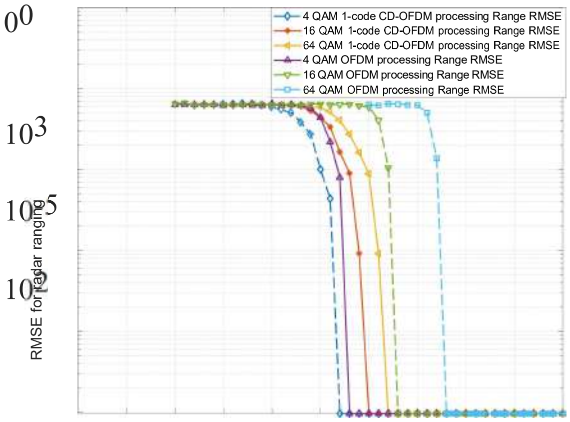


Fig. 8: RMSE for radar ranging of the 1 code channel CD- OFDM JCS processing versus the OFDM JCS processing

curves of “CD-OFDM and OFDM JCS processing” in this section can both be achieved by the proposed CD-OFDM JCS system. As a contrast, we introduce the TDD OFDM JCS system from [10] and present the JCS simulation performance of it, where there is only one JCS device transmitting JCS signal at an assigned time slot, and the mutual interference between communication and radar echo signals is avoided. We adopt M-ary QAM with Gray code as the constellation mapping method

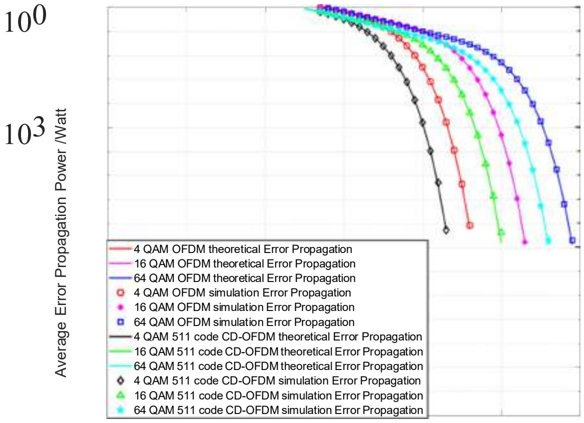
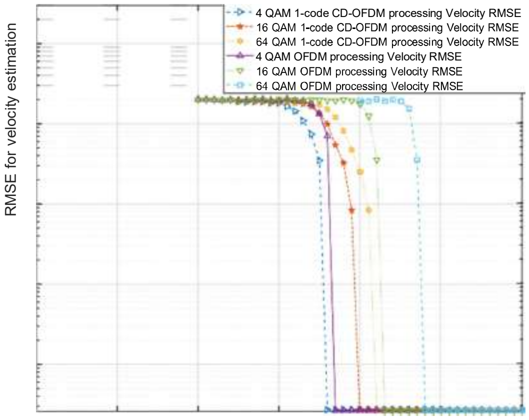
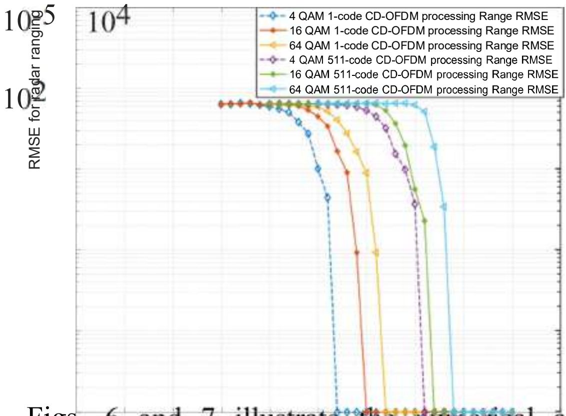


Fig. 7: Normalized AEPP of the 511-code and OFDM JCS processing under 4, 16 and 64 QAM.

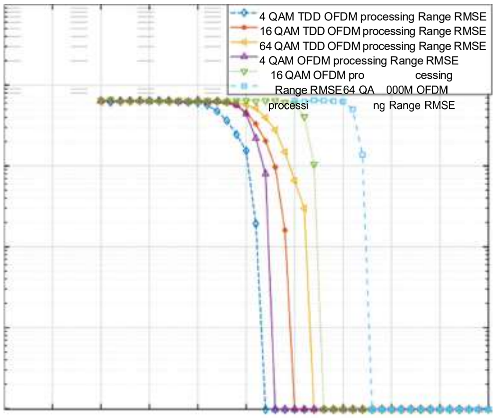
.Fig. 5 presents the BER simulation results of the proposed CD-OFDM and the conventional OFDM JCS systems, which verifies our analysis in the Section III-A. From Figs. 5(a), 5(b) and 5(c), we can see that the BER of the CD-OFDM JCS processing is lower than the OFDM JCS processing because the MAI interference imposed on the JCS communication demodulation is suppressed. We can identify that when the numbers of code channel are 1, 255 and 511, the values of

Fig. 9: RMSE for radar ranging of the 1 code channel versus the 511 code channel CD-OFDM JCS processing





Figs. 6 and 7 illustrate the numerical and simulation results of the average error propagation power (AEPP) with normal- ized unit transmit power, changing against the communication SINR under 4, 16 and 64 QAM. Through the Figs. 6 and 7, we can conclude that the proposed CD-OFDM JCS pro- conclude that the proposed CD-OFDM JCS pro-



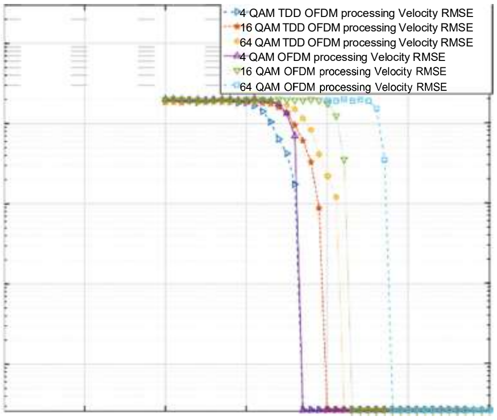


Fig. 10: RMSE for radar ranging of the OFDM

Fig. 11: RMSE for velocity estimation of the 1 code channel CD-OFDM JCS processing versus the OFDM JCS processing

JCS processing versus the TDD OFDM JCS rocessing

Fig. 12: RMSE for velocity estimation of the 1 code channel versus the 511 code channel CD-OFDM JCS processing

cessing can reduce the AEPP compared with the OFDM JCS processing by providing CDM gain, and the 1 code channel and 511 code channel CD-OFDM JCS processing have 30 dB and 3 dB SINR gain compared with the OFDM JCS processing, respectively, given the same AEPP constraint. This corresponds to the results in (38) and (39). We can also draw the conclusion that the increase of the number of used code channel results in the increase of the AEPP, as the CDM gain decreases according to (37).

Figs. 8 to 13 present the simulation results of radar ranging and velocity estimation RMSE changing against the commu- nication SINR. Because the frequency-domain IPN in (29) is i.i.d., the simulation curves of the velocity estimation in Figs. 11, 12 and 13 have the same variation pattern as the ranging estimation in Figs. 8, 9 and 10, respectively. As shown in Figs. 8 and 11, the sensing RMSE performance of 1-code channel CD-OFDM JCS processing is better than OFDM JCS processing given SINR, because the CDM gain reduces the AEPP that deteriorates the sensing performance. The increase of code channel number deteriorates the sensing RMSE perfor-mance as shown in Figs. 9 and 12. From Figs. 8 to 13, we can find that the TDD OFDM JCS processing needs smaller SINR than the OFDM JCS processing to guarantee given RMSE constraint, because the TDD OFDM sensing does not risk the error propagation of failed communication demodulation, while the sensing of OFDM JCS system suffers from the error propagation due to SIC-based processing method. In contrast, the CD-OFDM JCS processing can achieve comparable sens- ing performance to TDD OFDM JCS processing when a small number of code channels are used.

In the practical operation of MTC JCS system, we have to choose the proper signal processing method to achieve satisfying communication and sensing performance, which is achieved by DSSS switch module as shown in Fig. 2. It is obvious that the CD-OFDM JCS processing obtains the flexi-

$NC \quad 1$

$d_{i,n} = 0$ holds for $NC = 2n + 1$, $n > 0$, and $n \in Z$,

$\Sigma \quad k$

ble CDM gain, and can satisfy the reliability constraints in the low SINR regime at the cost of occupying more computation resources than the OFDM JCS processing. Besides, the CD- OFDM JCS system can achieve comparable sensing RMSE compared to TDD OFDM JCS system when a proper number

$n=0$

then we can have of code channels are utilized. he right hand side is a sum of even number of constellation points, which can never be an entry of M-ary QAM constella- tion. Thus, (41) does not hold. Thus, by reduction to absurdity,

CONCLUSION:

This work has put forward the CD-OFDM JCS system for low-speed 6G MTC scenarios, which can achieve high communication reliability and sensing performance. The CD-OFDM JCS signal and corresponding SIC-based processing technique have been proposed. Moreover, we have proposed the unified JCS channel model based on MIMO communication and MIMO radar channel models. With the proposed CD-OFDM JCS signal processing method and the unified JCS channel model, we conducted simulation and presented the BER, radar ranging and Doppler estimation RMSE, and average error propagation power of our proposed CD-OFDM JCS system compared with those of the conventional OFDM JCS system. We finally draw the conclusion that the CD-OFDM JCS system can achieve better BER performance than the OFDM JCS system in the low SINR regime at the cost of using more computation resources, while OFDM JCS system can only achieve the same communication performance as CD-OFDM system in the high SINR regime. Moreover, the CD-OFDM JCS system can achieve comparable sensing RMSE performance compared with the TDD OFDM JCS system when a proper number of code channels are used. In practical usage, whether to choose CD-OFDM or OFDM JCS processing mechanism should correspond to the real-time SINR and requirements for sensing and communication of the MTC scenarios.

REFERENCES

[1] M. Latva-aho and K. Leppänen, “Key drivers and research challenges for 6G ubiquitous wireless intelligence,” *6G Research Visions*, vol. 1, Sept. 2019.

[2] N. H. Mahmood, S. Böcker, A. Munari, F. Clazzer, I. Moerman, K. Mikhaylov, O. Lopez, O.-S. Park, E. Mercier, H. Bartz *et al.*, “White paper on critical and massive machine type communication towards 6G,” *arXiv preprint arXiv:2004.14146*, April 2020.

[3] X. Liu and X. Zhang, “NOMA-Based Resource Allocation for Cluster- Based Cognitive Industrial Internet of Things,” *IEEE Transactions on Industrial Informatics*, vol. 16, no. 8, pp. 5379–5388, Aug. 2020.

[4] X. Liu, M. Jia, X. Zhang, and W. Lu, “A Novel Multichannel Internet of Things Based on Dynamic Spectrum Sharing in 5G Communication,” *IEEE Internet of Things Journal*, vol. 6, no. 4, pp. 5962–5970, 2019.

[5] X. Chen, Z. Feng, Z. Wei, F. Gao, and X. Yuan, “Performance of Joint Sensing-Communication Cooperative Sensing UAV Network,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 12, pp. 15 545–15 556, Dec. 2020.

[6] H. Yang, Z. Wei, Z. Feng, C. Qiu, Z. Fang, X. Chen, and P. Zhang, “Queue-Aware Dynamic Resource Allocation for the Joint Communication-Radar System,” *IEEE Transactions on Vehicular Technology*, vol. 70, no. 1, pp. 754–767, Jan. 2021.

[7] N. H. Mahmood, H. Alves, O. A. López, M. Shehab, D. P. M. Osorio, and M. Latva-aho, “Six key enablers for machine type communication in 6G,” *2020 2nd 6G Wireless Summit, Levi, Finland*, 2020.

[8] Z. Feng, Z. Fang, Z. Wei, X. Chen, Z. Quan, and D. Ji, “Joint radar and communication: A survey,” *China Communications*, vol. 17, no. 1, pp. 1–27, Jan. 2020.

[9] F. Liu, C. Masouros, A. Petropulu, H. Griffiths, and L. Hanzo, “Joint radar and communication design: Applications, state-of-the-art, and the road ahead,” *IEEE Transactions on Communications*, June 2020.

[10] J. A. Zhang, X. Huang, Y. J. Guo, J. Yuan, and R. W. Heath, “Multibeam for joint communication and radar sensing using steerable analog antenna arrays,” *IEEE Transactions on Vehicular Technology*, vol. 68, no. 1, pp. 671–685, Jan. 2019.