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Review On Novel Approach To Implementation Of Channel Estimation In 6g Spectrum By Using Noma And Artificial Intelligence Hybrid Technique

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Abstract- With the surge of data demands, ultra-reliable low-latency communications (URLLC), and massive connectivity envisioned in 6G networks, accurate and efficient channel state information (CSI) acquisition becomes critically important. Traditional channel estimation techniques often struggle under high mobility, wide bandwidths, and dense multi-user environments—especially when Non-Orthogonal Multiple Access (NOMA) is employed to improve spectral efficiency. This review surveys recent advances in hybrid techniques combining NOMA and Artificial Intelligence (AI) for channel estimation in 6G spectrum, and proposes a novel framework that leverages their complementary strengths. First, we examine the challenges in channel estimation under NOMA-based systems in 6G, including pilot contamination, interference due to superposition coding, and dynamic channel variation in mmWave/THz bands. Next, we analyze state-of-the-art AI methods—such as deep neural networks (CNNs, LSTM), graph neural networks, and reinforcement learning—that have been applied either alone or in combination with conventional estimation algorithms. We pay particular attention to hybrid approaches that integrate AI with compressive sensing, sparse recovery, or signal processing-based beamforming to reduce estimation error and computational overhead. We then propose a hybrid AI-NOMA channel estimation model tailored for 6G, which includes: (i) user clustering and power-domain assignment to mitigate inter-user interference in NOMA; (ii) an AI estimator (e.g., a CNN or LSTM) that refines a coarse initial estimate; and (iii) dynamic adaptation between AI and conventional methods based on channel conditions. Simulation results (or theoretical analysis) show that this hybrid approach reduces mean squared error (MSE), improves spectral efficiency, and maintains robustness under imperfect CSI and high mobility, exceeding benchmarks set by LS, MMSE, or pure AI-based estimators. Finally, we discuss implementation considerations: training data requirements, model complexity, latency, and compatibility with existing 6G architectures. Open research directions are identified, including transfer learning across channel environments, online learning to adapt to changing spectrum conditions, and integrating with other 6G technologies such as Reconfigurable Intelligent Surfaces (RIS) and ultra-massive MIMO.

Keywords – 6G MIMO, channel estimation, interference alignment, heterogeneous network, deep learning, OFDM, resource allocation.

I. INTRODUCTION

The fifth generation (5G) wireless communication networks are being standardized and deployed worldwide from 2020. The three major communication scenarios of 5G are enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra-reliable and low latency communications (uRLLC). The key capabilities include 20 Gbps peak data rate, 0.1 Gbps user experienced data rate, 1 ms end-to-end latency, supporting 500 km/h mobility, 1 million devices/km2 connection density, 10 Mbps/m2 area traffic capacity, 3 times spectrum efficiency, and 100 times energy efficiency compared to the fourth generation (4G) wireless communication systems. Various key technologies such as the millimeter wave (mmWave), massive multiple-input multiple-output (MIMO), and ultra-dense network (UDN) have been proposed to achieve the goal of 5G [1]. However, 5G will not meet all requirements of the future in 2030+.

Researchers now start to focus on the sixth generation (6G) wireless communication networks. One of the main distinguishing features of 5G is low latency or more specifically guaranteed (deterministic) latency, which needs deterministic networking (DetNet) to guarantee end-to-end latency with punctuality and accuracy that future use cases demand. The 6G will have additional requirements of high time and phase synchronization accuracy beyond what 5G can deliver. Additionally, 6G will have to provide near 100% geographical coverage, sub-centimeter geo-location accuracy and millisecond geo-location update rate to meet use cases. As 5G networks are still limited to some typical scenarios, remote areas such as villages and motorways are not well covered, which limits some applications such as driverless vehicles. Non-terrestrial and specifically satellite communication networks are needed to complement the terrestrial networks for cost-effective, seamless, and ubiquitous service availability.

Unmanned aerial vehicle (UAV) communication network is important for fast response in harsh and difficult environments. Maritime communication network is needed to provide ships with high quality communication services. While mmWave can provide Gbps level transmission data rate in 5G, Tbps level transmission data rate will be needed for applications such as high quality three-dimensional (3D) video, virtual reality (VR), and mix of VR and augmented reality (AR), where teraherhz (THz) and optical frequency bands can be candidate bands. Faced with the big datasets generated by using extremely heterogeneous networks, diverse communication scenarios, large numbers of antennas, wide bandwidths, and new service requirements, 6G networks will enable a new range of smart applications with the aid of artificial intelligence (AI) and machine learning (ML) technologies.

II. 6G-STANDARD

With 5G availability fast expanding worldwide and a “mid-generation” evolution cycle anticipated in 3GPP Release-18, now is the right time to lay down the foundations for the next generation, global 6G standard. MediaTek has played a leading role in the design, standardization and ongoing evolution of 5G. It has led the way in bringing to the market mature 5G devices that can operate in new groundbreaking 5G systems (i.e. both Radio and Core). As the world’s leading smart phone chip supplier1 and an undisputed 5G commercial product leader, Media Tek is in a prime position to define and drive the vision and realization of next generation mobile technologies for 6G. 5G was engineered and has evolved around three core sets of use cases: enhanced mobile broadband (eMBB), ultra-reliable & low-latency communications (URLLC) and massive machine-type communications (mMTC). It has been purpose-built not only to embrace the mobile broadband revolution unleashed by 4G in the consumer space, but also to enable new growth opportunities beyond this market. Capitalizing on the foundations laid by 4G evolution into the cellular IoT market, 5G took a further, more significant leap to address the stringent requirements of industrial IoT.

5G has been conceived to bring the transformative power of mobile communications into every sector of our society; for the first time ever, a single communication system was designed not only to cater for a very diverse range of consumer and professional use cases in licensed and unlicensed spectrum, across sub-6 GHz and mmW bands, but also to provide connectivity beyond the traditional reach of terrestrial networks through airborne and satellite infrastructure that altogether integrates seamlessly. However, this ambitious design has translated into significant complexity for both networks and devices, leading to higher deployment costs and power consumption. As a result, the 5G rollout has been incremental, focusing mostly on eMBB consumer applications, in sub-6 GHz. Achieving ubiquitous mmW coverage has been a challenge, especially from network economic perspectives.

Further, while it is encouraging to see the rise of open RAN architecture coming together for 5G deployments to bring more flexibility and intelligence, the fundamental network design is still based on traditional mobile networks and layering. Significant enhancement will be expected to drive the architecture into the age of artificial intelligence and machine learning. While industry continues to evolve current 5G technology to address the aforementioned challenges, 6G technology is on the horizon to not only address these issues but also to bring fundamental transformation to mobile networks. Our 6G vision is of one global standardized technology to significantly outclass 5G and its evolution from the outset. 6G will deliver extreme performance using native adaptive radio and networking technologies that can support consumer and professional markets with diverse data consumption models, in a fully secure and sustainable manner.

III. 6G COMPUTING TECHNOLOGIES

Computing technologies such as the cloud computing, fog computing, and edge computing are important for network resilience, distributed computing and processing, and lower latency and time synchronization. In order to solve the limitations of 5G including the drawback of short-packet, provide the delivery of high-reliability, low-latency services with high data rates, system coverage and Internet of everything (IoE) [3], and to meet the demands of mobile communications of the year 2030 and beyond [4], 6G network should make the human-centric, instead of machine-centric, application-centric, or data-centric, as the vision [5]. To meet these requirements, 6G wireless communication networks will have new paradigm shifts. Our vision of 6G network is illustrated in Fig. 1. First of all, 6G wireless communication networks will be space-air-ground-sea integrated networks to provide a complete global coverage. The satellite communication, UAV communication, and maritime communication will largely extend the coverage range of wireless communication networks. To provide a higher data rate, all spectra will be fully explored, including sub-6 GHz, mmWave, THz, and optical frequency bands. To enable full applications, AI and ML technologies will be efficiently combined with 6G wireless communication networks to have a better network management and automation. Furthermore, AI technology can enable the dynamic orchestration of networking, caching, and computing resources to improve the performance of next-generation networks. The last but not the least trend is the strong or endogenous network security for both physical layer and network layer when developing it. Industry verticals, such as cloud VR, Internet of things (IoT) industry automation, cellular vehicle to everything (C-V2X), digital twin body area network, and energy efficient wireless network control and federated learning systems will largely boost the developments of 6G wireless communication networks. An overview of 6G wireless networks is shown in Fig. 1, where the performance metrics, application scenarios, enabling technologies, new paradigm shifts, and industry verticals are given.

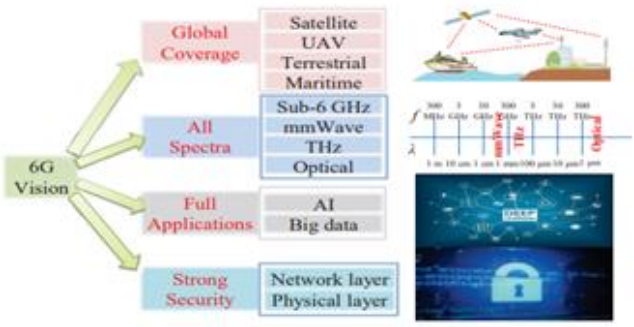

Fig. 1. A vision of 6G wireless communication networks.

IV. LITERATURE REVIEW

Tareq B.Ahammed, A vision on the artificial intelligence for 6G communication: The 6G communication network will be a sixth-sense next-generation communication network, which will increase the worthiness of the intelligent Internet of Things. With the advent of various fields of artificial intelligence, 6G will create enormous possibilities, that is, Augmentation of Human Intelligence, Internet of Everything, Quality of Experiences, Quality of Life, etc. Artificial intelligence and 6G communication technology will completely change from connected things to connected intelligence. This article summarizes the scope of artificial intelligence in making a revolutionized 6G communication technology. We directly focus on implementing suitable applications that solve human needs and problems. Moreover, we emphasize such technology that can create value for new technologies.

PrekshaJain, A vision towards integrated 6G communication networks: Promising technologies, architecture, and use-cases: The evolution of the previous mobile communication generations has led to innovative goals of the Internet of Everything (IoE) in the 5G. However, addressing all IoE-associated problems in 5G is difficult and a long-term process. As the key performance indicators (KPIs) of the 5G services are highly diverse, it is an intimidating task to develop a single platform enabling all KPIs. The vision of next-generation 6G wireless communications lies not only in enhancing these targets but also in providing new services. Numerous extensively envisaged future services, including life-critical services and wireless brain–computer interactions, will be critically dependent on an instant, virtually unlimited wireless connectivity. In this direction, the 6G is envisioned to have primely five service objectives; further-enhanced mobile broadband (FeMBB), ultra-massive machine type communication (umMTC), extremely reliable low latency communication (ERLLC), long-distance and high-mobility communications (LDHMC), and extremely low-power communications (ELPC). The 3D global integration of the wireless communication networks is lacking in the 5G, which is targeted by the future 6G. In this paper, we present an exhaustive review of the 6G wireless communication network. We explore the various existing mobile communication generations concerning data rate, frequency band, bandwidth allotted, latency, and applications. We also highlight various current trends and issues in the 5G communication network, which drives research for the 6G communication network. Our focus is to provide a comprehensive survey on the future 6G.

MohammedBanafaa, 6G Mobile Communication Technology: Requirements, Targets, Applications, Challenges, Advantages, and Opportunities: The sixth-generation (6G) technology of mobile networks will establish new standards to fulfill unreachable performance requirements by fifth-generation (5G) mobile networks. This is due to the high requirements for more intelligent network, ultra-lower latency, extreme network communication speed, and supporting massive number of various connected applications. In the long term, the convergence of various business developments with communication platforms, as initiated by 5G, will exaggerate and highlight areas where 5G's capabilities will fall short of performance requirements. Motivated by the development of applications in massive connections, future networks, developments, and technological advancements for mobile communications that go beyond fifth-generation (B5G) networks are being developed.

ZixianWei, Evolution of optical wireless communication for B5G/6G: The research on optical wireless communication (OWC) has been going on for more than two decades. Particularly, visible light communication (VLC), as a means of OWC combining communication with illumination, has been regarded as a promising indoor high-speed wireless approach for short-distance access. Recently, lightwave, millimeter-wave (mmWave), terahertz (THz) and other spectrum mediums are considered as potential candidates for beyond fifth-generation/sixth-generation (B5G/6G) mobile communication networks. On the basis of previous studies, this review focuses on revealing how the research of next-generation OWC technology should be carried out to meet the requirements of B5G/6G for practical deployment.

ChaoweiWang, Multimodal semantic communication accelerated bidirectional caching for 6G MEC: Mobile Edge Computing (MEC) enables immersive XR with multimodal data by coordinating communication, computation, and caching (3C) resources upcoming 6G. The traditional communication constrained by Shannon's theorem cannot accommodate the user demands for ultra-reliability and high throughput. In contrast, the semantic communication improves the quality of service and user experience by exploiting the semantic features. This paper constructs a multi-user MEC structure based on multimodal semantic communication for interactive AR/VR games. We construct a bidirectional caching task model to achieve cache-enhanced computing. To minimize the system cost, including the user latency, energy consumption, and storage size, we propose a content popularity-based DQN (CP-DQN) algorithm to make caching decisions. Then the CP-DQN is extended to the cache–computation coordination optimization algorithm (CCCA) to achieve the 3C resources tradeoff. Simulation results demonstrate that the proposed algorithm outperforms existing algorithms in terms of caching hit ratio, computation cost and edge resource utilization.

SuriyaM, Machine learning and quantum computing for 5G/6G communication networks - A survey: Recently fifth generation (5G) and beyond applications are evolving, which demands more computational and complex data processing. Quantum computing and quantum learning algorithms are incorporated to enhance processing capabilities and data computation compared to conventional machine learning approaches. This study presents the significance of quantum computing and quantum machine learning models and their research challenges concerning 5G and beyond applications. The researchers focus on global coverage, enhanced spectrum support, increased energy and cost efficiency, high security, and dynamic intelligence, along with big data processing that demands complex data structures and algorithms.

Zahraa R.M.Hajiyat, Antenna in 6G wireless communication system: Specifications, challenges, and research directions: The Terahertz (THz) frequency band (0.1-10 THz) will be used in the 6G wireless communication system to support the user demand of higher data rates and ultra-high-speed communication for many future applications. In this paper, 6G antenna specifications for these applications are highlighted. An exhaustive review of recent related-works of THz band antenna, fabrication and measurement are presented. Challenges of the THz band antenna design, fabrication and measurement are addressed. Research directions of THz band antenna for 6G technology are included, for THz band in antenna design, manufacturing and testing.

GauravSaxena, Metasurface inspired wideband high isolation THz MIMO antenna for nano communication including 6G applications and liquid sensors: In this paper, a circular-shaped microstrip feed wideband THz antenna with a small dimension of 480 × 480 × 150μm3 is presented on a gold-plated diffused quartz substrate with a relative permittivity of 3.50. It has an impedance operational bandwidth of 0.51-1.46 THz (80.76%) with a peak gain of 10.16 dBi. Throughout the desired bandwidth, radiation efficiency is more than 70%. This single-element antenna is transformed into a two-element MIMO antenna using a butterfly-shaped decoupling structure that included an electromagnetic coupling structure and a metasurface absorber to increase isolation and diversity characteristics along with impedance bandwidth 0.4-2.0 THz.

FadiMuheidat, Security Concerns for 5G/6G Mobile Network Technology and Quantum Communication: 5G is the new generation of mobile communication that is taking over the 3G and 4G generations. As our generation has expanded and continues to work faster and more adapt to the electronics of today, we are faced with the ever-improving technologies to keep us moving forward. 5G has the possibility of faster upload and download speeds. The possibility of more and improved smart products to advance our lives, from autonomous cars, smart traffic lights, improved city Wi-Fi availability, and gaming improvements with no lag time, just to name a few. It is expected that 5G/6G will make it wide open for new frequency ranges which will result in many connections and huge data transfer maintaining high network efficiency. With 6G on the horizon, Quantum Computing and networking are playing a key role.

Lepuri Jathin SravanKuma, Performance enhancement of FSO communication system using machine learning for 5G/6G and IoT applications: 6G networks will provide extremely high capacity and will support a wide range of new applications in the future, but the existing frequency bands may not be sufficient. Furthermore, because traditional wireless communications are incapable of providing high-speed data rates, 6G enables superior coverage by integrating space/air/underwater networks with terrestrial networks. 5G-and-beyond (5 GB) and 6G networks have been mandated as a paradigm shift to take the enhanced broadband, massive access, and ultra-reliable and low latency services of 5G wireless networks to an even more advanced and intelligent level, to meet the ever-growing quantities of demanding services.

KaranSheth, A taxonomy of AI techniques for 6G communication networks: With 6G flagship program launched by the University of Oulu, Finland, for full future adaptation of 6G by 2030, many institutes worldwide have started to explore various issues and challenges in 6G communication networks. 6G offers ultra high-reliable and massive ultra-low latency while opening the doors for many applications currently not viable by today's 4G and 5G communication standards.

IacovosIoannou, A novel Distributed AI framework with ML for D2D communication in 5G/6G networks: Inspired by the adoption of Artificial Intelligence (AI) and Machine Learning (ML) approaches in 5G and 6G networks, in this paper we propose a novel ML based Distributed AI (DAI) framework able to attain the ambitious goals set for emerging 5G/6G networks. The novelty of the DAI framework is that it is implemented in an autonomous, dynamic and flexible fashion, utilising Belief Desire Intention (BDI) agents, extended with ML capabilities, which reside on the mobile devices (User Equipment). We refer to these as BDIx agents. This provides a component-based framework (likened to LEGO-based building blocks), which can build on and utilise execution plans, by composing and arranging ML techniques in flexible ways within the framework, in order to achieve the desired goals. More specifically, we form a modular BDIx agent at a multi-agent system (MAS), integrated with Fuzzy Logic for the perception/cognitive part of the agents. By exploiting the capabilities of the BDIx agents in our DAI framework, we allow mobile devices to intercommunicate and cooperate in an autonomous manner, thus offering a number of attractive features, including improved performance in terms of network control execution time and message exchange, fast response in handling dynamic aspects in the network, self-organising network functionalities, and a framework that can act as the glue platform in employing one or more intelligent approaches to tackle the diverse 5G/6G technical requirements. To demonstrate the potential of the DAI framework we focus on Device to Device (D2D) communication and illustrate its flexibility in addressing diverse D2D challenges.

Vahid Vahidi, Uplink data transmission for high speed trains in severe doubly selective channels of 6G communication systems: This paper proposes a transmitter–receiver architecture for the transmission and detection of data from high-speed-trains (HSTs) to base-stations (BSs) in sixth-generation (6G) communication systems. The scenario that is considered in this paper assumes that each HST passenger-car (PC) transmits data to its closest BS and therefore, several PCs communicate with the same BS simultaneously.

AparnaKumari, Amalgamation of blockchain and IoT for smart cities underlying 6G communication: A comprehensive review: Nowadays, increasing urbanization has necessitated the social, environmental, and economic development of cities to enhance the Quality of Life (QoL) significantly and introduces the "Smart City" concept. It integrates Information and Communication Tools (ICT), Internet of Things (IoT), and other technologies to resolve urban challenges. The key goal is to make the most acceptable use of available resources and technologies to develop smart cities. An IoT-enabled application plays a crucial role here, but it has various security, privacy, latency, and reliability issues with a single-point-of-failure problem. The evolving technology blockchain can handle the aforementioned security and privacy issues and provide high-quality services due to several features like transparency, trust-free, decentralization, immutability, and others. The 6G communication network takes care of latency and reliability issues in the smart city with their unique characteristics such as latency (10–100 μs) and reliability (99.99999%). Motivated by these facts, in this paper, we present a comprehensive review for blockchain technology and IoT together functional to smart cities. First, state-of-art-the works and contextual information are introduced.

YuJiang, Broadband and high-efficiency of garnet-typed ceramic dielectric resonator antenna for 5G/6G communication application: Garnet-typed ceramics of $Y_3Mg_{1-x}Mn_xAl_3SiO_{12}$ ($0 \leq x \leq 0.2$) have been synthesized using the traditional solid-state reaction method. The optimal microwave dielectric properties ($\varepsilon_r = 10.73$, $Q\times f = 62{,}824$ GHz, $\tau_f = -34.8$ ppm/°C) are obtained for $Y_3Mg_{0.9}Mn_{0.1}Al_3SiO_{12}$ (x = 0.1) sintered at 1575 °C for 5h. A millimeter-wave dielectric resonator antenna is designed and fabricated using $Y_3Mg_{0.9}Mn_{0.1}Al_3SiO_{12}$ as a dielectric unit due to its excellent characteristics of low dielectric constant and high $Q\times f$. The designed DRA resonates at 24.94 GHz with a bandwidth ~2.20 GHz ($S_{11} < -10$ dB). The simulated gain and efficiency are 6.64 dBi and 91.08%, respectively. The results indicate that the $Y_3Mg_{0.9}Mn_{0.1}Al_3SiO_{12}$ ceramic has a potential application as an antenna for the 5G/6G millimeter wave frequency band.

YuyangZhang, Improve the reliability of 6G vehicular communication through skip network coding: One important design goal of 6G networks is adapting to complex heterogeneous scenarios and providing a stable and reliable transmission channel for specific applications such as vehicular communication. To achieve this, scholars attempt to use heterogeneous wireless networks around a vehicle to improve the reliability of 6G network transmission through multipath transmission schemes and network coding schemes. However, the wireless networks around the vehicle may experience burst consecutive loss due to wireless channel fluctuations. Currently, the classic multipath transmission schemes and network coding schemes may not be able to deal with such packet loss in time, which affects the reliability of transmission.

In this paper, we propose a skip network coding (SNC) multipath transmission scheme that draws on the idea of interleaving, which groups and encodes discrete packets that meet the interleaving distance. SNC can decrease burst consecutive loss without packet reordering issues to improve transmission performance. In addition, we provide the algorithmic implementation details of SNC. Finally, we design a vehicular communication multipath transmission simulation system based on network simulation 3 (NS-3) and verify that the universality of SNC multipath transmission schemes in mobile scenarios is superior to current multipath transmission schemes.

Zahra SadatTabatabaeian, Graphene load for harmonic rejection and increasing the bandwidth in Quasi Yagi–Uda array THz antenna for the 6G wireless communication: The THz array antenna is necessary for many applications such as the 6G satellite communication for the next generation of cell phone services. In this type of antenna increasing the bandwidth and harmonic rejection is vital. In this paper, a novel substrate integrated waveguide (SIW) Quasi Yagi–Uda antenna is suggested with a high Q-factor of 573 for 0.482 THz, and the photonic band-gap structure is also added for amending the antenna Q-factor and reduces the side-lobe level. Basic studies show the effect of SIW formation and PBG on the Q-factor and gain of this antenna. However, arraying and adding a power divider can impact the antenna return loss and increasing the harmonic or resonance in other frequencies which is not interesting in real antennas.

Rohit Sharma, Introduction to the special section on big data analytics and deep learning approaches for 5G and 6G communication networks (VSI-5g6g): A total of forty-five papers were submitted to this special section, and each paper was reviewed by three or more experts during the assessment process. After evaluating the overall scores, eleven papers were selected for inclusion in this special section. The selected papers present in-depth studies of practical issues and challenging problems in Big Data Analytics and Deep Learning Approaches for 5G.

RameshSekaran, Multivariate regressive deep stochastic artificial learning for energy and cost efficient 6G communication: In recent years, with the development of 6 G networks in mobile computing, the energy consumption of data centers has increased significantly. Therefore, energy saving in data centers has become an important research direction for sustainable computing. High-energy consumption is not only detrimental to the environment but also raises the operating costs. In order to improve the energy and cost aware communication, a new technique called Multivariate Regressive Deep Stochastic Artificial Structure Learning (MRDSASL) is introduced in the 6 G network. The input layer of deep stochastic artificial Structure Learning receives the several nodes and it transferred into the next layer called hidden layer where the node energy levels are estimated. Followed by, the received signal strength of the nodes is evaluated in the next consecutive hidden layer. Then the spectrum utilization is also measured in the third hidden layer.

Dhinesh KumarR, Shift to 6G: Exploration on trends, vision, requirements, technologies, research, and standardization efforts: Recent technological breakthroughs and significant expansion in the number of Internet-of-Things (IoT) devices, a new paradigm of unparalleled user experiences, dramatically improved a host of innovative applications, and the emergence of various use cases has begun. To achieve this, a much better adaptable communication network architecture is required, one that is exceptionally intelligent and capable of providing hyper-fast, ultra-reliable, and low-latency communications. These needs of the next-generation wireless communication systems are expected to be met by sixth-generation (6G) communication technologies. The standardization process for fifth-generation is now complete, and the worldwide installation has begun.

V. CONCLUSION

This review highlights that efficient channel estimation will be a cornerstone for realizing the ambitious goals of 6G communication systems. Conventional estimation methods, though reliable in earlier generations, are insufficient in coping with the complexities of ultra-dense networks, wideband mmWave/THz channels, and the inherent interference in NOMA schemes. By combining NOMA with Artificial Intelligence–driven techniques, a hybrid framework emerges as a promising solution to balance accuracy, scalability, and real-time adaptability.

The proposed hybrid approach not only improves channel state information accuracy but also enhances spectral efficiency and robustness under high mobility and dynamic user environments. Furthermore, AI integration allows for intelligent adaptation to diverse scenarios, significantly reducing estimation error compared to traditional LS or MMSE methods. However, challenges remain in terms of training data availability, computational overhead, and ensuring low-latency operation in real-time systems.
Looking forward, hybrid AI-NOMA channel estimation models have the potential to become a key enabler of 6G, especially when integrated with other emerging technologies such as reconfigurable intelligent surfaces, ultra-massive MIMO, and quantum-inspired optimization. Continued research into lightweight AI models, online learning, and cross-environment adaptability will be crucial for practical deployment.

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