Towalds Integrate & Sensing rand Communication for for GGA & St Standalidization Perspective

Ar Aryak akatishik Robi S Siggh S Shalatika Dayarathna, Rajjibla S soanayak ke Mutco: DDR etizozo Migugh Dajerjer, HHyoungju Ji, YYounsun Kiim, Wincenzo Sciancalepore, Allessio Zappone, and Wonjaja S Shiin

Alisstracte t-The hra dia diamounication ali vision infelimentaliae fiotial (Telécoralmificiation) binionic (Iffd is RU has receifffly-adopted Integrated Sensing land: Communication (ESAC) Changethe key triage (\$&A:C)oarforn EMT-20 N/6GustSACs is enavisioned rtd N/III/ 2030al 66le 16 Alfé ispenniste nyideless generation ktandardst lin this work, gwe brings together active ratipard another land his sovotike aspektsing ISAGethechnologyrafromanaghubaht6Gastaridardizattivn perspectived in Slading obthologyst find and adademi 6 Groguess. Specifically at his carticlet iprovided of Goge quot tements ustudal SACA enabled vision: decleding various advects bis 6G stelled andizations 6@efits;ofid8A@rctsexistenE8,A@d-integrationichalleriges.luMingoverious aspsentskof 66abting dechlichties, includings infellige 61 metastirfaceeridachdSACe gratebuscOrthoggaal Tilordovquency Space (OKES)e wavelforgut design lagdesin terfénelicegrinaballégrent fore tSAC: fitinally details Asspects are litiscussed to good various FesegrehnoppSytaniti(s) The hallenges nord things Acidtect no logy towards & Gagardesst domination Catibins ally, future aspects are discussed to open various research opportunities and Index Jerms Integrated sensing and communication (ISAC), challenges on the ISAC technology towards 6G wireless G standardization, ISAC coexistence, waveform design, inter-

Index Terms—Integrated sensing and communication (ISAC), 6G standard 24501, NISAC coexistence, warmfoongoing in the distribution of an intermediation of Fifth Generation (5G) wireless networks and amplementation of Fifth Generation (5G) wireless networks and support the Sixth Generation (6G) goingess metworks a for oatmap in plane Grieffestrial Wifele Generation (inc.) being formed work teliver painterrupied townsels very laritous tension to remain a full that type during the Sixth please station (6G) muintelason at wisters of the advantational Gelecommunication of the wister to the tension that the mean recommendation of the full the news recommendation of or the wister to the tension of the tension

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- SSD Dayarathna and R. Senanayake are with the Department of Elebrical & Elebrotic Eigheging ething etsitives Melbourne balantic Elebrotic Eing Eeging ething etsitives Melbourne balantic (e. dayiku hadayithakenunayikk) seninnelyeda (an) nimelb. edu. au).
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sion of the International Telecommunication Union (ITU-R) successfully drafted the new recommendation for the vision of International Mobile Telecommunication 2030 IMT-2030 (6G), which was recently approved at the meeting held in General on June 2023. As depicted in Fig. ??, the development of IMT-2030 encompasses several emerging technology trends, including artificial intelligence (AI), Integrated Sensing and Communication (ISAC), sub-Tera Hertz (THz) transmission, channel adaption via reconfigurable intelligent surfaces (RIS) and holographic multiple-input multiple-output (MIMO) surfaces, etc. Specifically, ISAC possesses abilities to sense and better understand the physical world and transmission environment.

ISAC is envisioned to play a key role in the upcoming generation. For example, integrated positioning, recognition, imaging, and reconstruction are expected to provide complimentary features that will be helpful in smart living, industrial advancements, and social governance. Moreover, the evolution of ISAC will further enhance wireless sensing capabilities and enable seamless collaboraright : Key technology trends adopted in ITU-R FTT Report to between sensing and communication systems. Indeed, MAC in 6G will unlock new possibilities for smart applications, enabling enhanced sensing capabilities, efficient approved at the meeting held in Geneva on June 2023. As resource utilization, etc. For example, some of the key depicted in ISEC in 6G are summarised below. passes several emerging technology trends, including artificial intelligence, (Ad) a Integrated, Sensing and Communication (ISAC), esub-Teras Hertz (THz) transmission, channel adaption via reconfigurable intelligent-surfaces (RIS) and holographic multiple-input multiple-output (MIMQ) synfaces (etc. SpecificallyitisACfpassesses abilitias to tsense and better understand the physical_world and transmission environment. Moreover,

ISACA is envisioned to that satisfy the inchange in the numerousing generation. For example, integrated positioning prognition, imaging, and reconstruction are expected to provide complimentary fertures that with bothelpful for smart living cindustrial advancements, and social governance. Moreover, the exclusion of ISAC or illustrates enhanced wireless he using papabilities and quality seamless collaboration between assing papabilities and quality seamless collaboration between assing papabilities munications systems to be advanced by a consideration of the exclusion of the seamless collaboration of the end will number known possibilities for smart applications, enabling enhanced sensing capabilities and ficient resource but it zation testes. For a example, some of the decapers of ISAC in 6G are supposed below:

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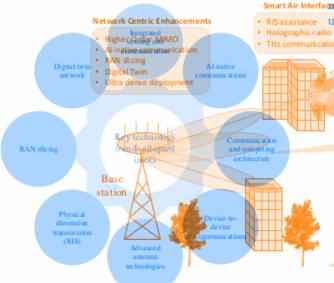


Fig. 18 s Kreyworks notorgyntering die adopted tibh Toplink zation, Report Work management, etc. Moreover, ISAC can be used to assist wireless communication parameters, such as Health of the grant of the learning of the lea

- Bata fusion Sensing and Control of Sensing A Sarge number 66 seksorlarda arevielso are rendento to enselutareu udare tree 66 incherense. Ale breibigioguna farcipi pharani in 15 Ad cowards the collection of data from various solices will and while accurate and comprehensive translitting on authorizing of sensing which controlled the property of the controlled the property of the controlled t
- ofgsensing enroughities, including vision, taudio, motion,

Understanding the long dient sensing notes ISAC profite this articledrings to get breatons a such any ount ment in realtive approximersiVsAexpertences, lending diswittance, peantilizare shift ninnour in a remute wire less estander of the cifically, this workI highligight Sengthy land Communication Coleralization 6G the uppositing wireless generation along with more features and inhaldinges a rechtliques test jointus trising and a codamic programmation I Special Most executing to part smatter its AIS AGH enabled decelerations and resistance tion, making intetti genottata phocessing unfettigent vehicular paper chieflits geveral research directions, opportunities,

and life Gaseing the need and emergence of ISAC in 6G, this article brings together several paramount and innovative aspeets & SACFEFEC, leading Noward Fa paradig in Shinch our culveith wireless islandards f Specifically ethis twork thighlights technical aspects land standardikation Cof the upcoming wireless generation, alonge with howelpfp at grest and bhallenges land the tatest-industrial tinel Worleh Bordrogress rour IN-AGO MOreover, the pager (MiRitiagisesFIS AGsenabled denesits life mtl6Gppurview) eighaintegrated docalizational sensinghijoint are sources, sharing, exct-furthermore? the paper highlights several research directions, opportunities, and use cases.

A. Network Centric Enhancements

This encompasses: Doth the evolution of current 5G cajWithlithes rapid theecirofof@rimplementation.teheninitiation 5 GpA tlocol of or mattlo 6 Gor A G tloch workely sistal mady outside rway.

Smart Air Interface etwork-centric enhancements will be at the forefront of

• RIS assistance upcoming wirelessUperMestated Enhancements

 THz communication • Evolution of Existing Clipabilities: Experiences from RISthe previous generations open new doors for the evolution of current tareabilities. Everaging advancements in spectrum efficiency, network capacity, etc., 6G aims to surpass the performance of its predecessors and unlock new possibilities. For example, a higherorder MIMO is intended to employ a larger number of an Changelenabling enhanced coverage and improved interference management.

> Al-Native Communication: 6G is expected to embrace AI, enabling it to intelligently allocate resources, enhance network performance, improve energy efficiency, etc. Al-assisted communication is intended to lewrage several new capabilities as an intrinsic component of the network.

Fig. 2: An illustration of targeted 6G enhancements. regation of network-level responsibilities via slicing Indeed, the stepping istone has already been placed during the World Radiocommunication Conference-2023 (WRG-23)erfor ease of conddistanding the proposed enhancements are grouped into three entegeriest as depicted in Fig. 22.

- Digital Twin: Digital twin is the modern learning tool
- A. Meworkate arriving inclination of the physical network This encompasses both the context of wireless communication, the notion of a digital twin provides real-time ities and the incorporation of new techniques in 5G-Advanced and off. As the wireless framework's core, network-centric This, in turn, brings seyeral innovative features, in-enhancements will be at the forefront of upcoming wireless chiding the replication, update, and synchronization generalions.
- generations of the physical networks, etc.

 Evolution of Existing Capabilities: Experiences from the B. 30f current gapabilities. Leveraging advancements in spec-
- trum efficiency, network capacity, etc., 6G aims to surpass Unlik performance viriles predecession and announless precessing intieth for example, a higher-order MIMO techniqued will to employ a three tillianter of afternas, establing interfective making it government to tune the wireless channel for more favorable propagation conditions (?) Some of the potential techniques auch de la listensistance aubelos resources, dinhand THz network performance, improve energy efficiency, etc. AI-
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replication, update, and synchronization of thesphysicalerface networks, etc. Network Centric Enhancements R IS assistance

- - Holographic radio
 THz communication

· Higher Order MIMO B. Smart Air Interface Al-native commun

Unlike previous wireless generations that employ processing at the transceiver ends, enabling 660 techniques will focus on the utilization of a smart air interface, making it convenient to tune the wireless channel for more favorable propagation conditions [?]. Some of the potential techniques include RIS assistance, holographic radio, and THz communication.

- RIS Assistance: RIS assistance is indeed an emerging component of 6G's smart air interface. The notion of RIS technology mainly affivores the manipulation of wireless signals while reflected through passive intelligent surfaces [?]. Enabled by channel estimation and dynamic phase tuning, RIS can help in several ways, e.g., assisting in beamforming, interference mitigation, coverage extension, etc. Already, potential use cases of RIS have been verified by numerous existing Figral: An illustration of
- Holographic Radio: Holographic radio is another groundbreaking ne chnique, that a comes under neotential co Gornablera id ?LdSpecifically thit saimatto etransforms sexeral wireless aspects, from signal, transmission to freception and processing. Enabled by advanced signal processing
- algorithms, and ichannel incoherence, holographic, gadio enables the simultaneous transmission of multiple data streams over the tsame time-frequency perource). Unlike
- THz: Communication: One step, ahead, 6G, frontiers, are focusing tiont THz treommunication tra? Irigle veraging a feequencies in the THz range; Octable THz eUnlike blower freque nevi bands...T.Hz; wayes of fer ivider, hand widths that in turn enable ultrabigh data rates apotentially reaching multi-terabit-per-second speeds. Also, THz communication holds promise for data-hungry applications, e.g., holographic imaging, immersive virtual reality, etc. User Assisted Enhancements

C. 6UséroAssiste do Enhancentidusng the end user's computational frebilities receive on nitrizing uneventruser in community and abilitys i without piewiff cantisubardiening false overwark systems. and power consumption of diagretworks system omputational

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leveraging advanced positioning technologies, including a tight integration of acoust unication and positioning. Ultrahigh position accuracy opensoup new 6G possibilities for applications like augmented reality, autonomous vehicles,

lemenand advanced logisticsent monitoring

III. 6G Standardization and ISAC Co-existence

Standardization plays a crucial role in advancing ISAC by providing a common ground for developers, researchers, and industries to repllaborate effectively. A comprehensive set of standards fosters compatibility and scalability and facilitates the integration of new technologies into existing ecosystems.

A. Efforts and Organizations

Embracing standardization will unlock the full potential of ISAC and pave the way for a connected, intelligent, and sensor-driven future. The major standard development organizations (SDOs) in the wireless communication domain, such as Third Generation Partnership Project (3GPP) and European Telecommunication Standard Institution (ETSI), will focus on innovative work on islacionaverbrias high processing for years ing. By the grasting of the control Grouph (ASGs) awile thosus eachien metrice nor usacipal evant use eassistinnings trates brighterwittingsscrupe and engage for communication and biliting for applications like augmented reality, autonomous vehicles, and advanced logistics.

B. Third Generation Partnership Project (3GPP)

IIAn Greesta indestacz is the adulant Inches frog affection first stage of the 5G standard as the scope of 5G-Advanced. While the governional, 5G providing verly ere manifestion, services was the core of its function. ISAC can be important in its function to contribute to communication-assisted new set of standards fosters compatibility and scalability and recylices - To lidentify, such now ISAC service is enarios ithree key scenarios are discussed: object detection and tracking, environment monitoring, and motion monitoring.

· Object Detection and Tracking: When user equipment A. Effect is a characted it at he work, various methods such as

Espositioning and aUE/safeed back untake the network-track of ISMC VEd However the network careed phainingen infor sensmation of rom the pressive object on dargets evident having ganithei.netverkosonnectioniifunctionalityiiInathisi spenario. such high programment in the such high programment of the such high programment in the such high progra and beuther key to dracking that have nonested and unconnected (ETSPY GOLD focus on innovative work on ISAC waveforms and Environment Manitoring Thethis (scenario), the base station the Isrused as an environmental representation in the resisting reme metrmunication/equipment: Insparticular a sensing device will tweenblain environmental information such as the existence of rainfall, the level of flood, human gathering, and trafficload information. Since monitoring information is time-

B. Third all estensible to the thety of shini hard of less Replacessary.

A Matione Man 18 Nitte indoor a hyman-mation a falceph monit stageoringh sports monitoring sandegesture reconflition/arecuse Whiteasts: inothis ascenario, the very inqueinly terminimize atalse servidetection rather than location accuracy SAC can be impolita@GPP, ithefusectiond phasentof bittle: studyonwillincontinue tossislenti fyevtheerISAG-rellatede ktefy requiremen IS Aftither.viAt thersames, timeseRAN, sowhich is an appinetible dorologic access technologic sackeds, ten studyn whether ophysical, layer support from RACings necessary for 5G-Advanced. However, existing chango by models continued the nyarivus incharacteristics continued the nyarivus incharacteristics continued the reflectors of explicit surveying the consider the reflectors of explicit surveying objects and abuildings and how a contain cluster contributes either so both jeonomication and sensing the change model study in which there is an account of the contributes are considered will be the heginning of thy speakings (PHY) and sign of its Adril be the key to tracking both connected and unconnected devices.

C. Etpopaon Talacommunications [Standards: Institute] (ETSD)

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C. European Telecommunications Standards Institute (ETSI) INTELLIGENT METASURFACES-AIDED ISAC AND

Hereafter, We discuss the significance of standardization An RASI and it Holiographic rMIMQ-assisted ASA Censuring data intTheitmeendionibigwieg wirtstesiscorinkunteation tedweiks And Sentante system from air Entropean should relieve to enough Wearst. Waithy the 46eds has been Salehabling the to texts force between then two disestems and inthics amounted the attended in the second seco tioner when striptelinearing har alog innegration by the recommend ISAC in East a dealer of the control to obtain a vignerate amount of the twe hold to a facility which ansingte thateweit of a rorification as Aconglic extretion of that isodesigned to admy information Gymbotical swettelas dignition environmenti beforing another amberring in printerple, this could be adbiAvedwbweidoptingedargee multiplie gantenna larrays, e.gd massivenMdM@ngbut practical considerations prevent from taking/filhis/Approach:eIn/6th60 words, RW6iforde6tA/Ging massive anteribasaivayseproinidess highermates nitratisonleads of oransignificant drielling consumption indicase) [2] dlff bldelSta Guccessfully intAgraIS A@mmunications and a sensing in raysing let platforing the required radio stesodares must be secured with stistalinable onerdyr constlmption: One appiroach swithin the reotential acyachieve this goalris based on the rebent tephhological breakthrological hdlographienMIMOebeitanformingp (The main fidenabdhindkthis approlachlisatoʻorquipowiarless, transcoiversl with reconfigurable suct as infracely explicit ican EbE SI sed fors transmit and/or receive bealmfologing, with much TSW dr. Knergy Reguirements.nd ETSI THratebigenHractasurfacesaprovide a novel approach for wireless communications, in which planar structures of metamaterials are equipped with elementary selectromagnetic (EM) units spaced at sub wryalength distances with each other. Each unit can apply an individual EM response to an input signal, A. RIS and Holographic MIMO-assisted ISAC operating directly in the analog domain, i.e., without the need to Employtegetiginal transceiver/chains Theruserof athismnovel rrankeerved archrieerungstillows bore derfeelt ze datu inventig dock fadio oreguenevs chanitwith br ≪ousinhasinhmar way on awhien hybrid-MIMO carchitectures throthy o After impinging contine fremsonfacePoststraignap thevers or the Decenvet, Postert raniother mentisurface beatwise functed in the shelded plate facce identical. theorigion etalis. This afetiteteure this entirety intranation e6mbaretwo f wartisonali timultiple whichna aicule chard ward holder MINIO spreking energies waveform that is designed to carrycinformation symbols asyndl aspectormemeironesent sensions vide sthe mache largere number of thee phiamerers that achievad by adapting largenmultiple puttom a criev system massiverAffMfee.bytoprovai.culecerniderentionemerenentatione takingcohigungganagal-dineyth group toladaghilo adenlariga massing autranous regy the revides this her is a tranifed bedwadn to a rignificant appergrepor sumption increase [?]. In order to.seconsfully tintegrate consumunitation and techning the sinalgenhathber of the requireders for system design with es secured lowish energy inablementary and sumption of perable proaghetasithrathe dant but held the agestive devices only regard on the racentane chrolingiest chronic throughout the hardwhie MIMO hoonefus ming eThoremore ideanly birad this low prouch is to continue in less promote the resemble of the surfammand/withouse abeliate une different and submand/withouse ive beamforming with much lower oversy requirements digital

Intelligent metasurfaces provide a novel approach for wirfelestheonwords; chtiedgraphie whith Olabeam fetrisch yr 65 of metavurteei ela are segni apedrariah masave MIM eletrav wan nation (EWE) units greeged eathern's avereless at he distance anwitch 6#charthres Eace surity cean apply out inclinity at 15th are spouse berrorinantesi pravingostativ srdir epakarindes son kspalamajin. hozavith autele need teenalevendisiteht var sei ve eksim The grant of other movel transpositions and the following the control of the cont to senthesize sainare waverokuratio akonte parance perwith the different sincilars was ishould be obtished. An architect t visceny orkut After i jossibe i neomrabing e pervolaca telensienes travelse other receivers where conthen water urface raunbe ulacedoin fale, fieldmatible accuracy, radior frequency achains. Beisterchitanturming, tarrother educat assecompane directent ristional avultiral casatempre seribit ent une standal and mission of MIMO architectures:

B. OFFin Waveform Resign frey Brack MIMO architectures, it 6Gp and dreyond unlirblegers yestenber and flikely atomic orporate higher frequency inhands, fourthes manifestated and dfl-the Besides.

performance. Moreover, the reflection coefficients can be reconfigured in real-time, in order to adapt to fluctuations and varieties of the electromagnetic channel between transcription and receiver.

*Compared to existing massive MIMO architectures, the large number of the parameters for system design comes at lower factor consumption and cost. Reconfigurable metasinates can be ready, passive devices, only requiring a small ancient of fuergy to power the hardware compared factoristic the reconfiguration (low-power switches like PD) diodes or varactors). Moreover, the inetasinases operate in the analog domain without requiring energy-consuming conversion to from the digital domain.

In other words, holographic MIMO beamforming by a metasurface varieties of a communication of MIMO array with much lower energy requiremental and the MIMO array with much lower energy requiremental and the mount of radio resources that can be optimized for optimal system performance. Having many free parameters for signal optimization appears to be a critical requirement for the successful integration of communication and sensing, not only in order to synthesize suitable waveforms but also to balance between the different metrics that should be optimized. In an ISAC system, multiple, possibly contrasting, performance metrics must be optimized, e.g., the communication rate, latency, detection rate, estimation accuracy, energy efficiency, etc. Besides beamforming, another grucial aspect is the efficient ISAC waveform design presented in the following.

B. OTF₀S Waseform Design for ISAC

6G and beyond wireless systems are likely to incorporate higher frequency bands, such as mmWaye and TFig. 4: The PSLR distribution of modulated ISAC-OTFS THZ. Besides, these systems are expected to support high mobility communications with speeds greater than 1,000 km/h, such as hyper-high-speed railway (hyper-HSR) and these systems are expected to support high mobility communigations with spotds preatgrathen de 000 km/hs such as hyperhigh-speed railway (hyper-HSR) and airline systems [2] - Asor rasult..futurel wireless systems will experience doubly dispersive channels that wary in both time, and frequency of However, the performance of the classical orthogonal frequency division multiplexinge(QEDM)hmodulation/suffers/from high/Doppler spread, specifically in very high frequencies where the channel is doubly dispersive at This then its their suitability of OFDM in future[66] notworks. This has distroduced a requirement for new communication technologies capable of handling high Doppler sprend introduced by the doubly dispersive channels wireless chamotevated threathe lagranopoistic dature of (IBD wireless) chame ineformatic odel ay: Dopplero (dothraino) (DiDedomlain) unthérinformationesymbles of the forthogonal time brequency space (OTFS) wave forms the modulatednin the Dedomain (fisteadonfathe denventional Office frequency (of Findomain of the tise of OFFS inodellation die communication systems (is the Bostudied) cartdoit is shown that the confidition error performance of hOTES can be imprised that their by back of LDW density countylethock (bDRCOandScollyolution-coded OTFS [?].

Coming to the ISAC counterpart, the modulation of communication data changes the properties of the OTFS waveform used in radar sensing. As such, it affects the performance of raday seasing the lattler illustrate this, let us consider the rendigues Burton that represents the response of a transmitted signal is received with a certain base detay and a Doppler shift. As a simple division Fig. 77 plots the contour plot of the anthogeter lines and product realizations of 4-quadrature amplitude tred rate of (CAM) modulated ISAC-OTFS waveform were different sommunication data matrices of size 4×8 in Dissorbain. From Fig. ?? we can observe that the behavior of the ambiguity function, especially outside the mainlobe regime, depends on the communication data modulated onto the OTFS waveform. Indeed, reden Second realization less communication downs and OFDM hased ASACT systems provide as accurate local radar estimates (delay and Doppler resolution and meanradar estimates (delay and Doppler resolution and meansquared error of estimates) as frequency-modulated continComing to the ISAC counterpart, the modulation of comnous wave (FMCW) while OTFS-based systems provide a
munication data changes the properties of the OIFS waveform
higher pragmatic capacity for communication. ?? Neverused in radar sensing. As such, it affects the performance of
theless, the global accuracy in radar sensing has received
radar sensing. To further illustrate this, let us consider the
limited attention and a detailed analysis of the impact of
ambiguity function that represents the response of a matched
data modulation on global radar performance is essential
filler when the transmitted signal is received with a certain
for the successful implementation of OTES modulation in
time delay and a Doppler shift. As a simple illustration, Fig. ??
inture ISAC systems
plots the contour plot of the ambiguity function for two realizaturns are proposed to the peak-to-sidelobe ratio (PSLR) is a
tions of 4-quadrature amplitude modulation (QAM) modulated
well crown global radar performance metric used to idenck powie global radar performance metric used to iden-ISAC - OTFS waveform with different communication data matrix the capability of detecting weak targets in the presence rices of size 4×8 in DD-domain. From Fig. ?? we can observe of nearby interfering targets ?? As a simple illustration that the behavior of the ambiguity function, especially outside Fig. ?? plots the distribution of the PSLR for 4-QAM the maintobe regime, depends on the communication data modulated ISAC - OTFS waveform with 1,000 random modulated onto the OTFS waveform with 1,000 random modulated onto the OTFS waveform indeed, recent research communication data matrices of size 4×4 in DD-domain has shown that both OTFS and OFDM-based ISAC systems. From Fig. ?? we local redearly observe that the PSLR provide as accurate local radar estimates (delay and Doppler of OTFS varies from -10.3 dB to -4.6 dB based on resolution and mean-squared error of estimates) as frequency-the modulated communication data. The forther smaller modulated continuous wave (FMCW) while OTFS-based sysprobability of false alarms a smaller PSLR value a tems provide a higher pragmatic capacity for communication desired property in ISAC systems. received limited attention and a detailed analysis of the impact of data-modulation on global mdan performance is essential for the successful implementation of OTFS modulation in future the successful implementation of OTFS modulation in future That her more is ISAC has great potential for more efficient resource utilization by integrating communication. Furthermore, the peak-to-sidelobe ratio (PSLR) is a well-and sensing into a single system, which has traditionally known global radar performance metric used to identify the been performed on separate hardware. In addition to the capability of detecting weak targets in the presence of nearby existing intra-system interference within the communication and sensing systems, the co-existence of sensing and distribution of the PSLR for 4-QAM modulated ISAC-OTFS communication within a single system brings out a new waveform with 1,000 random communication data matrices challenge in managing inter-system interference between of size 4-x-4 in DD-domain, from Fig. ?? we can clearly the two functionalities, two candidate approaches exist observe that the PSLR of OTFS varies from =10.3 dB to -4-6 for tackling this problem: orthogonal ISAC, where time or dB based on the modulated communication data. Due to the frequency resources, are allocated orthogonally and nonsmaller probability of laise alarms, a smaller PSLR value is a orthogonal ISAC, which has the opportunity to maximize desired property in ISAC systems. for both functions.

C. 1/SAS-thusgriftungs All and general in Fig. ??, the orthogonEurhleumbien IS A Ginhasorg feat upotentials for ensore cofficient sesoighefutivization by integrating communication between sing

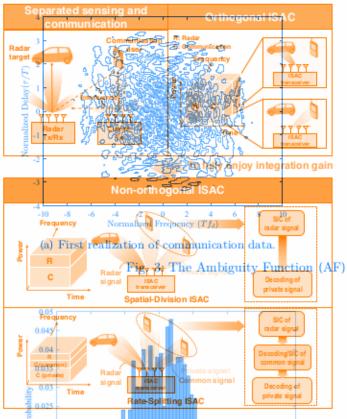


Fig. 59.02The evolution of ISAC from orthogonal to nonorthogonal approaches for efficient use of wireless resources.

0.01

into a single system, which has traditionally been performed on separate hardware. In addition to the existing intra-system interference within the communication and sensing systems, the co-existence to a sensing and continuous ation within configuration. system brings out a new challenge in managing inter-system interference between the two functionalities. Two candidate approaches.exist_for_tackling_this problem:forthogonaleISAC. where timezor frequency resources are sallocated orthogomally, and non-orthogonal-ISAC, which has the opportunity to maximize resource efficiency, by esharing, where tand afrequency resources for both functions different functions to achieve intlyf@rthogonitligk8461 [As shown in Fig. ??, the orthogonal allocation of times are frequency respueses provides as straightforwardewayeto manage duterforence between the take functions...Inglime-division-ISAC-edifferentswaysforms can be utilized for communication and sensing in separate time slots. On the other hand, frequency-division ISAC typically employs of DM waveform, with the allocation of distinct subcarriers communication and sensing purposes, spatial-division for different functions to achieve interference mitigation [?]. ISAC has the potential to achieve superior spectral

- 2) Mon-orthogonal ISAC: to The thon-orthogonal ISAC with a attracted a great deal of interest due to its ability to take full advantage of resource efficiency. This approach can be broadly categorized as follows:

 advantage of resource efficiency signi approach can be broadly categorized as follows:

 a proportion of the property of
 - Spatialadivision: ISACcrByiespatihHye dividing gbe ansador conhtiphrication oarid as ensing capterposes enspatialadivisión ISIACcshaththéspoteint ab do ciclejevel is tipen braspec tighels ficiency: espapalide to corthogon and ISIACcsWith an sufficient

- number of antennas to form a narrow beam, it is effective when line-of-sight (LOS) paths dominate the communication channel Froveyer source interference can occur in scenarios where the target is real multiple users or in a rich scattering an terment. To dodress this issue, introducing additional ratar searly and corresponding successive interference cancertation. SEC went be a solution, as shown in the
- Rate splitting ISAX fore pitting is ACCI hased on ratesplitting multiple across (RSMA) coming attention as the
 next generation of molecular access schemes. In RSMA,
 messages intended for each aser are splitting common
 and private signals and transmitted. The common signal
 plays a triple role in rate-splitting 4SAC: intra-system
 interference management, inter-system interference management seand bearing forming on inheritarizer. Induced, it
 has been studied that the common signal can function
 like a radar signal regardless of whether an additional
 radar signal is employed. In addition, there is no loss of
 perfoliorated in the absence of a inday signal charks to

the common stream in RSMA [?].

Refurther research is essential to mittigate such interference by exploring advanced user scheduling, traine structive design and cooperative strategies using multiple ISAC transceivers etc. Addressing these issues will play a key role in improving the performance of ISAC systems.

Formally, 6G has been envisioned as the successor to the previous wireless generation, with greater capabilities. However, it is not merely an evolution of its predecessors, but rather a paragigm shift to enable novel use cases that would be difficult to support over the precedent wireless generations. Thereby, to fulfill its ambitious vision, there are various critical challenges that need to be resolved.

- Inter-operability Harmony: Inter-operability harmony is essential for the sentiles integration of sensing and communication technologies, enabling devices to function as sensors and communication nodes. However, it fosters a collaborative environment which is a challenging task. To achieve inter-operability harmony among communication and sensing units, collaborative efforts between industry stakeholders and standardization bodies are required to establish common protocols. Moreover, other integration
- Fig. challenges in entire resolving interoperating issues a cross or the congeneration of the
 - Sectionisty listed of History: Dantotherlitting History is drivered due to the plittickying official ascerse (R Shish) it god hing that top of organism is ignaled and ratid dition of the landscars driving the top of organism is graded and the results of organism and section in the results of organism and the results of th

sybornthreats:fedatacbreaches;eanditunauthorizadi access-Ensuring helatauppi vaclyndseeks cintilals tob buildstrukte dant bag tisers to safeguaid personal funformations and sensitive data fregardhauthofized etdees sor mishisé o Collaboration ambrig industryedtakeholdérisorreséarchers; caholsregfujatofrychodies is theeskarytte establishacosignohtkeeukitytottandardsubest ptactices and Management and privacy of

Further research is essential to mittgate such intertrust, reliability, and widespread adoption, of intelligent ference by exploring advanced user scheduling, frame structure design, and cooperative strategies using multiple ISAC transceivers, etc. Addressing these issues will play a key role in improving the performance of ISAC systems.

Being key enabling technology for 6G, ISAC is at the forefront of wireless communication, which opens several doors for presearch directions, and other opportunities one

· Emerging Trends in ISAC: Several trends are shaping Fothe attelution loss ISAG networks ed. JSAG combled stransthe paissions will desing reasingly nhambs sing (edge acomputing Howeapabilities to process data closer to the source providing but several abenefitigainshifting endblediolatency; captimized wouldandwidthcrandtonhancedtrealetimhedataeanalytics; b)leAl geneandomachinerdeamingfuWill playnabivitals relejoin, ISAC are vnotworks; ichablingalidnanseth data epròces sing: eintelligent

resource allocation, and self-optimizing network behavInter-operability Harmony, inter-operability harmony
ior, c) TSAC networks will enable collaborative comis essential for the seamless integration of sensing
munication, where devices and sensors, work together
and communication technologies, enabling devices to
to share information and collectively improve system
function as sensors and communication nodes. Howperformance,
ever, it fosters a collaborative environment which

to share information and collectively, improve system function as sensors and communication nodes. How-performance.

ever. it fosters a collaborative environment which the system of the collaborative and Applications: ISAC cois a challenging task, To achieve inter-operability existence is set to revolutionize the landscape of forth-harmony among communication and sensing units coming wireless communication, promising several new collaborative efforts between industry stakeholders opportunities including: a) ISAC is intended to play a and standardization bodies are required to establish pivotal role in shaping smart cities of the future, enabling common protocols. Moreower, other integration challed in the monitoring of traffic flow, energy distribution, lenges include resolving interoperability issues across public safety (such as response and recovery in a disaster-heterogeneous networks and ensuring data, privacy affected region), etc. By integrating sensors with compand security concerns. Overall, inter-operability harmunication, capabilities, smart cities, car optimize several things, e.g., resource allocation, reduce congestion, possibilities for innovative applications and drive the etc. b) The fusion of sensor data and communication next generation of intelligent connectivity, makes ISAC the core of Industry 4.0/5.0, revolutioniz-Security and Privacy: Another, big challenge, arises ing industrial, automation. ISAC is set to provide real-dute to the breaching of data secrecy, transmitted time, monitoring of machines, and processes, facilitating on the top of sensing signals. In addition to the nurpredictive maintenance, etc., and c) ISAC is set to drive merous possibilities, the comm-sense fusion of ISAC transformative applications, especially in the realm of autonomous vehicles, Moreover, integrated sensors and cerns. ISAC networks superimpose sensor data and communication that requires robust security measures incles, making it convehient to offer improved safety, to protect against, every threats, data

Undoubtedly, ISAC technology holds immense promise in transforming households and industries. Countless envisioned use cases and applications of diverse pature, including smart cities, healthcare, industrial automation, environmental moni-holders, researchers, and regulatory bodies is necestoring agriculture, transportation, and many more to establish common security standards, best

practices, and guidelines. The security and privacy of ISAC networks are of paramount importance to

Understanding the limbiditance and icheependead by SAG in the updothing wireless generation, we have presented several

essential and VinnoVStAvC aspects of PSA Septechnology from a 6GB standardization in purview Specifically Cthis work, can the concluded or swale. This carticle is unimarized of Goreguizements and the vision of ISAC integration covering various aspects of 6G standardization, advantages of ISAC co-existence, and of oc. standard Trends in ISAC. Several trends are snaping related challenges, b) Additionally, the article has highlighted the evolution of ISAC networks: a) ISAC satisfies key enabling technologies, e.g., intelligent metasurface-aided transmission will be increasingly harnessing edge ISAC, and also presents the OTFS waveform design for ISAC. Computing capabilities to process data croser, to the computing capabilities to process data croser, to the source, providing several benefits, including reduced opening the doors for various research avenues concerning latency, optimized bandwidth, and enhanced reafted technology for 6G wireless communication. ISAC technology for 6G wireless communication. time data analytics, b) Al and machine learning will

play a vital role in ISAC networks, enabling advanced data processing, intelligent resource allocation, and self-optimizing network behavior. c) ISAC networks will enable collaborative communication, where devices and sensors work together to share information and collectively improve system performance.

 Envisioned Use Cases and Applications: ISAC coexistence is set to revolutionize the landscape of forthcoming wireless communication, promising several new opportunities including: a) ISAC is intended to play a pivotal role in shaping smart cities of the future, enabling real-time monitoring of traffic flow, energy distribution, public safety (such as response and recovery in a disaster-affected region), etc. By integrating sensors with communication capabilities, smart cities can optimize several things, e.g., resource allocation, reduce congestion, etc, b) The fusion of sensor data and communication makes ISAC the core of Industry 4.0/5.0, revolutionizing industrial automation. ISAC is set to provide realtime monitoring of machines and processes, facilitating predictive maintenance, etc, and c) ISAC is set to drive transformative applications, especially in the realm of autonomous vehicles. Moreover, integrated sensors and communication enable real-time data sharing among vehicles, making it convenient to offer improved safety, navigation, and traffic management.

Undoubtedly, ISAC technology holds immense promise in transforming households and industries. Countless envisioned use cases and applications of diverse nature, including smart cities, healthcare, industrial automation, environmental monitoring, agriculture, transportation, and many more.

VII. Conclusion

Understanding the importance and emergence of ISAC in the upcoming wireless generation, we have presented several essential and innovative aspects of ISAC technology from a 6G standardization purview. Specifically, this work can be concluded as: a) This article summariz es 6G requirements and the vision of ISAC integration, covering various aspects of 6G standardization, advantages of ISAC co-existence, and related challenges, b) Additionally, the article has highlighted key enabling technologies, e.g., intelligent metasurface-aided ISAC, and also presents the OTFS waveform design for ISAC, c) Moreover, the article