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SURVEY

6G: Technology Evolution in Future Wireless Networks

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ABSTRACT The Sixth Generation (6G) Wireless Communication Network (WCN) is the successive provision to ameliorate the gain with ultra-low latency, and e xtremely high energy efficiency. The 6G WCN enables the specifications of artificial intelligence to optimize the services and capabilities. The vision of the 6G era is expected to address a seamless fusion of communication between the human, physical world, and digital world. The latest 6G WCN standard is a fundamental foundation and requires immense attention in the field of research. This paper presents the framework of 6G WCN with an illustration of its key technologies. The different technologies involved in 6G are well explained with the demonstration of the communication scenario such that the key performance indicators are improved with major differences. The primary contribution of this paper is the explanation of the 6G with the technologies that have a drastic impact on the characteristic aspects of a wireless communication network such as data rate, spectrum efficiency, energy efficiency, connection density, and reliability. All these technologies have the capability to revolutionize the subsequent WCN.

INDEX TERMS 6G technologies, SaFi, terahertz communication, VLC, RIS, DICN, AI.

I. INTRODUCTION

The 6G WCN is envisaged as broad with its ambitious future targets. It is expected to provide intelligently enabled seamless connectivity everywhere with reduced energy consumption for the enhancement of society and living as a whole. The increasing demands in terms of connecting devices and data traffic are the fundamental driving forces behind the requirement of 6G evolution. The key motivating and expected trends in 6G include very high data rates of 1Tbps, extremely low latency (reduction by one-tenth of 5G), 50x faster than 5G, 2x more energy efficiency, 2x more spectrum efficiency [1]. The standard bodies including International Telecommunication Union-Radio Communication Sector (ITU-R) illustrated the opening edge of 6G work by 2030 in terms of quality as well as quantity for the new world such that mobile data traffic will exceed the limit of more than 5ZB per month. Moreover, enhanced reliability, new spectrums, high network availability, intelligent networking, green communication, computing, localization, control, green communication, and sensing are the other characteristics features of 6G communication network [2]. The 6G flagship-based projects (such as 6Genesis) have already been initiated, that target advanced technologies. The primary characteristics features include the latency limited below 0.1ms in the user plane and 1ms in the control plane, downlink spectral efficiency limited to 100bps/Hz or more, execution in the sub terahertz and terahertz bands, expected data rate up to 1Tbps, and battery-free Internet of Things (IoT) devices. The network coverage has been extended by incorporating different technological integrations such as satellite and terrestrial systems [3]. The 6G network is expected to offer native intelligence with boosted spectral efficiency and global coverage. The concept of cognition intelligence in 6G in the form of decision-making has paved the way for the evolution of communication networks [4]. Numerous large scale executions are anticipated significantly from the technologies of 6G network. In view of various applications,

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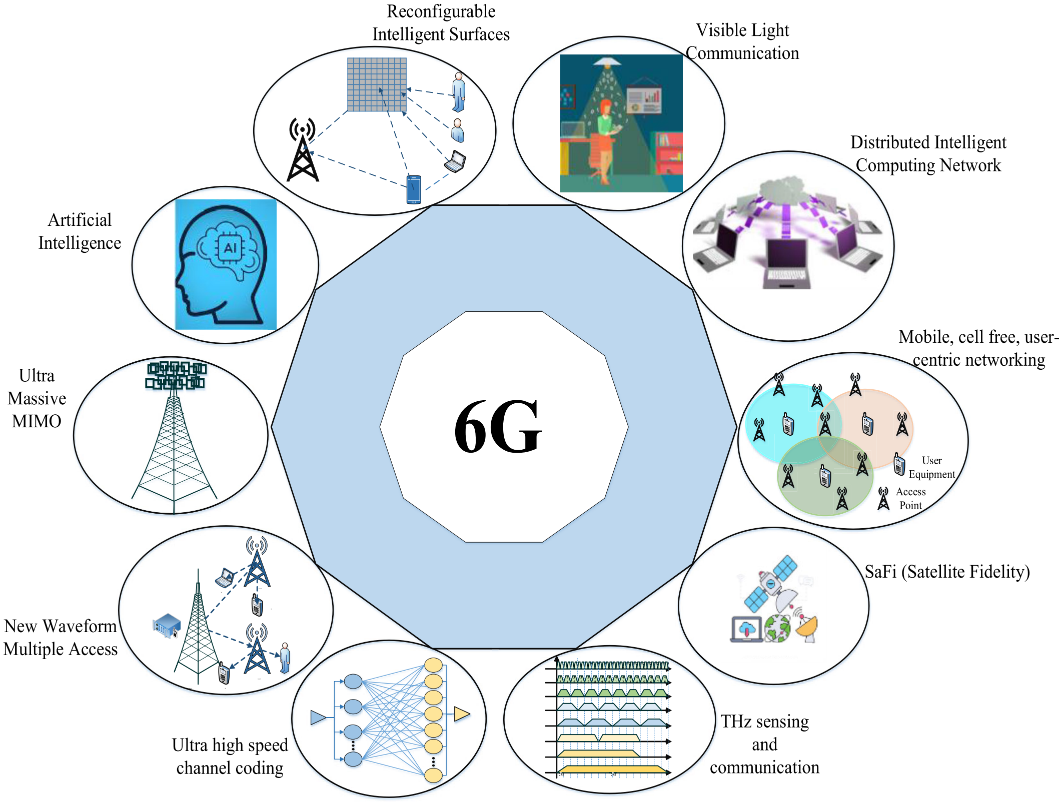

FIGURE 1. **6G technologies.**

6G network is capable to support high end data rate service applications such as augmented reality, virtual reality, mixed reality, 3D mapping, implants, internet of healthcare things, autonomous vehicles, sensing, and the applications related to internet of smart things. To get the insight about 6G network, this paper presents the perspective of generalized 6G technologies.

The primary contribution of this article is defined as follows:

a) The article illustrates comprehensively the vision of key enabling technologies in 6G WCN.
b) Each of the technologies is highlighted in this paper with the detailed realization of 6G to provide clarity and concrete research perspective towards the development of the future WCN.
c) The key 6G research areas have been identified in order to actualize the vision and allow use cases for future-generation communication networks. While some of the technologies are evolutionary advancements that have been employed in earlier generations, some technologies are disruptive and can unleash the potential that goes beyond Shannon's bounds.

The 6G era involves the fusion of the physical, digital, and human worlds to provide seamless connectivity between machines, humans, and the virtual service field. To summarize the 6G era, the following 10 technologies are identified to envisage the future of wireless communication. These technologies are (1) Reconfigurable intelligent surfaces, (2) Photonic and visible light communication technology, (3) Distributed intelligent computing network (4) Mobile and cell-free user-centric networking (5) Satellite fidelity (6) Terahertz sensing and communication (7) Ultra high-speed channel coding technology (8) New waveform multiple access (9) Ultra Massive MIMO (10) Artificial Intelligence. Each of the technologies is comprehensively illustrated from section II to section XI. The key technologies of the 6G WCN are depicted in Fig. 1.

II. RECONFIGURABLE INTELLIGENT SURFACES

The perspective of Reconfigurable Intelligent Surfaces (RIS) in the 6G communication network has been discovered as cutting-edge technology with the latest promising set of research opportunities. The ability to analyze smart radio environments provides a cost-effective, energy-efficient solution to satisfy the demands and services anticipated for the upcoming decades. The use of cost-effective passive reflecting elements incorporates the phase shift in the signal to create an appropriate propagating channel between the transmitter end and the receiver end [5]. RIS is also called holographic Multiple Input Multiple Output (MIMO), intelligent reflecting surfaces, and intelligent beamforming metasurfaces. The technology possesses the ability to sense and execute the propagation communication environment intelligently, thereby raising the research on their use in 6G

WCN. To shape electromagnetic waves through anomalous refraction, reflection, polarization, and absorption, RIS consists of dielectric scattering elements or sub-wavelength metallic elements. Wireless signals can be coherently mixed and guided in the desired directions by suitably and dynamically modifying the phase and amplitude of each of the RIS parts dependent on the propagation environment.

An accurate analysis of Channel State Information (CSI) is required to unravel the full potential of RIS. However, CSI analysis incurs significant overheads due to the high density of elements on RIS. Innovative efforts have been carried out to address the issue of channel estimation in RIS. In the case of active and passive elements, RIS with passive elements is considered to be more energy efficient and more economical.

The utilization of RIS in indoor communication scenarios or on building facades could focus the energy of a propagating signal onto a specific spot, thereby, improving coverage in Non-Line of Sight (NLoS) communication environments with the consumption of less energy.

The use of RIS makes it possible to adapt the propagating channel as per requirement and thus add a programmable entity with the possibility of increasing the overall capacity of the nework [6]. As far as the construction of RIS is concerned, it consists of a planar structure with the characteristics to adapt and control electromagnetic waves dynamically. An IRS is made up of a lot of inexpensive, passive components that reflect the incident signal differently with a certain phase shift to work together to produce beamforming and reduce interference at the specific receiver(s). The fundamental components of such an RIS are so-called metamaterials, which, in contrast to a material with attributes based on its atomic constituents, are artificially constructed structures with specific properties that interact with electromagnetic radiation in a desirable manner. The major target advantages offered by the technology of RIS in 6G WCN include low power consumption, shorter transmission delay, simple hardware, durability, and lower cost [7]. The overall communication scenario of RIS is shown in Fig 2.

A. RELATED WORK

In [8], Conventional research focused on the solely working Intelligent Reflecting Surface (IRS). In [9], The latest research direction occupies prodigious attention on the coordination of multi-IRS. Based on the CSI for both user equipment RIS and the corresponding base station RIS communication links, various optimization schemes have been formulated. These optimization schemes involve the technique of compressed sensing CSI estimation scheme using KatriRao and Kronecker products [10], two-stage channel estimation using angle differences, angular parameters, and propagation path gains [11], Bilinear Adaptive Vector Approximate Message Passing (BAdVAMP) algorithm [12], machine learning-based CSI estimation [13], and subspace CSI estimation techniques [14], channel estimation based on message passing algorithm using matrix calibration for the problem of sparse matrix factorization [15], channel estimation by resolving the tensor completion problems while assessing time delays, angles of arrival and path gains [16]. In [17], CSI is considered one of the salient parameters required for the execution of multi-IRS methodology. Therefore, the deployment of the IRS suffers from the curse of dimensionality. To counteract this issue, the technique of blind beamforming has been adapted. The strategy of blind beamforming optimizes the phase shifts over several IRSs without the requirement of CSI. Blind beamforming for optimizing phase shifts without the status of CSI for a single IRS. The work in [17] has considered a subset of possible elucidations, which are random in nature. From the subset, the received power of the signal has been estimated to deduce the final phase shift. However, the obtained solution is not limited to the considered subset.

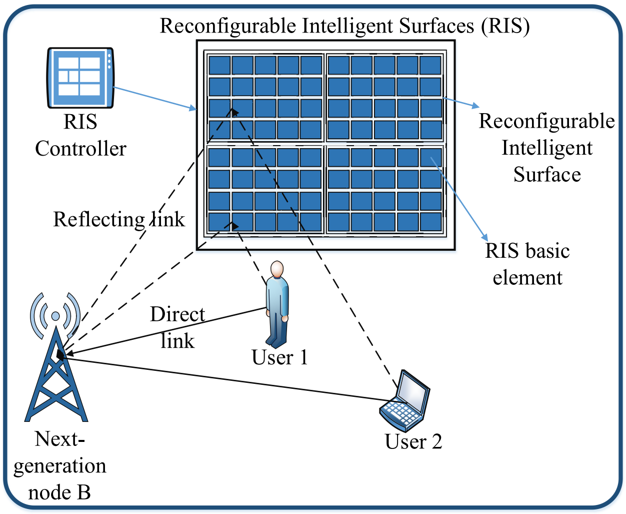

FIGURE 2. **Communication network using reconfigurable intelligent surface technology.**

Following a similar technique, the work on the generalization of blind beamforming for multiple IRSs is the latest research direction. In [18], generalized blind beamforming for multiple IRSs is given. It incorporates the measurement of the user terminal received power of the signal with respect to the phase shifts obtained randomly for each IRS. One of the significant reasons to adapt blind beamforming is channel estimation as the number of channels is exponential in the number of respective IRSs. CSI is manageable in simpler cases for example in the case where two IRSs are considered or in the case where all channels are ignored that are multi-hop reflected phenomena [19], [20], [21]. Techniques such as the two-time scale optimization approach [22], and deep learning [23], have been incorporated in IRS systems for the reduction of overheads in the CSI estimation. In addition to its computational complexity, CSI estimation presents a significant practical barrier due to network protocol and chip issues. Currently, channel estimation is not commonly used in the present IRS prototype [24]. In [25], a communication model for RIS based on inhomogeneous surface impedance boundaries has been formulated. The scheme incorporates the concept of global and local criteria of optimality such that the purely reactive impedance boundaries are identified. In [26], as the application and services offered by RIS technology are concerned, it supports remote sensing, unparalleled data transmission, and wireless charging with the vision of next generation WCN having energy efficiency, low cost, and ubiquitous connectivity.

In [27], it is given that RIS consists of a planar surface consisting of several reconfigurable elements creating an appropriate phase shift and amplitude concerning the incident signal. In [28], based on the metasurfaces RIS may have three categories, viz. waveguide RIS, refracting RIS, and reflecting RIS. In [29], various optimization techniques for the transmission design in RIS based wireless network are given. In [30], 256 two bit element design of RIS has been incorporated. It involves the combined framework for radiation and phase shift on the electromagnetic surface.

RIS technology enables leveraging degrees of freedom for Integrated Sensing and Communication (ISAC) therefore enhancing the beamforming. Thus, signal coverage and correspondingly quality of service can be upgraded. Other research work has been investigated in the RIS system. It includes the deployment of the RIS system in the WCN, joint beamforming [31], and resilient transmission schemes in the RIS system [32], [33]. Radar-based RIS system deployment has also been investigated. In particular, RIS beamforming can enhance sensing performance [34], [35]. Similarly, RIS based joint active and passive beamforming approach leads to increase in performance in rich scattering settings [36]. In [37], it is given that the accuracy of angle assessment can be enhanced by self-sensing RIS architecture.

The deployment of the RIS system is used to enhance the estimation of user equipment location such as in GPS (Global Positioning System) [38], localization method based on strength of the signal [39], localization method based on the angle of departure and time of arrival [40]. In [41], Joint RIS beamforming has been implemented using the combination of alternating optimization semi-definite relaxation and alternating optimization Riemannian gradient techniques. In [42], phase shift-based optimization scheme has been investigated in Multi-cell RIS integrated with multi-user MIMO system. The uplink communication channel is assessed using the linear mean square error method and matrices of channel covariance for optimization of RIS phase shifts. Thereby, maximizing the overall average sum of power gains corresponding to the users.

In [43], RIS integrated with millimeter wave and non-orthogonal Multiple access in consideration with multiple user equipment has been investigated to optimize energy efficiency. The optimization is based on the beamforming vectors, power, and minimal rate of user devices. In [44], large intelligent surfaces in the form of an array with an autonomous single antenna terminal are considered for data transmission. Under the fixed limit of transmission power with the constraint of space normalized capacity is achieved when the wavelength approaches zero. Therefore, optimal sampling lattice is estimated for designing large intelligent surfaces. In [45], The impact of ambient backscatter-based individual communication links is examined. The channel characterization in the RIS assisted ambient backscatter based communication network is evaluated to facilitate energy efficiency and spectral efficiency. The evaluation of the communication network is performed on the basis of the average symbol error rate, asymptotic outage probability and diversity order. To verify the analytical results, Monte Carlo simulations are attained.

The outline of the RIS based related work in terms of research provisions include coordination of multiple intelligent surfaces, CSI estimations of RIS assisted communication network, artificial intelligence based CSI estimations in RIS based network, multiple element design of RIS, blind beamforming, transmission schemes in RIS system, adaptive IRS sensing, active and passive beamforming approaches in RIS assisted network, joint beamforming approaches, multi-cell RIS integrated with MIMO systems, location enhancements using RIS, and large IRS array systems.

III. PHOTONIC AND VISIBLE LIGHT COMMUNICATION TECHNOLOGY

Optical wireless communication is already in use as a supplemental technology to meet the demand for more bandwidth. It has the potential to spread more widely since it combines fast speed, high quality, and affordable deployment. The availability of over 300 THz of license-free bandwidth carried on visible and Infra Red (IR) wavelengths, robustness against interference, and secure communications, such as in indoor environments where the radiation can not penetrate walls, are key advantages over radio frequency-based access networks. Visible Light Communications (VLC) also referred to as Light Fidelity (LiFi) is defined as data transmission through high bandwidth intensity modulation by incorporating commercial Light Emitting Diodes (LEDs) for lighting. The photodiode acts as a receiver. The technology acts as a practical strategy that makes it simple to integrate into the current and future infrastructure, especially for Line of Sight (LoS) indoor applications.

6G WCN possesses the capacity to incorporate the available spectrum resources with better efficiency including optical wireless bands, sub-6GHz, terahertz, and whole millimeter waves in order to meet the demands for massive traffic, massive and smart connectivity, and the requirement to address the issue of saturation of radio frequency bands. VLC channels have a minor Doppler impact and do not experience small-scale fading. Different useful LED sources with unique radiating patterns are used in actual VLC systems. A white LED illuminator emits incoherent light with a power spread across the visible light spectrum in the specified range from 380nm to 780nm.

In [46], the suggested open All-Photonic Network (APN) could facilitate data processing and transfer while realizing an infrastructure with high capacity, low power consumption, and low latency. For instance, it allows low latency service by enabling a direct end-to-end optical link connection across domains between points or any user terminals with low photoelectric conversion. To construct such an end-to-end all-optical link, integrated optical devices (photonic integrated circuits) might offer the routing and termination functionality. The communication scenario of VLC is represented in Fig. 3.

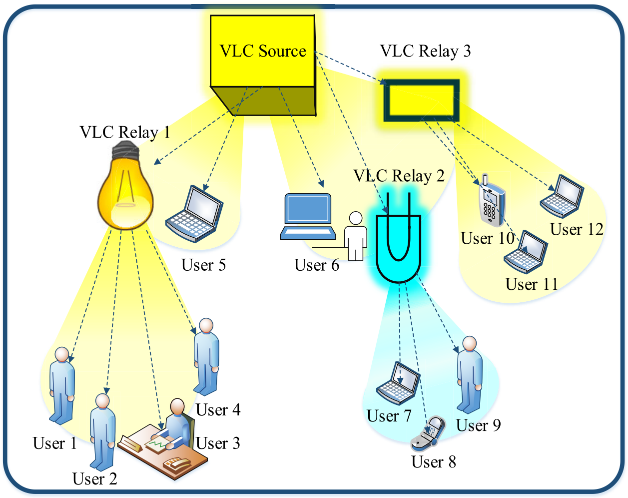

FIGURE 3. Communication network using photonic and Visible Light Communication (VLC) technology.

A. RELATED WORK

VLC is considered the capable technology to be integrated with Unmanned Aerial Vehicle (UAV) to offer services such as lighting and seamless communication. The combination of the two can prove a solution for rescue and search operations. The use of VLC-enabled UAVs can prove highly energy efficient by using LED-based transmitters thereby reducing the requirement of additional hardware [47]. The integration of the two has grabbed a lot of attention in the field of research for enhancing the performance of the communication network [48]. VLC-enabled UAV-based location optimization is performed by maximizing the sum rate of the network [49], [50]. Joint optimization between power allocation, location, and user associated has been assimilated in a UAV-based VLC network [51]. Further, RIS has been combined with the VLC-enabled UAV network to further reduce the transmit power and increase energy efficiency [52]. Similarly, various UAVs in a VLC network are considered to further enhance optimization [53]. Multi-agent reinforcement learning method is used to minimize the transmit power and maximize the sum rate of the UAV-enabled VLC network [54]. Coverage probability has been increased to improve the single UAV-based VLC network [55].

Trajectories of VLC-based UAV networks are optimized using Particle Swarm Optimization (PSO) such that the location of the UAV is optimized according to the location of the user. The optimization involves the parameters of rate fairness, sum rate of the network, and power consumption [56]. Transmission Matrix-Assisted Neural Network (TMANN) has been implemented to enhance the performance of the VLC-based communication network. The mechanism provides the reduction of computational complexity by 59.23% with a transmission rate of 6.689Gbps [57]. A hybrid network of light fidelity network and wireless fidelity network is operated in [58]. An adaptive target condition neural network is executed to optimize the issue of load balancing in this hybrid network. The mechanism is based on a deep neural network such that access points are selected as per the single targeted user corresponding to the condition of the other operating users. In [59], VLC in integration with vehicular communication networks, provides another alternative. However, fluctuations, mobility, and connectivity are a few of the challenges that affect the Vehicular Visible Light Communication (VVLC) network adversely. Blind interference alignment VVLC is incorporated with the reconfigurable photodetectors to obtain channel response with linear independence.

In [60], MIMO is combined with the VVLC network to improve the performance. The weighted two-step approximation methodology is followed to enhance the probability distribution of SINR, thereby ensuring the ergodic capacity of the network. The Asymmetrically Clipped Optical Orthogonal Frequency Division Multiplexing (ACO-OFDM) technique is implemented in the VLC network to enhance spectral efficiency and energy efficiency. The performance is improved by the optimal power allocation such that the minimum mean squared error is maintained [61]. Further, phase multi-band Carrierless AmPlitude (m-CAP) modulation integrated with the parameter of received strength of the signal has been performed to obtain visible light communication and sensing corresponding to the same signal [62]. The use of VLC link is evaluated for highly mobile vehicles such as high-speed trains. The communication link in the network between the Base Station (BS) and User Equipment (UE) is established via relay. The communication link between BS and relay is executed by backhaul Radio Frequency (RF) links while between relays and UEs links are supported by the VLC network. The parameters outage probability and average bit error rate are considered for the evaluation of the network performance [63]. For indoor flying VLC networks, physical layer waveform using an end-to-end learning framework is used to optimize the performance. Mixed carrier communication in a VLC network integrates multiple communication streams for signaling, data, and control to support dimming and localization. Symbol error rate and signal-to-noise ratio are the parameters of analysis for this scheme [64].

For the upcoming next generation WCN, various technologies such as free space optics, fiber wireless, and VLC are integrated to meet the current network demands. The VLC network is implanted using m-Quadrature Amplitude Modulation (m-QAM) at 550MHz with a 39GHz mmWave operating link [65]. Multiple LED with Non-Orthogonal Multiple Access (NOMA) using relay-aided VLC network has been evaluated in [66]. The protocol of decode and forward relay is applied such that outage probability is estimated to characterize the performance of the network. Apart from mobility, there are several other challenges associated with VLC networks such as limited modulation bandwidth, optical reflection effects, interference, randomness in receiver orientation, and device non-linearity. Similarly, for the reliable implementation and privacy-preserving of the transfer of the data, the federated learning approach in the VLC network for the optimization of the reliability is given in [67].

The summary of the research provisions in photonic and visible light communication technology includes, VLC integration with UAV, VLC integrated with RIS, VLC integrated UAV network using reinforcement learning, VLC integrated UAV network using PSO, VLC network using TMANN, VLC network using ACO-OFDM, vehicular VLC network, MIMO integrated VLC network, VLC for highly mobile vehicles, VLC network using m-QAM, multiple LED with NOMA using VLC network, and federated learning approach in VLC network.

IV. DISTRIBUTED INTELLIGENT COMPUTING NETWORK

The 6G WCN is described as a distributed intelligent computing network architecture concerning one of the prime targets of, smart connectivity. The performance criteria for future 6G application scenarios will undoubtedly be much more stringent than those for 5G in terms of data rate, latency, spectrum efficiency, reliability, security, and energy consumption. This will affect the processing architecture as well. In other words, the information and communication technology will continue to converge and an enormous amount of data will be processed in distributed systems through a network rather than processed at the end-user devices. This results in challenging latency and data rate requirements. Moreover, device-independent edge networks or the cloud could be used to offload computing power. The system must be able to train and deploy AI (Artificial Intelligence) based innovative approaches across all system nodes to support pervasive distributed intelligence. We anticipate that 6G systems will be specifically designed to develop distributed AI workloads. Distributed Intelligent Computing Network (DICN) requires the latest AI approaches that continuously learn from vast amounts of data produced by intelligent devices.

Conventional centralized AI-based networks require processing of the end device data at the central cloud. On the contrary, DICN operates end devices to learn locally from distributed data sets without sharing the data [68]. Three possible computing infrastructures in DICN of 6G WCN include Mobile Edge Computing (MEC), fog computing, and femto cloud. MEC is an approach that offers services to the edge network and reduces the traffic at the core network. The framework of MEC acts as an aggregation point in the cloud execution deployment or can directly be present at a mobile backhaul for instance small unit gateway.

A distributed computing framework consisting of fog computing-based nodes deployed on any architectural or schematic point that lies in between the terminal device and the cloud is known as fog computing, often referred to as fog networking. The primary services offered by fog computing include storage close to the edge, which lowers traffic congestion, increased security and scalability due to a reduction in the movement of the data across the network, and enhanced spectrum efficiency. The main concept of femtocloud is to get controlled by the controller such that the operation and execution of the cluster are achieved. The primary services offered by the cluster include reduced dependency on the infrastructure and enhanced scalability. FemtoCloud specifically carries out numerous tasks that are transmitted to the control device via computing services [69]. Fig.4 shows the relationship between the various technologies involved in DICN.

A. RELATED WORK

Conventional distributed computing networks do not cooperate with the high-paced advancements of Deep Neural Networks (DNN). Heterogeneous DNN is formulated with the distributed hierarchy such that intelligent computing is supported. The framework is maintained to support heterogeneous neural networks, heterogeneous computing nodes, and heterogeneous system tasks [70]. For the embedded vehicular network, the current cloud computing does not assist prompt service access and data processing as it suffers from cloud center congestion and propagation delays. To enhance the controllability and flexibility of the network, fog computing integrated with a software-defined network is introduced in the vehicular network [71]. The whole architecture is divided into control, network, and fog layers. The computing tasks are distributed based on the fog-based BS with respect to the multiple paths in the fog layer. Linear programming is used to optimize the distribution model by evaluating the delay computations.

In [72], fog computing network resources including storage, power processing, and networking are distributed at multiple sites of the network. These network sites include fog nodes and edge devices such as gateways, access points, and local servers. To decrease the delay of the responses, and to enhance the energy efficiency, the network architecture offloads a portion of the computational tasks to the immediate nearby fog nodes. The network offers an efficient strategy of computational offloading by incorporating centralized optimization, decentralized game theory-based offloading, and matching. Following the strategy of the heterogeneous network, the MapReduce framework is introduced in [73] and [74]. It consists of the shuffle phase, computational phase, and reduced computational phase. The shuffle phase performs the exchange of the intermediate values from the distributed nodes via heterogeneous communication. The computational load is determined by the total sum of the computation node loads. In [75], codes distributed computing has been devised. It involves the combination of

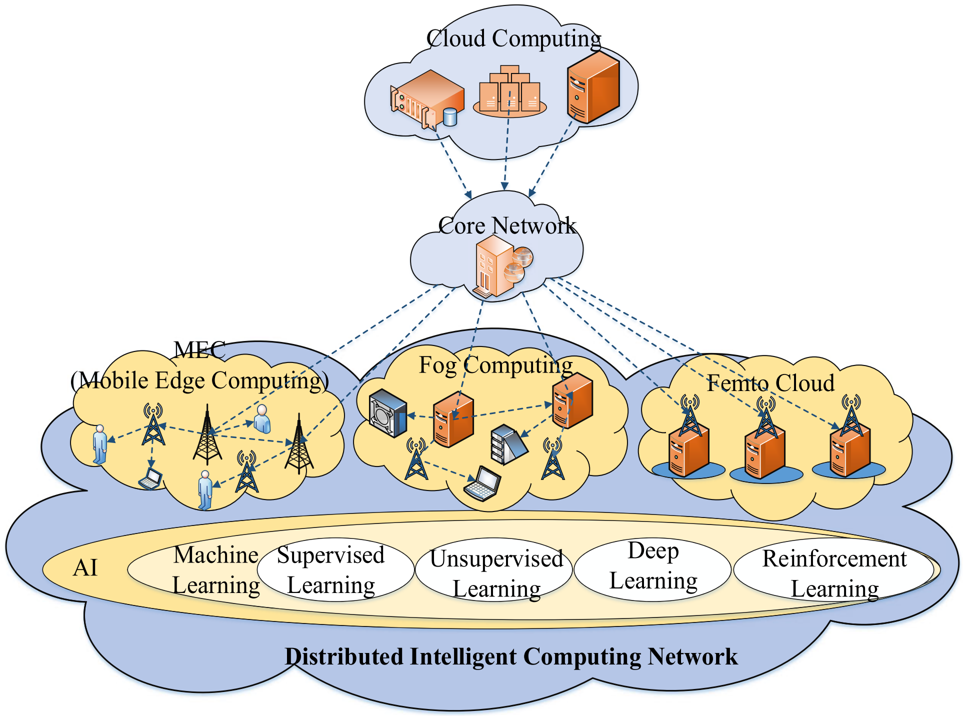

FIGURE 4. Distributed Intelligent Computing Network (DICN).

distributed computing and theoretic techniques of coding. The framework is quite considerate to manage channel noise in a cellular and WiFi network.

In [76], a wireless distributed network is integrated with a decision-making process to optimize the energy harvesting network. The primary feature of the decision-making ability of the distributed network is the decision process of the energy harvesters of the network to execute under the condition of uncertainty. The collaborating nodes and the respective allocation of the tasks are also formulated by utilizing this framework. In [77], a fine-grained elastic computation partitioning scheme has been described in the distributed DNN. The scheme addresses the challenges of resource efficiency, multi-objective optimization, branching mechanisms, and efficiency in the partitioning methods. Two scenarios in collaboration were considered for the evaluation of the performance. The reinforcement learning technique is used for the DNN computation partitioning and DNN branching method at the layer granularity.

For distributed task scheduling in the edge computing network, scheduling competition has been incorporated. The scheduling competition is based on the partially observable stochastic game for allocating computing resources and non-cooperatively scheduling the tasks [78]. In [79], a distributed deep learning mechanism known as the ubiquitous neural network has been developed. The mechanism enhances the efficiency of the communication while maintaining the accuracy of the global neural network in the respective cloud and the local neural network at the edge. However, the accuracy is ameliorated by the algorithm based on knowledge distillation and covariance computation. Task loading -Software Guard Extensions (T-SGX) based scenario has been incorporated in [80] to preserve the confidentiality of the distributed network. Further, the scheme allows the enhancement in the efficiency by the dynamic loading of the object sharing for the task. Batch processing-based coded distributed computing has been incorporated in [81] to issue of latency in the distributed computing network.

The optimization problem is based on the minimization of the task completion time to configure the computation load [81]. A coding theoretic scheme is investigated to handle the straggler-like problem. Maximum distance separable is estimated such that lower bounds and upper bounds of the latency are obtained in closed form. The maximum distance separable depends on the characteristic condition of the channel by the probability of packet erasure [82]. A cascaded coded distributed computing mechanism has been investigated in [83] wherein the output function is estimated a number of times. The methodology is based on the linear relationship between the number of input, and output functions and the number of computing nodes. A distributed approach based on cooperative multi-agent reinforcement learning has been examined in [84] to obtain adaptive and efficient joint communication and computing resource allocation.

A distributed learning and inference scheme allows edge devices to train machine learning models devoid of the exchange of raw data. Thereby, the mechanism offers reduced communication latency and overheads and improves data privacy. However, there are certain open challenges in the execution of distributed intelligent computing networks. These challenges include uncertain wireless communication scenarios, hardware resources, limited wireless resources, dynamic channels and interference, and computational power [85]. Distributed task allocation scheme based on a social concave game with Nash equilibrium mechanism. The implementation utilizes two no-regret learning methodologies such that regret with sublinear growth is followed. The first strategy known as bandit gradient ascent is based on the algorithm of online convex optimization. The second strategy is based on the Lipschitz bandit based on an algorithm of EXP3 multi-armed bandit [86]. A densely deployed multiple service provider mobile edge computing network is analyzed wherein user equipment is exposed by various BSs from multiple service providers to improve the user experience [87]. A cloud and edge computing system with a terminal layer, an edge computing layer, and a cloud data center layer is proposed in [88]. A collaborative computation offloading and resource allocation algorithm that maximizes profit while ensuring that task response time restrictions.

The latest research specifications in the field of DICN include, heterogeneous DNN framework, cloud computing for embedded vehicular network, optimization in DICN using linear programming methodology, MapReduce framework in DICN, codes distributed computing, decision making abilities in DICN, fine grained elastic computation partitioning scheme, multi agent reinforcement learning techniques, techniques for granularity, task scheduling, batch processing, joint communication and computing, and edge computing with cloud data center schemes.

V. MOBILE AND CELL-FREE USER-CENTRIC NETWORKING

The current network architecture of cellular arrangement is created to reduce interference at cell borders between cells. However, it is ideal to communicate at short distances through low path loss with increased redundancy over multiple communications paths to achieve high capacity, ultra-high speed, and high-reliability communications. Cell-free networks, in which base stations are dispersed over a vast region and coordinate coherent joint transmission to provide service to each user, are one possibility for such a spatially distributed topology. This strategy will produce a greater gain and Signal-to-Noise Ratio (SNR) as well as a more constant user experience across diverse locales. However, the implementation calls for complicated processing tasks, close synchronization between base station locations, and the transfer of massive volumes of data.

A cell-free user-centric framework is expected to be a promising architecture for 6G WCN. The strategy of cell-free user-centric communication is based on the networking consideration of network MIMO, massive MIMO, Cloud Radio Access Network (CRAN), virtual MIMO, small cell networks, and Coordinated Multi-Point with Joint Transmission (CoMP-JT). The transmitters in these systems are defined as access points in the cell-free massive MIMO architectural schematic, remote radio heads in antenna systems with distributed network base stations in tiny cells, and CRAN [89]. In a cell-free dispersed network, a single or group of Control Units (CUs) also known as a central processing unit a Base Band Unit (BBU) a CRAN data center, or an edge-cloud processor controls the access points. Additionally, the centralization and capacities of these CUs differ from the conventional controlling units. The terms Distributed Unit (DU) and Centralized Unit (CeU) are used because the New Radio interface specifications for 5G identify a distributed framework for the next-generation NodeB (gNB) connected to DUs through the F1 interface [90]. The general mobile and cell-free user-centric networking is shown in Fig. 5.

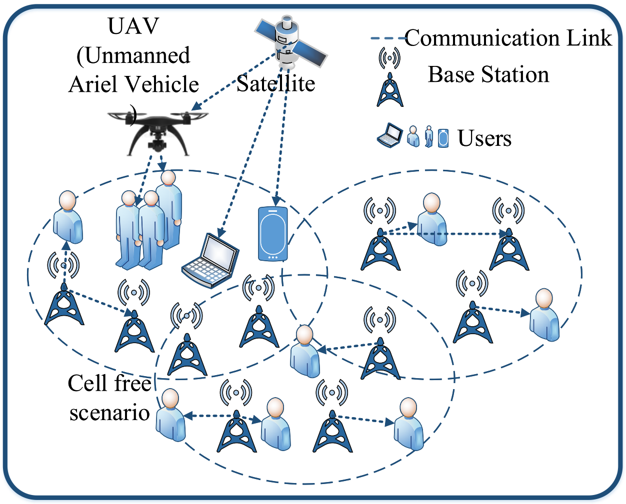

FIGURE 5. Communication network using Cell Free user centric networking technology.

A. RELATED WORK

The cell-free network is considered as the primary architecture for 6G and the upcoming next generation wireless communication network. In [91], an architecture based on interdependent cellular and cell-free networks has been proposed. The architecture integrates the interdependent relationship between the low-layer-based cell-free network and the high-layer-based cellular network. In [92], a cooperative 3D beamformer in 3D space has been formulated. Multiple BS antennas are incorporated for the combined utilization of zero forcing pre-coding technique to attain the beam for the transmitting signal in a particular 3D direction. The technique is configured for the cell-free and cell-based communication network. In [93], Multicarrier division duplex-enabled two-tier terahertz scheme has been executed in a cell-free massive MIMO network. The access links are applied over the sub-6G band while fronthaul links rely on the orthogonal subcarrier set in the THz band. The scheme implements device selection, assignment of resources and subcarrier sets, mixed integer non-convex optimization problems, and the incorporation of clustering of access points.

In [94], simultaneous transmitting and reflecting RIS-assisted cell-free massive MIMO system has been employed to determine the performance of the network. The mechanism utilizes the joint concept of multiple antennas per access point and correlated Rayleigh fading such that the design of the beamforming corresponding to the CSI is obtained by the maximum beamforming ratio. A deep reinforcement learning-based collaborative caching scheme for the vehicular edge network supported by the cell-free massive MIMO system has been implemented in [95]. The roadside units are assisted as roadside access points and macro BS as the central processor unit. A deep Q-network algorithm is used for the optimization to cache the decision as per the request of the user preferences. In [96], the energy efficiency of the RIS-assisted cell-free ultra dense heterogeneous network has been investigated. The joint optimization of the transmission power of BS and the phase shift matrix of RIS are executed. The joint optimization is based on the Riemannian product manifolds. The problem of optimization involves a block coordinate descent algorithm by utilizing the degree of performance loss parameter. In [97], an architecture assisted by the cell-free radio access network involving hierarchical NOMA slicing with mobile edge computing has been evaluated. The scheme addresses certain requirements such as joint allocation of caching resources, computing, and joint communication. Also, a multi-agent deep reinforcement learning algorithm is used to solve the complex coupling strategies.

In [98], distributed cell-free MIMO architecture involves the independent positioning of access points devoid of the central processing unit. The baseband processing is executed in a distributed manner. The applications of the industrial Internet of Things can be assisted by this proposed scheme. Further, a precoding algorithm based on user-centric cooperative clustering is used to maximize the capacity of the user equipment.

In [99], an algorithm based on joint execution of user equipment access point decoding and association in a cell-free massive MIMO user-centric communication network to maximize the mean squared error between the decoded and transmitted information. In [100], cell-free massive MIMO architecture has been proposed using κ-μ shadowed fading model and maximum ratio combining multiuser detection. The scheme provides the optimization of latency, energy efficiency, and reliability. In the case of small packet size, finite block length information theory is utilized to evaluate the relationship between achievable data rate, reliability, latency, and energy efficiency. In [101], the ergodic energy efficiency of mmWave cell-free communication networks has been studied. Semi-closed-form expression using discretization and general closed-form expression are investigated for the cell-free communication network. In [102], a scalable deep learning active user detection scheme is incorporated in channel sparsity for a cell-free massive MIMO communication network. The scalability of the conventional cell-free architecture is improved by the space expansion unit. The whole network is divided into multiple clusters, such that the space expansion unit for the corresponding cluster delivers distributed active user detection using 1D convolutional neural networks.

From the related work, the areas of research in the field of mobile and cell-free user-centric network are summarized as: It includes integrated architecture between low layer based cell free network and high layer based cellular network, cooperative 3D beamformer in a cell free network, RIS assisted cell free network, vehicular edge network services by cell free massive MIMO system, RIS assisted cell free network, hierarchical NOMA slicing in a cell free network, distributed cell free MIMO network, mmWave cell free communication network, and scalable deep learning cell free massive MIMO communication network.

VI. SAFI (SATELLITE FIDELITY)

The 6G WCN is expected to converge the terrestrial and non-terrestrial communication network in order to provide seamless connectivity, coverage, and heterogeneous services. The SaFi is an integrated satellite-terrestrial communication network that unifies the benefits of both terrestrial and satellite WCN including worldwide broadband connectivity for all sorts of users and has attracted a lot of interest from both academia and business. In conventional satellite communication, the communication links were unstable due to attenuation, longer distance losses, and obstacles leading to inefficient communication networks. To overcome such an effect, SaFi is introduced wherein SaFi routers are used as a relay connection such that the overall performance of the SaFi WCN increases drastically. Each SaFi router can be a UAV, VLC router, or relay to address the service to the users. The SaFi router receives the signal from the SaFi source module. In the case of remote communication scenarios, the SaFi source module can directly address the users. The basic architecture of SaFi is depicted in Fig. 6.

A. RELATED WORK

The 6G communication network extends the connectivity to both remote and rural areas. In [103], the integration of the satellite communication network with the terrestrial communication network to provide seamless connectivity with improved coverage. The hybrid network of the two consists of several challenges such as mobility, channel fading, transmission delay, and coverage. In [104], it is given that long propagation delays, high dynamics, complex communication link conditions, and network topology are some of the other challenges in the satellite and terrestrial communication network. In [105], the terrestrial network makes use of the higher frequency band in the integrated satellite-terrestrial communication network. Cognitive radio and NOMA are introduced to enhance the spectrum-sharing

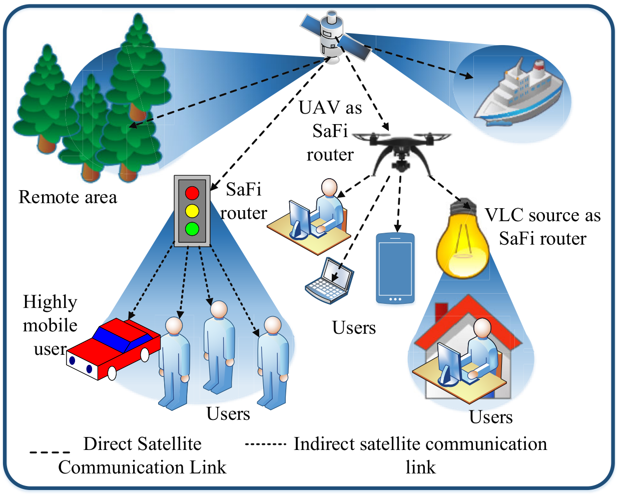

FIGURE 6. Communication network using SAFI (Satellite Fidelity) technology.

performance in the integrated satellite-terrestrial communication network. The scheme assists multiple terminals to approach busy and idle spectrum to obtain higher spectrum efficiency.

In [106], joint allocation of resources is formulated for the integrated ground and satellite communication network. Network slicing is used for reserving and selecting particular resources for the latest incoming request of the user in the integrated satellite-terrestrial communication network. Machine learning technique is used to select the resources such that the pattern of the requests of the user is evaluated. Communicating point-to-point links in the satellite aerial network is studied in [107]. The point-to-point communicating links are classified into three types, which include high altitude platform to high altitude platform links, satellite-to-satellite links at the same layer, and satellite-to-satellite links at different layers. The spatial network consists of possible connecting links such as free space optics and radio frequency links.

In [108], antenna array for air, space, and ground networking and communication is studied. Based on the seamless connectivity for various communication scenarios such as remote and rural areas, varied high-speed railways, cloud radio access network, and decoupling of user/control plane integrated space ground cloud railway network has been proposed. The network consists of space-ground layers consisting of Low Earth Orbit (LEO) satellite baseband units operated by the Geostationary Earth Orbit (GEO) satellites. The communicating link between the GEO satellites and terrestrial trains improves the mobility support of the integrated air, space, and ground network [109].

In [110], the Rate Splitting Multiple Access (RSMA) scheme based on the technique of deep reinforcement learning for power allocation in the LEO satellite network has been investigated. Proximal Policy Optimization (PPO) is used to efficiently allocate power to the private and common streams. The strategy of the optimization policy is based on the maximization of the sum rate of the communication network devoid of prior information. Random Access Protocol (RAP) in the Space Air Ground Integrated Networks (SAGINs) has been proposed in [111]. Virtual Deadline Indicator (VDI) is used to identify the layer for random access to the Machine Type Communication Device (MTCD). MTCD offers random to the specific layer of the SAGIN by analyzing the remaining deadline differences between the traffic and that of the VDI. Therefore, minimizing the deadline rate optimum shift of the VDI is obtained.

In [112], hybrid FSO/RF high altitude platform-based SAGIN has been explored under atmospheric and weather conditions. RIS-based mirror array is attached to the UAV to redirect the signals from the high-altitude platform. The channel model involves hovering pointing errors and atmospheric turbulences. Intelligent Coordinated Scheduling Algorithm (ICSA) has been described in [113] to improve the quality of service by considering transmission reliability and queuing latency. The ICSA is based on particle swarm optimization such as optimal completion rate and total priority is achieved corresponding to the different number of task scheduling. RIS-based satellite communication system consisting of RIS, terrestrial receiver, satellite, and a warden is studied in [114].

The terminal at the ground receives the signal from the satellite and redirects from the RIS. The warden overhears the same signal from the satellite and the redirected signal. The primary parameter is to maximize the convert rate such that the quality of the signal is improved while maintaining the constraint of onboard resources. Artificial intelligence-based cloud edge device framework for the SAGIN-assisted Power Internet of Things (PIoT) is studied in [115]. The proposed SAGIN PIoT provides a solution for computing services, improved quality of service and seamless connectivity. Network dynamics and multi-dimensional resource heterogeneity are the services offered by this proposed scheme. Queue-aware Deep Actor-Critic (Q-DAC) enables optimization of the decision-making based on the task offloading under the condition of improper information. In [116], Software Defined Network (SDN) enabled SAGIN architecture has been proposed. It follows the strategy of multi-controller deployment. The network consists of two layers of the SDN control plane. The primary controller layer is on the ground network and the secondary controller layer is on the space-based network. The corresponding data plane consists of a ground-based network, air air-based network, and space space-based network. A clustering algorithm using the K-means strategy is used to determine the position of controllers, switch nodes, and the number of controllers. With server-less edge learning architectures for 6G satellite swarm networks, this research expands the capabilities of traditional cloud platforms and offers a novel distributed training design from a networking standpoint. Multi-agent deep reinforcement learning is effectively fulfilled for the service level agreement, which dynamically orchestrates communications, compute functions, and resources across diverse physical units. For end-to-end connection, communications, and learning performance, novel ecosystem enhancements are explored, such as anti-jamming transmissions, ultra-broadband access, and resilient networking [117].

The related research work in the fields of SAFI include integrated networks such as SAGINs, SAGINs with PIoT, SAGINs with RIS based network, SAGINs with SDN, cognitive radio and NOMA in the field of SAFI, joint resource allocations, point to point link communication, antenna array system for SAFI, mobility management in SAFI network, RSMA schemes, VDI schemes for MTCD, FSO/RF platforms for SAGINs, intelligent communication environments such as multi agent reinforcement learning, task offloading schemes in SAGINs.

VII. TERAHERTZ SENSING AND COMMUNICATION

The research on Terahertz Communication (THzCom) has advanced significantly in recent years as a result of recent developments in THz hardware technologies, with the main areas such as channel measurement and modeling, experimental findings, device technologies, and standardization. The spectrum management in the THz band offers huge bandwidth and therefore can be utilized by THz-based beamforming and THz band antennas for the processing of THz signals with smaller wavelengths. Thus, the collaborative integration of different 6G enabled technologies is expected to satisfy the QoS targets by incorporating THzCom. The peak data rate required by 6G networks is expected to reach one terabit per second (Tb/s), which is 100 times faster than that of 5G. This is far faster than what the most advanced wireless systems can now provide. The great potential provided by the massively accessible bandwidths of the THz band must be investigated to satisfy this demand.

Although the vast availability of spectrum above 300 GHz in the THz regime, channels at multiples of 2.16 GHz are introduced for contiguous bandwidths of a few tens of GHz that are aimed at 100 Gbps. Precisely, an 8-PSK modulation scheme with an approximate 50 GHz of bandwidth can attain data speeds of around 100 Gbps. To achieve larger data speeds, higher-order modulation schemes are required to be employed, for instance, 64-Quadrature Amplitude Modulation (QAM) can deliver data rates greater than 200 Gbps for an approximate bandwidth of 50 GHz. Channels made up of several tens of GHz of continuous spectrum can be freely assigned for active services, with high order modulation and advanced coding algorithms, which will be necessary to meet the capacity requirements and achieve high data rates. Utilizing an extraordinarily large bandwidth characteristic allows for high-resolution sensing imaging and high-precision positioning of a network, and it also offers a chance to broaden the use of THz communication.

The molecule absorption varies greatly within the THz band at relatively long transmission distances, optimized spectrum allocation is required to be formulated. Modulation-based spectrum allocation algorithms are the latest research direction to incorporate the efficient use of bandwidths present in the THzCom band. Given the high bandwidth found at the THz band, Inter Band Interference (IBI) can be avoided by properly spacing out the sub-bands. As a result, THzCom systems using sub-bands with adequate spacing can reach substantially higher data rates than those predicted by cutting-edge mmWave systems. Because of this, to profit from multi-band-based methods, the impact of IBI must be properly anticipated, examined, and then suppressed or removed [118], [119]. The description of the THz band is shown in Fig. 7.

A. RELATED WORK

Terahertz band exposes the perspective as one of the significant technologies of the 6G to justify the upcoming demands. It incorporates four primary advantages. The first is the contiguous bandwidth from 10s to 100s of GHz. The second advantage is the incorporation of thousands of sub-millimeter-long antennas. The third is the picosecond level symbol duration. The fourth advantage is the deftness of integration with standardized and regulated spectrum. The Terahertz technology is expected to create a boom in the case scenarios of Tbps WLAN system (Tera-WiFi), Tbps Internet of Things (Tera-IoT), Tbps Integrated Access Backhaul (Tera-IAB), Terahertz Space Communication (Tera-SpaceCom) [120].

The technological evolution of terahertz allows high carrier frequency, therefore creating a higher integration level and thus permitting the smaller antenna size. Approximately more than 10,000 antennas can be incorporated into a single THz-based base station to deliver multiple hundreds of narrow beams. Therefore, counteracts the massive propagation losses, thereby achieving elevated traffic capacity. Thus, applications such as ultra-massive machine communications including IoE (Internet of Everything) can be addressed with the feature of massive connectivity [121]. As far as channel modeling approaches in THz technology are concerned, the issue of measurement of data insufficiency has been developed substantially. The channel sounding at THz. In a variety of contexts, including indoor communication, intelligent vehicle communication, chip-to-chip communication, and smart rail mobility, there have undoubtedly been significant attempts made to perform channel sounding at THz [122].

In heterogeneous scenarios, THz technology is expected to be implemented as an extension of mmWave systems. The transition to the THz system is anticipated to offer larger bandwidths, larger array sizes, and smaller footprints. However, due to higher frequency, certain challenges are evolving such as synchronization problems, hardware problems, and large antenna arrays. Besides, advanced multiplexing schemes are required to be formulated as Orthogonal Frequency Division Multiplexing (OFDM) waveform is not appropriate for wideband for THz technology due to high Peak-to-Average Power Ratio (PAPR). Another important concern is the localization of the base station

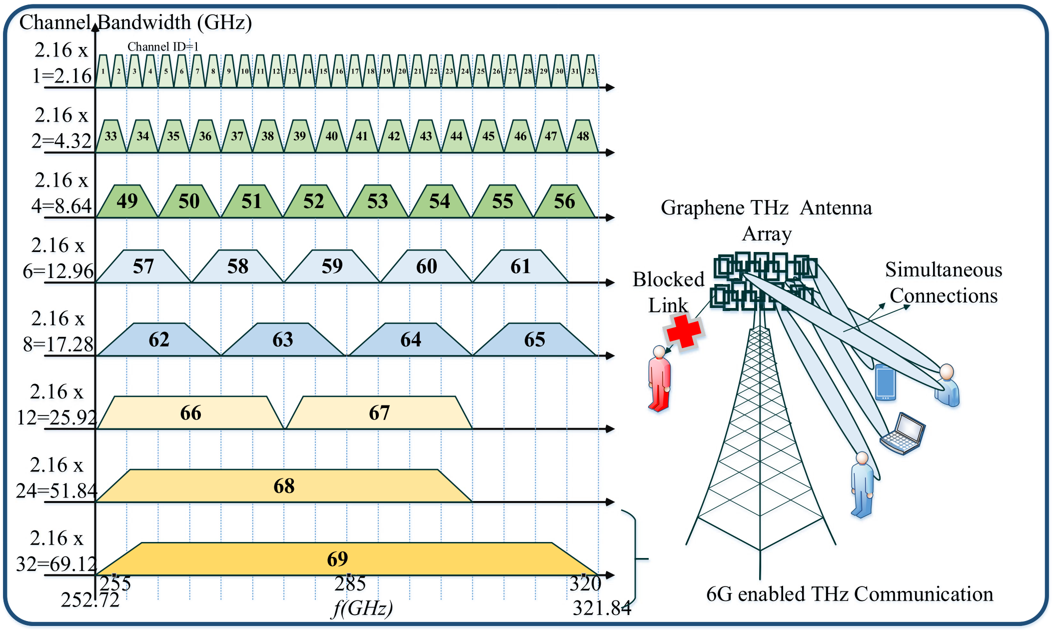

FIGURE 7. Terahertz sensing and communication technology.

in THz technology, as the path loss is high for larger distances [123].

In [124], cooperative network localization accuracy in large-scale WCN is investigated. It provides position information routing interpretation and offers a random walk-inspired method for evaluating the Equivalent Fisher Information Matrix (EFIM). In [125], unified factor graph-based architecture for passive localization has been described by using the time of arrival data. Based on the linearization of range measurements, the corresponding Gaussian message-passing technique is used to determine the target location and build a factor graph model. The framework for analyzing cooperative network synchronization's performance is developed in [126]. To represent the features of a random walk over the network, notions of relative Cooperative Dilution Intensity (CDI) to characterize the interaction between agents. In [127], a framework for widely used, highly accurate indoor localization that is based on factor graphs, wherein range and fingerprinting are effectively combined to provide an effective accuracy with respect to deployment cost tradeoff.

For the nano-on-chip antennas, the use of THz technology can prove beneficial in terms of ultra-high-speed links [128]. Therefore, specific scenario-based channel models are required to be formulated with the incorporation of THz technology. Irrespective of several advantageous features of THz band communication, there are certain challenging features associated with it [129]. Beam management in the THz band is one of the issues in the 6G WCN due to the propagation peculiarities of the sub mmWave [130].

For the upcoming communication network, specified devices are required to be formulated concerning the THz band is concerned. The project Traceability for Electrical Measurements at Millimetre-Wave and Terahertz Frequencies for Communications and Electronics Technologies (TEMMT) has evolved as the measurement system for 330-500GHz, 500-750GHz, and 11-15THz band [131]. However, using the quarter-wave calibration technique, measurement traceability has been developed. Assembling, defining, and testing appropriate standards of reference has been given in [132], comprising in-depth electrical and dimensional evaluations. The channel measurements at 201-209GHz for indoor scenarios are analyzed in [133]. Near-field THz channel estimation [134], using non-linear phase property of spherical waves to assess range of the near-field [135], [136], near-field THz sensing [137], wavefront distortions in ultra-broadband THz links, mobility management in THz band, interference modeling [138], efficient mechanisms to generate wavefronts [139], energy efficiency in the THz band are the recent open challenges that require immense attention for the incorporation of the THz band in 6G WCN.

The research specifications in the field of terahertz technology include scenarios of Tera-WiFi, Tera Space-Com, Tera IoT, Tera-IAB, massive connectivity, channel modelling using terahertz technology, synchronization in terahertz technology, ultra massive machine communications including IoE, intelligent vehicle communication, chip to chip communications, smart rail mobility, advanced multiplexing schemes, TEMMT, wavefront distortions in ultra-broadband THz links, interference modeling, cooperative communication using terahertz band, CDI, advanced antenna array systems such as nano on chip antennas, beam management, near field THz channel estimations, THz sensing, interference modeling in THz technology.

VIII. ULTRA HIGH-SPEED CHANNEL CODING TECHNOLOGY

The concept of channel coding is the primary requirement of WCN to correct transmission errors and improve reliability. The new KPIs including very high throughput, low power consumption, availability, etc., necessitate improvements to contemporary channel coding schemes like Turbo, Low Density Parity Check (LDPC), and polar codes. Spatially Coupled Protograph (SCP) LDPC-coded, channel aware Coding, and transform domain precoding are the latest possible channel coding techniques in 6G WCN.

In the transform domain precoding technique offers maximization of the spectrum efficiency with restricted feedback overhead. Transform domain precoding is considered a realistic solution as it involves factors such as frequency domain windowing, hybrid beamforming, and power allocation [140]. Protograph LDPC codes are a kind of structured LDPC codes that have been developed to reduce complexity [141]. Numerous protograph-based extrinsic information transfer techniques have been evaluated to simplify the design and analysis of Photograph-LDPC-coded systems. The current research projects in terms of LDPC codes are evolving with the incorporation of next generation WCN. The SCP-LDPC codes are expected to possess great potential for a suitable error correction coding scheme. The technique provides various advantages in terms of performance and implementation. The general scenario of ultra-high-speed coding is shown in Fig. 8.

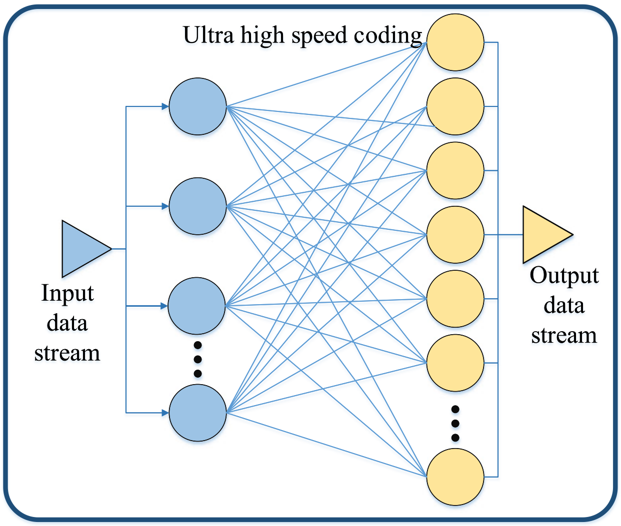

FIGURE 8. **Communication network using ultra high speed channel coding technology.**

A. RELATED WORK

Joint source-channel coding is employed for 6G wireless communication to provide ultra-low latency and improved energy efficiency. There are two schemes of joint source-channel coding which include double polar codes and double low-density parity check codes [142]. Sparse Code Multiple Access (SCMA) enables massive connectivity for the 6G WCN assisted with the NOMA scheme. The architecture is based on the ultra dense network, fiber-based VLC, and NOMA scheme. The framework involves the connection between the wireless access link and the optical front haul [143]. Two-channel coding structure assisted NOMA is adapted for 6G WCN to provide lower error rates and higher data rates. These structures include polar convolutional parallel code and polar convolutional serial code [144]. Sliding window network coding in the mmWave-based communication network is adapted in 6G WCN to provide ultra-reliability and low latency. The fixed sliding window Random Linear Network Coding (RLNC) enables lower latency with mmWave backhaul network [145]. In [146], protograph-coded bit interleaved coded modulation with iterative detection and decoding has been investigated for 6G WCN by using NAND flash memory irregular mapping. Protograph-based Extrinsic Information Transfer algorithm enables the analysis of linear minimum distance growth property and decoding thresholds. Based on its gain characteristics read voltage optimization technique is incorporated to obtain the optimal voltage levels, thereby decreasing the decoding thresholds. In [147], a separated random linear network coding technique assisted with the coded packet and coding coefficient using cooperative control frames is investigated. The technique enhances the performance of the retransmission by decreasing the overheads during retransmission. Convolutional autoencoder based on the physical layer network coding for a two-way relay channel is evaluated in [148]. The deep learning technique is used for constellation demapping and mapping of symbols corresponding to each node, thereby enhancing the performance of the bit error rate for higher-order modulation. Protograph Low-Density Parity-Check (PLDPC) based on Multi-Pulse Position Modulation (MPPM) using a Generalized Space Shift Keying (GSSK) modulation scheme is adopted in [149].

Code Division Orthogonal Frequency Division Multiplexing technique for 6G Machine Type Communication to provide joint sensing and communication and therefore, enhance spectrum efficiency [150]. The scheme provides an increase in radar sensing accuracy and reduces interference using successive interference cancelation compatible with OFDM WCN. Cutting Edge Opportunistic Network Coding Schemes (CEONCS) are used to improve the performance of the network including a reduction in latency and an increase in data rates. A comprehensive survey on network coding schemes is given [151]. In [152], designing codes based on a learning framework for channels having active feedback is presented. The analytical coding scheme is devised based on the latent features of the learned codes. It has been analyzed that a deep learning framework is a significant tool for deducing analytical communication schemes for various communication environments.

The latest research provisions in the field of ultra high-speed channel coding technology includes, joint source channel coding, SCMA two-channel coding structure using NOMA, parallel code and polar convolutional serial code, RLNC, protograph-coded bit interleaved coded modulation, random linear network coding, physical layer network coding, PLDPC, CEONCS, and design codes.

IX. NEW WAVEFORM MULTIPLE ACCESS

Adequate waveform design is essential for the smooth operation of wireless networks. While OFDM is still a top contender for 6G waveforms, other application-specific waveforms or scalable waveforms that are unified need to be investigated, for instance, joint communications and radar sensing. The various spectrum ranges, device properties (such as phase noise and power efficiency), and system properties (such as signal bandwidth) must also be considered. For high mobility scenarios with significant Doppler dispersion, Orthogonal Time Frequency Space Modulation (OTFS) is one of the new waveforms being considered. Additionally, single-carrier waveforms might become increasingly prevalent to meet the demands of power efficiency in future devices. It might be advantageous to loosen the orthogonality criterion for wireless channels, as is accomplished for NOMA.

When compared to waveforms from earlier generations, OTFS has a unique characteristic in that information-bearing signals are put in the delay Doppler domain instead of their typical location in the time-frequency domain. OFDM, a very successful and widely used waveform, has several drawbacks that are overcome by OTFS. One of the major weaknesses of OFDM is its susceptibility to frequency offset and Doppler, which OTFS is believed to be more resistant to. The future generation of wireless communication technologies must enable both higher frequency ranges of operation and more mobility. However, OTFS continues to have a similar implementation complexity as that of OFDM [153]. The overall scenario of the new waveform multiple access scheme in 6G is shown in Fig. 9.

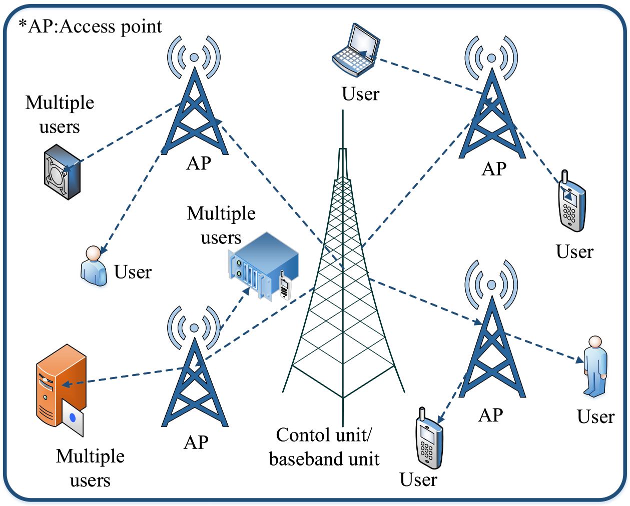

FIGURE 9. Communication network using new waveform multiple access technology.

X. RELATED WORK

In [154], RSMA (Rate Splitting Multiple Access) assisted with integrated radar sensing and communication architecture for 6G WCN is addressed. The architecture supports simultaneous communication of probe detection and downlink users to a mobile target. The scheme increases the Minimum Fairness Rate (MFR) and decreases the Cramer Rao Bound (CRB) corresponding to the power constraint per antenna. The OTFS (Orthogonal Time Frequency Space) waveform design for 6G is given in [155]. The OTFS modulation consists of specific features contrary to the conventional generation waveforms. The signal with information is positioned in the delay Doppler domain contrary to the conventional location of the information signals in the time-frequency domain. The OTFS is more robust to Doppler and frequency offset and supports highly mobile users. For multiple-user communication networks, OFDM assisted with Index Modulation based on the NOMA technique is presented in [156]. The scheme optimizes the subcarrier activation ratio and power allocation factor, such that resources are available to share services with the users more efficiently. In [157], code domain NOMA, power domain NOMA, and other related NOMA multiplexing schemes are addressed. Universal Filtered Multi-Carrier (UFMC), Filter Bank Multi-Carrier (FBMC), and Filtered Orthogonal Frequency Division Multiplexing (FOFDM) are some other multi-carrier waveforms in 5G WCN.

NOMA combined with OFDMA and multi-carrier Code Division Multiple Access (CDMA) is presented in [158]. The approach is devoid of the power imbalance requirements concerning signals of the user such that all users are provided similar performance and data rates. In [159], the classification of users is performed based on the dynamic user grouping method such that the performance comparison is achieved between power domain NOMA and NOMA 2000 assisted with the Rayleigh fading channel. The power domain NOMA exhibits high performance with a low Bit Error Rate (BER) in both the Rayleigh fading communication scenario and the user grouping scenario.

In [160], Doppler Division Multiple Access (DDMA) with Range-Division Multiple Access (RDMA) is used to realize the functionality of MIMO frequency-modulated continuous- wave radars. The scheme allows simultaneous transmission from a multi-transmitting antenna. A competitive precoding technique based on the time reversal phenomenon for devices with low complexity dependent on the ultra-wideband waveforms has been proposed in [161]. The scheme targets the reduction of the interference level while balancing the complexity of the processing from the transmitter side. Orthogonal Time Frequency Code Space Modulated Waveform (OTFCSMW) for Vehicle to Everything (V2X) is presented in [162]. The waveform enables simultaneous positioning and random access realization. The approach provides the spreading gain and identification of the terminal based on the combinations of the orthogonal spreading.

In [163], inter-carrier interference is managed by the rate-splitting multiple access scheme in the OFDM waveform. It incorporates the estimation of minimum mean square error to determine the optimal subcarrier. Two case studies of waveforms are formulated in [164]. the first case involves performance analysis of the block error rate for the two users using power-balanced NOMA. The second case consists of an OFDM joint radar communication scheme based on the mean square error estimation of the channel. Space-Division Multiple Access (SDMA) based time modulated array is formulated in [165] using multibeam characteristics. The scheme allows maximization of the signal power at the receiver end by the harmonic selection method. The scheme provides enhanced spectral efficiency for the traditional single radio frequency chain system.

Spectrum and Energy Efficient Multiple Access (SEEMA) transmission protocol based on the multiple access channels in wireless sensor networks has been presented in [166]. The sensor makes use of the common shaping waveform for the transmission and superposition of the analog transmitter signal received at the fusion center. The scheme provides the advantage of spectrum and energy efficiency. Optical Pulse Division Multiplexing (OPDM) is used to enhance the capacity of the receiver end by utilizing the Signal to Noise Ratio enhancement technique under the limited bandwidth of the optical modulator [167]. The scheme provides improved spectral efficiency and modulation order.

In [168], frequency selective fading channels downlink MIMO- Sparse Code Multiple Access (SCMA) system. The complexity of optimal detection grows exponentially with respect to the product of the number of users, channel length, and antenna. In order to facilitate unified non-orthogonal waveform (uNOW) signaling over multipath channels, computationally effective iterative receivers from a unified variational inference context have been formulated. For equalization, the parametric message-passing methods are generated by using the Bethe approximation and Mean Field (MF) on top of the built multi-layer factor graph [169]. NOMA with Faster Than Nyquist (FTN) signaling assistance is developed, and its feasible rate is measured in the presence of the various random link delays of the users. Using link delays results in an increase in the Signal-to-Interference-plus-Noise Ratio (SINR), and sending the data symbols at FTN rates can raise the DoF [170]. In [171], two-dimensional FTN signaling, based on Mazo's FTN signaling concept to pulse trains modulating a group of subcarriers. Although the subchannels are not orthogonal, the signal processing is comparable to that of OFDM transmission. The technique achieves the isolated-pulse error performance in as that of half the bandwidth of conventional OFDM, despite non-orthogonal pulses and subcarriers.

In [172], multi-carrier FTN signaling across frequency-selective fading channels, a low-complexity Parametric Bilinear Generalized Approximate Message Passing (PBiGAMP)-based receiver is envisaged. In order to address the intrinsic ill-conditioning issue with MFTN signaling, we develop a frequency-domain received signal model that is segment-based and takes the form of a block circulant linear transition matrix. This can be efficiently computed through the use of a two-dimensional fast Fourier transform. The joint channel equalization and estimation approach for Spectrally Efficient Frequency Division Multiplexing relying on Index Modulation (SEFDM-IM) signaling across frequency-selective fading channels has been investigated in [173]. In [174], combined user activity data detection and tracking method based on the factor graph architecture. It makes use of a complex combination of hybrid message forwarding and Expectation Maximization (EM) algorithms.

The latest research directions in the field of new waveform multiple access schemes from the above mentioned related work is summarized as: it includes RSMA, OTFS, OFDM assisted index modulation, factors of subcarrier activation ratio and power allocation factor, UFMC, FOFDM, DDMA, RDMA, OTFCSMW, SEEMA, OPDM, SCMA, SEFDM-IM, and EM algorithms.

XI. ULTRA MASSIVE MIMO

The introduction of massive MIMO in 5G addressed various requirements in terms of data rates, huge density of users, and availability. With the rise of using shorter wavelengths and higher frequencies, it is now possible to place more antennas in a limited space to produce more focused beams. Additionally, this is required to make up for increased losses at high frequencies. To address the propagation losses in 6G WCN, ultra-massive MIMO antenna systems have been proposed for high attenuation at THz communication. These massive antenna arrays are entirely digital beamformers are associated with huge power and are comparatively more costly. Group of Sub Arrays (GoSA) is the latest technique of hybrid beamformers for wideband ultra massive MIMO structures to operate in the low THz band. To enhance the spectrum efficiency, a joint ultra massive MIMO radar communication system has been evolved. It involves the communication between the base station and the user with multiple antenna user equipment, such that the base station tracks the target of the radar using multiple beams by directing toward the target and the receiver [175]. The communication scenario for ultra-massive MIMO is shown in Fig. 10.

A. RELATED WORK

The technology of ultra-massive MIMO provides specific characteristics of the channel such that channel modeling and channel measurements are examined. 3D Non-stationary geometry-based stochastic scheme for ultra-massive MIMO system has been investigated [176]. The properties of the channel model and channel measurements for the scheme

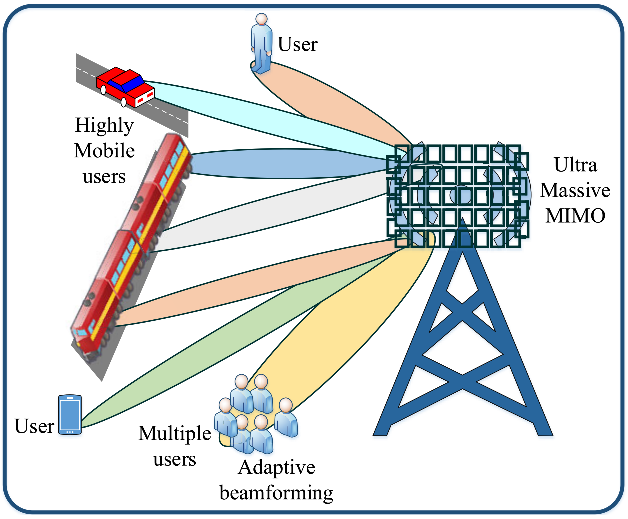

FIGURE 10. Communication network using ultra massive MIMO technology.

include angular Power Spectral Density (PSD), delay PSD, Degrees of Freedom (DoF), singular value spread, spatial cross-correlation function, and normalized correlation matrix of the user. The framework of hybrid analog and digital beamforming structure to provide signal processing in the ultra massive MIMO system. The hybrid system consists of a power combine or divider and a phase shifter to investigate the analog signal processing of the network [177]. Beamformers in the joint ultra massive MIMO-based radar communication system have been inspected in [178] to optimize the spectrum such that the trade-off between desired beamformers of radar and beamformers of unconstrained communication is balanced. In the scheme, BS aids as a multi-antenna user equipment at the receiver end and the radar generates multiple beams in the direction of the target and the receiver. Channel measurements at 5.3 GHz are investigated for the ultra massive MIMO aided with various configurations of antenna array under different scenarios. The configuration of the antenna array consists of a distributed uniform linear array and a uniform linear array. The communication scenario for the measurement consists of a single-user fixed-to-mobile scenario, a single-user fixed-to-fixed scenario, and a multi-user fixed-to-fixed communication scenario [179].

The channel model based on 3D space-time frequency non-stationary analysis is described for ultra massive MIMO 6G THz WCN aided for long traveling paths. As a result of frequency-dependent diffuse scattering, a unique characteristic of THz channels that sets them apart from mmWave channels, the relative delays and angles of beams inside a cluster will change with time in the frequency domain. Next, using the Equal Area Method (EAM) to determine discrete angles, a comparable simulation model is suggested in [180]. The representation of the Spatial Modulation Assisted Vertical Bell Labs Space-Time (SMVBLAST) network is examined in [181] with an emphasis on ultra-massive antenna configurations over generalized fading channels. Specifically, by taking advantage of the connection between Hamming Distance (HD) and Pairwise Error Probability (PEP), the simplified Average Bit Error Probability (ABEP) low bound of the Rayleigh fading channel is deduced for generalized m-Phase Shift Keying (m-PSK) modulation.

In [182], the Hybrid Spherical- and Planar-wave channel Model (HSPM) is investigated. The scheme demonstrates its efficiency and accuracy by utilizing the Spherical-Wave channel Model (SWM) across subarrays and the Planar-Wave channel Model (PWM) within sub-arrays. A two-phase HSPM channel estimation technique is also examined. To complete channel estimation, the remaining channel parameters' geometric relationships between reference sub-arrays are used in the second phase of design, which involves building a Deep Convolutional Neural Network (DCNN) to estimate the parameters of the reference sub-arrays. In [183], the optimal maximum likelihood ABEP constraint for an ultra-massive MIMO system using generalized Amplitude Phase Modulation (APM) has been devised. A holographic radio implementation using a meta-surface-based antenna known as a Reconfigurable Holographic Surface (RHS) is implemented in [184]. RHS can create holographic beamforming over the spatially quasi-continuous apertures by integrating low-power, tightly packed, and tunable metamaterial elements. Based on the hardware design and full-wave analyses of RHSs, a holographic beamforming optimization technique is developed for beam pattern gain maximization to ameliorate the functionalities of the RHS as an antenna array for achieving ultra-massive MIMO. An overview of beamforming for THz ultra massive MIMO systems is presented in [185].

The beamforming technique in the THz band is presented, which includes beam training, summarizing codebook design, and beam training protocol. To stimulate research on THz communications, a MIMO system with a precise stochastic MATLAB simulator for statistical THz channels is formulated in [186]. To overcome the constraint in THz communications lengths, ultra-massive MIMO antenna designs are devised as critical infrastructure enablers. Three low-complexity estimators as Partitioned Sub-array Cross-correlation Combining (PSCC), Partitioned Sub-array Auto-correlation Combining (PSAC), and power iteration max correlation successive convex approximation are devised in [187] to overcome the challenges of complexity. In [188], an existing geometry-based stochastic model is transformed to propose a beam domain channel model for 6G ultra-massive MIMO wireless communication systems.

The current research trends in the technology of ultra massive MIMO includes 3D non-stationary geometry based stochastic scheme, joint ultra massive MIMO based radar communication system, channel measurements for ultra massive MIMO, SMVBLAST, m-PSK modulation, HSPM, DCNN, beamforming for THz ultra massive MIMO and geometry based stochastic model for 6G ultra massive MIMO.

XII. AI (ARTIFICIAL INTELLIGENCE)

Currently, several WCN applications already use Artificial Intelligence (AI) and Machine Learning (ML) for self-management and control functions. These comprise the preliminary network planning stage, network control, and optimization such as traffic, dynamic spectrum, and adaptive and predictive resource allocation. The traditional methods of data processing are not applicable for the 6G communication network as the network operators are limited with processing time and processing space constraints. The data for the 6G communication involve high dimensionality, complexity, heterogeneity, and unpredictability. Therefore, computational intelligence is the necessary requirement for the upcoming 6G communication network to analyze big data. The computational intelligence provides the platform to investigate and identify underlying correlations and patterns such that specific tasks can be comprehended. In the communication network, the network operator receives huge unstructured or structured and unprocessed data. The received data is converted in the suitable form using various computational analysis tools. The primary tools are in the form of Artificial Intelligence. The AI provides the solution by leveraging massive data and estimates the predictions based on the datasets.

It becomes exceedingly challenging to manage wireless networks that increase in size and complexity since new components and technologies must be integrated in order to take advantage of advancements in 6G technologies. Such vast and intricate networks generate far too much data, both in terms of volume and complexity. Artificial intelligence is helpful in analytics because it can produce smart recommendations, forecasts and extracts meaningful information from unprocessed data. In order to handle jobs instead of using the brute force method, AI is a collective virtue that includes resource efficiency, optimized energy, better security and privacy, optimal scalability, data mining algorithm and intelligent smart contracts. Various challenges such as route management, security, topology control, transmission network privacy have been resolved by the recent advances of AI. Wireless communication networks rely on associated intelligence and learning capabilities of the model to provide the accurate analysis. In general, AI in 6G seeks to increase machine intelligence through guided learning or rule compliance to carry out intellectually demanding tasks that typically call for human assistance, such as planning, classification, scheduling, clustering, regression, detection, identification, and segmentation.

Future WCNs are predicted to include AI in every aspect of the system. This might entail a physical layer design that can be optimized end-to-end rather than just for each radio transmission chain component. It also takes into account the unique propagation channel and environmental factors. AI and machine learning will be crucial for the deployment and operation of 6G WCN because of the complexity growth in terms of device types, spectrum ranges, and flexible network topologies. This will enable system performance to be optimized in terms of maximizing user experience, cost-effectiveness, and energy usage. The comparison of performance parameters between 5G and 6G is depicted in Table 1.

TABLE 1. Comparison of expected performance enhancements from 5G to 6G.

Performance Metrics	5G	6G
Peak data rate (Gbps)	10	100 to 1000
Energy Efficiency	1x	5x to 100x
User experienced data rate (Gbps)	0.1	1 to 10
Connection density (in devices/km^2)	10^6	10^7 to 10^8
Ultra low Latency (in ms)	1	0.1
Reliability	99.999%	99.99999%
Spectral efficiency	1x	2x
Mobility management	1x	3x
Positioning (in cm)	20 to 100 in 2D	1 in 3D

A. RELATED WORK

In [189], model-driven methods are executed for digital domain cancellation, which has shown to be inadequate to meet the increasing complexity of future communication systems. To get over the complexity barriers of conventional techniques, machine learning techniques have been created for digital Self-Interference Cancellation (SIC). The effectiveness of diverse machine learning techniques is evaluated by employing distinct performance indicators, including the attained standard deviation, memory usage, training overhead, and computational complexity. Multi-Agent Reinforcement Learning with Emergent Communication (EC-MARL) approach is used to solve high dimensional continuous control problems with partially observable states. The agents are incorporated to solve complex tasks by developing an emergent communication protocol for the 6G WCN. It provides the ability to make autonomous decisions to solve challenging problems like flying base station network planning, smart city applications, robot navigation, and autonomous driving [190]. AI-based radio resource management solutions for 6G networks are summarized in [191].

A variety of robust and explainable AI approaches involves sensitivity analysis, interpretability, model reduction, feature visualization, and model compression. Scalable radio resource management of vehicular networks is achieved by simplifying the model by decreasing the input size of deep reinforcement learning agents through the use of AI techniques. In [192], security in a 6G network corresponding to the applications of AI algorithms and Zero Trust Architecture (ZTA) is emphasized. A 6G security framework based

TABLE 2. Technologies of 6G wireless communication network.

S.No.	Ref.	Technology	Description	Algorithms/Techniques	Observational parameters
1.	[18]	Reconfigurable Intelligent Surfaces	Multi-IRS performance enhancement using blind beamforming without channel estimation	Blind beamforming	SNR boost, number of reflective elements, cumulative distribution function
2.	[54]	Photonic and Visible Light Communication Technology	UAV integrated VLC network based on two stage resource management	Multi-agent reinforcement learning	Data rate, power consumption
3.	[77]	Distributed Intelligent Computing Network	elastic computation partitioning mechanism for distributed DNN	Deep reinforcement learning	Computing latency, communication latency, computing energy consumption, communication energy consumption,
4.	[93]	Mobile and Cell-Free User-Centric Networking	End to end performance enhancement using multi-carrier division duplex frame structure	Multi-carrier division duplex scheme	Bandwidth, delay, rates per device, received power, number of devices
5.	[112]	SaFi (Satellite Fidelity)	RIS mounted UAV integrated with satellite network to improve the overall performance of SAGINs	Hybrid FSO/RF communication links in satellite-terrestrial integrated network	Outage probability, ground station aperture radius, transmission rate, average spectral efficiency
6.	[133]	Terahertz Sensing and Communications	Channel measurements in the indoor communication environments at 201-209 GHz	Ray-tracing-statistical hybrid model	Reflection loss, path loss, cluster delay, cluster loss
7.	[149]	Ultra High-Speed Channel Coding Technology	The performance of the generalized spatial multi-pulse position modulation system is enhanced by incorporating the use of Protograph extrinsic information transfer algorithm	Protograph extrinsic information transfer algorithm	Capacity, SNR, Bit Error Rate
8.	[154]	New Waveform Multiple Access	Generalized rate splitting multiple access integrated with radar sensing and communication is utilized to enhance the performance of the 6G communication network	Rate splitting multiple access	Minimum fairness rate, SNR, root mean square error, root cramer rao bound
9.	[176]	Ultra Massive MIMO	Statistical model is applied to ultra massive MIMO communication system with different antenna array configurations is studied at 5.3Ghz band	Three dimensional 6G –non stationary geometry based stochastic model	Channel capacity, delay, power, power spectral density, azimuth spread, antenna index, receiver antennas, number of users
10.	[190]	AI (Artificial Intelligence)	To incorporate autonomous decision making capabilities into network in the emergent communication network, multi agent reinforcement learning is used	Multi-agent reinforcement learning	Percentage of covered users

on ZTA based on AI algorithms incorporates flexibility and robustness known as hierarchical defensive agents. Combining wireless physical layer technologies with reconfigurable surfaces and deep learning techniques will pave the way for the development of secure 6G vehicular-aided heterogeneous networks [193].

TABLE 3. Current projects of 6G.

S.No.	Project name	Aim of the Research	Area of Research	Http Location
1.	Bharat 6G	To deploy 6G technologies in India	Multi-Disciplinary Innovations including Multiplatform Next Generation Networks, Spectrum for Next Generation Devices	https://dot.gov.in/bharat-6g
2.	Deterministic end-to-end communication with 6G	It consists of 6 objectives viz: new use cases with specific service definition, 6G and DetCom features, AI/ML based data driven techniques, E2E time synchronization, security design, and framework	Architectural aspect, performance aspect, and control aspect	https://deterministic6g.eu
3.	ADROIT6G: Distributed Artificial Intelligence-Driven Open And Programmable Architecture For 6G Networks	The project is implementing the first phase of the 6G SNS roadmap towards the evolution of a 6G architecture.	AI/ ML-powered optimizations, cloud-native network software, edge-cloud platforms, non-terrestrial networks, software driven, zero-touch operations	https://www.cyens.org.cy/
4.	PREDICT6G: PRogrammable AI-Enabled DeterminIstiC neTworking for 6G	Its main aim is to provide 6G end-to-end solution for improved network reliability and efficiency	End to end communication, AI-driven Multi-stakeholder Inter-domain Control-Plane, AI-powered Digital Twin (DT) framework	https://cordis.europa.eu/project
5.	TERA6G: TERAhertz integrated systems enabling 6G Terabit-per-second ultra-massive MIMO wireless networks	TERA6G aims at developing disruptive photonic wireless transceivers enabling Terabit-per-second data throughput unlocking the “Fiber-over-the-Air” concept.	massive Multiple-Input/Multiple-Output multi-antenna techniques operating in the millimeter-wave (30 GHz to 300 GHz) and Terahertz (300 GHz to 3 THz) bands of the spectrum, and mobile site connectivity scenarios	https://www.hhi.fraunhofer.de/en/departments/pc/projects
6.	Hexa-X-II	It aims to execute end-to-end (E2E) system design based on integrated and interacting technology enablers for 6G wireless networks	Ecosystem collaboration, society and business, human in the center, and cyber physical world	https://hexa-x-ii.eu/vision/
7.	6G-ANNA: 6G-Access, Network of Networks, Automation & Simplification	It aims to design for the sixth generation of mobile communications that includes an end-to-end architecture	Interaction between humans, technologies, and the environment, new sensors and algorithms for the recognition	https://6g-anna.de/en/
8.	DESIRE6G: Deep Programmability and Secure Distributed Intelligence for Real-Time End-to-End 6G Networks	It aims to design and develop a novel zero-touch control, management, and orchestration platform	Integration with artificial intelligence, eXtreme URLLC application, programmable data plane	https://desire6g.eu/
9.	ALLEGRO: Agile uLtra Low EnerGy secuRe netwOrks	It aims at designing end-to-end secure architecture for next-generation optical networks in order to achieve high transmission capacity	Optoelectronic devices	https://www.allegro-he.eu/
10.	6GTandem	It aims to advance dual-frequency distributed MIMO networks to enable services as ultra-high reliability and high-resolution position information within the European society.	Combined low-frequency and sub-THz distributed MIMO system networks	https://horizon-6gtandem.eu/
11.	6GNTN (Non-Terrestrial Networks)	It aims to design NTN (Non-Terrestrial Networks) key technical, regulatory, and standardization into 6G	NTN Edge computing, light indoors and in vehicles, flexible software defined payload	https://www.6g-ntn.eu/
12.	INDIA6G	It aims to deliver a cyber -physical continuum where networks will deliver enhanced services, while ensuring the integrity of the delivered information	Radio networks, artificial intelligence , massive IoT networks and cloud computing	https://www.ericsson.com/en/
13.	6Green	It aims to conceive, design, and realize an innovative service-based ecosystem to extend the communication infrastructure into a sustainable, interconnected, greener end-to-end system	Artificial intelligence, zero-touch operations, energy- and carbon effective systems	https://www.6green.eu/

Pervasive intelligence and the Internet of intelligence are expected to be executed for the 6G WCN. AI enables smart applications and dynamic scenarios across a range of industries and fosters the development of a ubiquitous intelligence environment and society. The flexible per-user customization, security, optimal speed, and dependability needed by future AI services are not achievable with the conventional session-oriented architecture. Users' demands for customized AI services might also emerge as a crucial component in the near future [194]. Numerous issues confront 6G networks including resource-constrained mobile devices, challenging wireless resource management, very complex heterogeneous network designs, rapidly increasing computational and storage needs, and risks to privacy and security. AI and blockchain in 6G networks may yield new discoveries in improving network performances in terms of security, privacy, efficiency, cost, and more to address these issues [195].

In [196], an evaluation framework for examining the lifecycle of network AI implementations together with an identification of the main emission sources is presented. To lower overall carbon emissions, a framework known as DETA- a hybrid Dynamic Energy trading and Task Allocation optimization system—has been created. The efficacy of the AI system is evaluated based on the federated edge intelligence. AI in 6G networks is expected to be facilitated by federated learning, a new distributed AI paradigm that protects privacy. Implementing federated learning effectively and efficiently in 6G networks faces a number of systems and statistical heterogeneity problems. The design of incentive mechanisms, network resource management, and personalized model optimization are the three optimization approaches that can be explored as potential solutions to difficult heterogeneity problems [197].

In [198], a resource allocation strategy based on reinforcement learning is used to optimize the allocation and processing of requests between near RIC (Radio Intelligence Controller) and non-RIC, thereby minimizing service latency. The Double Deep Q Network (Double DQN) technique determines whether requests are processed at a near RIC or a non-RIC, thereby allocating resources from the near RIC to complete the requests. In [199], digital twin presentations of radio propagation across various frequency bands, ranging from microwave to visible light, are made using ray-tracing-focused techniques. The methodologies based on material and field measurements are suggested for describing the electromagnetic characteristics of materials. Based on that, the corresponding parameters are inverted and the propagation mechanisms are built and verified. AI and real-time algorithms are combined to create a super-resolution modeling technique for the real-time simulation demand. In [200], AI assisted finite element method methodology is devised to provide precise spectrum prediction for THz fiber design operating in 6G communication window. In order to effectively support edge-intelligence operations, architecture called SEMantic Data Sourcing (SEMDAS) for identifying semantically matching data sources has been incorporated in [201]. The entire framework includes new design concepts for task-oriented wireless approaches, architecture, protocol, and semantic matching techniques. As the central element of SEMDAS, the framework addresses a range of machine learning-driven semantic matching methods aimed at various edge-intelligence applications.

The AI framework is used to optimize 6G core network configurations and reduces the execution time, essential for end-to-end routing in the user plane, by utilizing information from the core network control plane.The latest research trends in the artificial intelligence technology includes, model driven methods, digital SIC approaches, EC-MARL approaches, autonomous decision approaches, AI algorithms in the field of security, resource management using AI, RIC for optimized resource allocations, double DQN, and AI for spectrum prediction.

The summary of the technologies of 6G is given in Table 2 The current projects of 6G is given in Table 3.

XIII. CONCLUSION

This article provides insight into the possible technologies of 6G with the illustration of enablers, requirements, and efforts towards the next generation wireless communication network. It is anticipated that 6G will undergo remarkable changes that will significantly set it apart from earlier generations. To provide clarity and specific research requirements for the development of the 6G, each technology is highlighted with a detailed illustration. The main contribution of the paper is the vast description of 6G technologies that significantly affect dominant performance indicators in wireless communication networks. The enhancement in the characteristic parameters of 6G WCN includes data rates, mobile management, spectrum efficiency, ultra-low latency, energy efficiency, coverage, and connection density.

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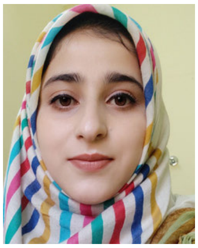

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