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Coalition of 6G and Blockchain in AR/VR Space: Challenges and Future Directions

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ABSTRACT The digital content wave has proliferated the financial and industrial sectors. Moreover, with the rise of massive internet-of-things, and automation, technologies like augmented reality (AR) and virtual reality (VR) have emerged as prominent players to drive a range of applications. Currently, sixth-generation (6G) networks support enhanced holographic projection through terahertz (THz) bandwidths, ultra-low latency, and massive device connectivity. However, the data is exchanged between autonomous networks over untrusted channels. Thus, to ensure data security, privacy, and trust among stakeholders, blockchain (BC) opens new dimensions towards intelligent resource management, user access control, audibility, and chronology in stored transactions. Thus, the BC and 6G coalition in future AR/VR applications is an emerging investigative topic. To date, authors have proposed surveys that study the integration of BC and 6G in AR/VR in isolation, and hence a coherent survey is required. Thus, to address the gap, the survey is the first-of-its-kind to investigate and study the coalition of BC and 6G in AR/VR space. Based on the proposed research questions in the survey, a solution taxonomy is presented, and different verticals are studied in detail. Furthermore, an integrative architecture is proposed, and open issues and challenges are presented. Finally, a case study, *BvTours*, is presented that presents a unique survey on BC-based 6G-assisted AR/VR virtual home tour service. The survey intends to propose future resilient frameworks and architectures for different industry 4.0 verticals and would serve as starting directions for academia, industry stakeholders, and research organizations to study the coalition of BC and 6G in AR/VR in industrial applications, gaming, digital content manufacturing, and digital assets protection in greater detail.

INDEX TERMS 6G, augmented reality, blockchain, digital content, industry 4.0, smart contracts, virtual reality applications.

I. INTRODUCTION

Augmented reality (AR) and virtual reality (VR) facilitates vivid immersive and real experiences in a variety of applications. AR includes the virtuality of real objects; it is combined with multi-sensory abilities such as audio, video, cognitive, etc. It provides a real-time three-dimensional (3D) presentation of virtual and real objects. On the other hand, VR presents the imaginative feel and inclusion of real-world objects. Thus, collectively AR and VR allow a user to experience the coexistence of the real and virtual worlds simultaneously. The technology has also gained

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promising directions post the outbreak of novel coronavirus (COVID-19) pandemic, as virtual presence, meetings, and conferences have gained importance over physical meetings.

AR and VR applications are explored in a variety of applications such as entertainment, advertising, intelligent healthcare, virtual experiences market, real estate, art, the gaming industry and monetization, manufacturing, social media, education, interactive training, and others. To support the real-world experience, AR/VR requires real-time connectivity, with massive bandwidth support to help the data-driven connections. Due to this, fifth-generation (5G) communication networks leverage super-fast connectivity and high bandwidth uplink and downlink data streaming requirements to support AR/VR applications.

TABLE 1. Abbreviations and their meanings.

Abbreviations	Meanings	Abbreviations	Meanings
4G	Fourth Generation	LTE	Long-Term Evolution
5G	Fifth Generation	LTE-A	Long-Term Evolution-Advanced
6G	Sixth Generation	mIoT	massive Internet-of-Things
AI	Artificial Intelligence	mMIMO	massive Multiple-in-Multiple-out
AR	Augmented Reality	mMTC	massive Machine-Type Communications
B5G	Beyond 5G	MR	Mixed Reality
BC	Blockchain	NR	New Radio
BCoT	Blockchain-of-Things	P2P	Peer-to-Peer
COVID-19	Novel Coronavirus	PoCo	Proof-of-Cache-Offloading
CAGR	Compounded Annual Growth Rate	QoE	Quality-of-Experience
CPPS	Cyber-Physical Production System	QoI	Quality-of-Interaction
D2D	Device-to-Device	QoS	Quality-of-Service
eMBB	enhanced Mobile Broadband	RR	Real-Reality
eRLLC	extreme Reliable Low Latency Communication	SCs	Smart Contracts
FeMBB	Further Enhanced Mobile Broadband	SDN	Software-Defined Networking
GPU	Graphics Processor Units	THz	Terahertz
IA	Intelligence Amplification	UAVs	Unmanned Aerial Vehicles
IC	Information-Centric	UE	User Equipment
IC-mIoT	Information-Centric massive IoT devices	uHDIoT	ultra-High Dense Internet-of-Things
IIoT	Industrial Internet-of-Everything	umMTC	ultra-massive machine-type communications
IIoT	Industrial Internet-of-Things	uRLLC	ultra Reliable Low-Latency Communications
IoE	Internet-of-Everything	VMR	Virtual Meeting Room
IPFS	Interplanetary File System	VR	Virtual Reality
IPv6	Internet Protocol version 6	WiFi	Wireless Fidelity
KPI	Key Performance Indicators	XR	Extended Reality

Network orchestration requires reliability and quality-of-service (QoS) based service sets. In networks, QoS is defined as network delay, jitter, audio/video drop ratio, and bandwidth. To enhance user experience and interactivity with multi-applications, quality-of-experience (QoE) is defined in terms of the degree to which any application or service provides flexibility, ease of interactivity, and overall annoyance or delight to the user [1]. However, improved QoE, with real-time interactions of real objects in virtual space through assisted networking, is further defined as quality-of-interaction (QoI). In AR and VR applications, effective QoE represents a satisfactory QoI for end-users. Thus, responsive network design leverages an improved QoI that represents a high QoE for user-centric applications. A perfect QoE establishment requires the applicability of all key performance indicators (KPI) in a particular communication network. Thus, network management and orchestration through 5G serviced networks is a promising fit to support the bandwidth and end-user latency requirements of AR/VR space. Table 1 presents the list of abbreviations and their associated meanings.

In a similar direction, earlier 5G new radio (NR) technology enables ultra-reliable low latency communications (uRLLC), enhanced mobile broadband (eMBB), and massive machine-type communications (mMTC). 5G allows latency of < 10ms, failure rates as low as 10^{-7} , high reliability of the order of 99.9999% through 5G-tactile internet (TI) service, and peak data rates up to 10 Gb/s to support QoS requirements for uRLLC [2]. 5G enables increased integration of cellular and assisted wireless fidelity (WiFi) technologies and standards, network decentralization through edge-centric architectures, mobile edge computing assisted radio access networks, device-to-device (D2D) communications, and user equipment (UE) assisted mobility [3]. 5G networks reduce

network scale-up time to an immense extent due to software-defined networking (SDN) leveraged network management, virtualization of cores, and assisted user plane management that reduces the overall network and communication costs. Moreover, 5G leverages massive multiple input multiple output (mMIMO) channels, which increases network capability and reliability. 5G uses convoluted and sophisticated antenna configurations, and the physical layer communication complexity is addressed through optimization and monitoring through artificial intelligence (AI)-based configurations [4]. Through AI, 5G networks can support massive communications and enhanced services that drive a range of verticals in healthcare, internet-of-things, telepresence, and many more. Moreover, 5G can be easily integrated with legacy fourth generation (4G) assisted long-term evolution (LTE), and long-term evolution-enhanced (LTE-A) networks [5].

FIGURE 1 presents the timeline of important events related to the early stages of AR/VR, like key breakthroughs like AR toolkits in the early 2000s, 3D stereoscopic view in 2000-2010. The timeline also depicts the evolution of wireless network generation, from first-generation (1G) analog services in the 1980-the 1990s towards 6G deployments by 2030. Similarly, the timelines show the evolution of BC from Bitcoin cryptocurrency to a decentralized internet and governance.

Historically, AR/VR applications started as early as flight simulator engines, telesphere masks, and head-mounted displays. In 1977, Sayre Glove was designed by the University of Illinois; in 1982, the technology advanced to form the power and the data gloves. At the same time, the world saw the emergence of first-generation (1G) analog mobile phone services that supported bandwidth of 30 KHz, and 2.4 Kbps data rate. In 1992, the universal second generation (2G) global mobile communication (GSM) standards

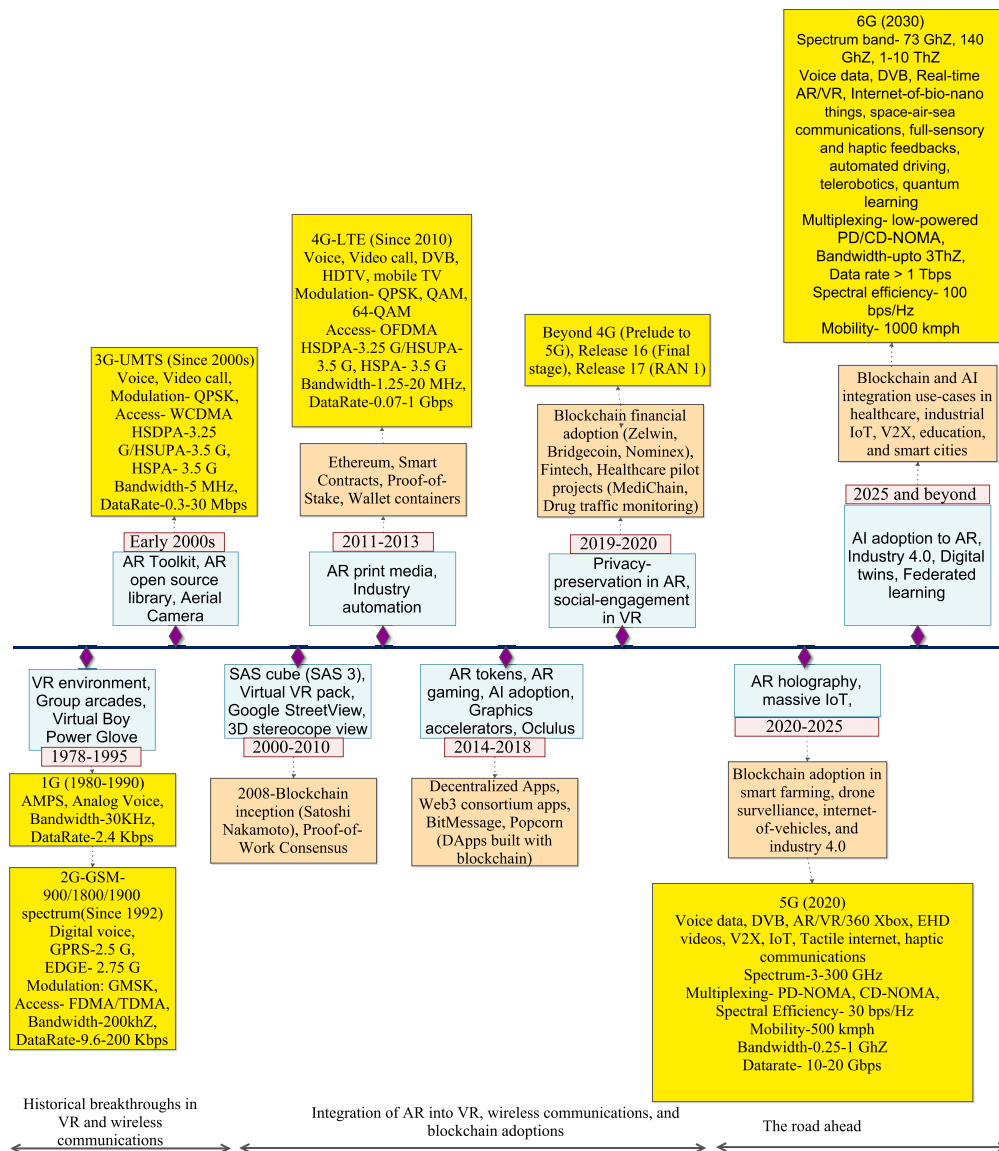


FIGURE 1. Timeline of events related integration of BC and 6G in AR/VR.

supported digital voice, and different standards were proposed. 2G further enhanced to support connectivity to the internet via general packetized radio service (GPRS) and enhanced data rates in the GSM environment (EDGE). Early 2000 marked the design of AR toolkits and open libraries for implementation. At the same time, third-generation networks were proposed to support higher data rates around 30 Mbps. In 2008, Satoshi proposed bitcoin as a decentralized ledger and marked the beginning of blockchain 1.0. Later the technology matured in BC to ensure trust among decentralized users. Later, with an increase in decentralized applications, ethereum was introduced, and smart contracts emerged. The same is termed Blockchain 2.0. At the same time, the AR industry entered into automation and print media. With the rise of decentralization, Blockchain 3.0 emerged with the design of decentralized applications,

and adoption of BC to different verticals started like healthcare, finance, and education sector. Fourth generation (4G) networks evolved as a prelude to fifth-generation (5G), and AR/VR saw the shift towards user data privacy.

At current, we stand at AR holography and shift towards the support of massive IoT. BC has matured as a technology, and solutions are proposed in smart farming, IoT, drones, and others. As artificial intelligence (AI) also progressed, 5G networks proposed intelligent radio access networks and proposed specific services with defined functionality. The multiplexing models shifted from orthogonal to non-orthogonal multiplexing models with the support of high data rates. We envision the integration of secured exchange among communication networks and real-time AR/VR integration in the future. With 6G networks, services are modeled

as orchestrated as encapsulated boxes, and AI would drive the behavior of 6G networks and services.

However, emerging applications such as telemedical presence, mixed reality (MR), holographic communication, real-time haptics, high mobility of vehicular networks, autonomous car driving, massive unmanned aerial vehicles (UAVs) surveillance are readily deployed in smart city, industry, and healthcare verticals, and involves rich virtual-experience, that involves increased adoption of AR/VR technology. The supportive networks require massive data ingestion rates, ultra-high dense connectivity at low-transmitted antenna power, extremely high data rates, enhanced precision, and ultra-high reliability to support the mission-critical cyberspace applications. Some use-cases involve self-driving cars with massive sensor connectivity [6], emergency medical facilities through delivery-based UAVs [7], accident prevention in vehicular networks through roadside infrastructure units, ultra-high dense IoT (uHDIoT) in industry 4.0 and manufacturing verticals, low-powered AI-assisted healthcare sensors that communicate with edge-health and cloud servers [8], holographic data communication that supports remote surgery (telemedicine) [9], and real-time immersive AR/VR experience in online gaming. To support the stringent requirements of such applications, extremely reliable network orchestration and management are required to provision the QoE for users. The current 5G networks in the future would face bottlenecks to provide real-time QoE in the use-case mentioned above scenarios. Thus, researchers globally have proposed beyond 5G (B5G) and emerging sixth-generation (6G) networks as a viable and preferred choice to address the network capacity and high volume of data traffic.

6G networks are human-centric, rather than device-centric, and they holistically integrate users, processes, mobile devices and network, service management to interconnect and coordinate a plethora of applications. 6G technology enables edge intelligence through AI machine learning and deep learning models that enable transformation and connectedness for humans and machine-centric applications. In AR/VR, 6G supports haptic sensory and neural communications, with blended holographic support [10]. 6G nodes support internet-of-everything (IoE) communications through virtualized services and network-in-box management that expands wireless-access interfaces to support massive multiple access points to form a distributed, cell-less MIMO system. 6G supports terahertz frequency bands, 1 Tbps user-experienced data rate, round-trip latency of 0.1 ms, and supports services like extremely reliable low latency communications (eRLLC), with a reliability rate of 99.9999999% compared to 5G and B5G networks [11]. 6G services are backed up by federated learning, deep reinforcement learning, and photonic communication, reducing communication latency and increasing user QoE. For AR/VR users, high QoI is achieved by 6G networks through its associated services. AR/VR devices are computationally intelligent, and thus 6G leverages massive data-transfer rates to

support high 4K resolution multimedia, multi-dimensional holograms, haptics with low latency and high precision that drives applications like telesurgery, 3D-printing, responsive digital twins in industry 4.0, immersed multi-player gaming, and many more applications.

However, 6G communication networks interact with AR/VR applications and heterogeneous sensors, where user data is shared among multiple nodes. Due to open channels, the collected user data from various sources suffer from security and privacy risks in decentralized environments. The collected information can be classified as *Observed* (location data, motion tracking, and user-provided information/generated data), *Observable* (like virtual person/object, avatar, and real-time world/in-app), *Computed* (recommendation/advertising, and biometric information), and *Associated* (login/contacts/payment information, virtual assets, and IP address). An adversary can form informed attacks on decentralized AR/VR applications. The attack scenarios include impersonation-based attacks, internet-protocol version 6 (IPv6) based spoofing, session hijacking, anonymous linkage of session details that can be used to gain access to private and sensitive information. An adversary can use private information to sell, market, and spy through third-party applications for personal benefits. Other associated risks are involved against immersive digital content like consumer data protection, IP-assets, copyright infringement, and many more. Due to this, different industry stakeholders require a trust-based model and secured privacy agreements among various heterogeneous AR/VR stakeholders. Thus, blockchain (BC) ensures trust, transparency, and accountability to avoid fraudulent and tampered entries in consumer-oriented AR/VR applications.

BC technology is an immutable ledger that enables transactions in a chronological and timestamped manner. The block details are added through consensus mechanisms that are transparent to all users in the network [12]. It eliminates the requirement of third-party applications and thus supports secure and trusted data exchange in AR/VR channels. Thus, researchers have shifted towards BC-based AR/VR solutions and commercialization and deployment of secured applications. Moreover, smart contracts (SC) can streamline digital content laws and privacy guidelines of data sharing among multiple AR/VR stakeholders in decentralized peer-to-peer (P2P) ecosystems [13]. This increases the communication effectiveness and ensures transparency among entire flow cycles in a range of vertical applications, simplifying the business logistics industry 4.0 and allied sectors.

In industry deployments, BC ensures trust among a closed group of AR/VR stakeholders through a permissioned or private network, where verification and ownership transfer of digital assets is transparent [14]. SCs have programmed logics developed for native decentralized applications, or *DApps*, where contracts are executed among participating entities only when specified criteria are met. In permission-based BC, consensus mechanism like practical byzantine fault tolerance is applicable for small networks but poses

TABLE 2. Blockchain (BC)-based solution to address the challenges in AR/VR.

Parameter	Description	Potential benefit in AR/VR applications
Decentralization	Engagement of nodes in the transaction without relying on a central authority for record maintenance or authorization. Eliminates the single-point risk of failure	BC can help in the decentralization of various devices under communication
Tokenization	Facilitation for digital representation of goods, services, and rights. Allows users to exchange values on different networks	BC can enhance financial transactions through digital tokens
Immutability	Data stored via a consensus mechanism in the distributed ledger is unalterable and tamper-proof. Maintains the integrity of the end-to-end system.	BC can enhance sharing and securing the exchanged audio/video data between server and device
Scalability	Ability to support an increasing load of transactions and number of nodes in the network	BC can help in storing and peering data using Interplanetary File System to increase transaction size in each block
Anonymity	Enables the trust between nodes in-network even if all nodes are unknown to each other	BC can allow the nodes to create unique digital assets that can not be copied
Security	Safeguards data against possible attacks and leakages through the employment of cryptographic algorithms. No relationship exists between private and public keys	BC can improve cybersecurity for tactical applications using AR/VR devices

limitations with an increasing number of nodes. For high performance and scalability in permissioned BC networks, PAXOS, and RAFT are considered a more viable choice due to high network throughput and better scalability [15]. In major industrial AR/VR deployments, permissioned BC networks are a preferred choice over public BC owing to ease of node verification, consensus, and improved transactional throughput [16]. Thus, integrating 6G and BC networks in AR/VR space can drive a secure and responsive experience that satisfies high QoI for end-users. 6G services support applications like edge computing, energy trading, spectrum sharing, network virtualization, and many more. Hence, 6G-envisioned BC-based AR/VR guarantees trust, security, access control, authentication, distributed content management, and improved auditing experience, with ultra-low latency, high bandwidth, and extreme reliability [17]. Table 2 presents the description of BC-characteristics and the associated potential benefits that BC leverages as a solution to AR/VR ecosystems.

A. POTENTIAL OF BC AND 6G IN AR/VR SPACE

BC proves to have immense potential to secure AR/VR space. Firstly, using BC decentralization, users can create their full-fledged virtual world governed by a set of rules without the intervention or risk from platform developers. Secondly, BC allows copyright protection of the content as a user can record contents in BC. Thirdly, BC can enhance the popularity of VR by merging the latter with the cryptocurrency market, which in turn leads to increased profitability. The potential benefits of the 6G and BC coalition in AR/VR are listed as follows.

- 1) 6G networks can support THz communication at sub-millimetre bands, with extremely low latency. 6G supports virtualized service sets that support enhanced management and simplify holographic communications over physical boundaries. This allows real-time experienced reality (XR) for 3D imagery, driverless

cars, simplified digital-twin processed in industry 4.0, and massive connectivity in Internet-of-Things (IoT) networks.

- 2) To secure massive data-sharing among 6G communication channels, and leverage trust in AR/VR applications, BC ensures trusted decentralization among multiple nodes.
- 3) As AR/VR assets require fast image/video display and processing, the data is stored and exchanged through a local central server because of memory and processing limitations. The utilization of BC can enhance sharing and securing the exchanged data.
- 4) As AR/VR-oriented applications are data and bandwidth-hungry, the central server may get overloaded due to multiple asynchronous communication among AR/VR devices. BC can provide data decentralization in such a situation.
- 5) BC can enhance improvement in cybersecurity through sensitive data sharing, law enforcement, and public safety for military and battlefield applications using AR/VR devices. This significantly improves digital data sharing and effective collaboration.
- 6) BC can help in the commercialization of AR devices through the creation of a user-defined marketplace for storing and uploading AR content in a decentralized fashion. Moreover, the data can be stored and peered using an interplanetary file system (IPFS), that allows authorized stakeholders to access records with IPFS key, and hashed IPFS references are stored as external references in the BC ledger.
- 7) BC based decentralization can help users and developers to download and upload content, creating storefronts and marketplaces to enable commercialization of AR/VR devices for e.g. Decentraland [23], VibeHub [24].
- 8) BC-based tokenization enhances financial transactions where AR devices act as hardware and perform peer-to-peer transactions on digital tokens [25].

TABLE 3. Industry use-case deployments of BC in AR/VR and potential benefits of 5G/6G adoption in the projects.

Project	Organization	Objective	Duration	Valuation	Application	Benefits of 5G/6G adoption
Property Trading Game [18]	Upland	It is a decentralized application made to buy, sell and trade virtual real estate linked to real maps. Building a house and starting a business is made easy by BC-based economy in existence	2021-present	\$23,000	BC proves identity and provides authentication with virtual property and high speed networks	5G network ensures high throughput to support ultra-high resolutions of 3D-maps for virtual tours of real-estate property.
BC-based Ecosystem [19]	Victoria VR	Combines BC and VR to create a full-fledged virtual world without any third party intervention	2021-present	\$25,000	Allows users to create a world entirely of their own and with no risks due to trusted rules enforced by BC	Through eMBB services, a bandwidth of 100 Gbps is realized in 5G, and FeMBB has 1 Tbps in 6G, that ensures smooth interactions and improves QoI for virtual world applications.
Render Token [20]	OTOY	To transfer the power of graphics processor unit (GPU) into a decentralized economy of connected 3D assets. It uses high-speed networks and cloud technology	2020-present	\$300 million	Render Token aims to make it possible for any 3D object or environment to be authored, shared, and monetized through the Ethereum BC protocol.	Very High bandwidth of 6G network will enable processing and generation of realistic sensations and replicate the 2D image to a 3D transformation.
Virtual Lands [21]	Sandbox VR	To allow players to build and monetize their own gaming experiences on the Ethereum BC.	2019-present	\$68 million	Provides a virtual land which is a piece in 3D virtual space where users can do anything for an assortment of experiences.	6G network enabled by BC will create a virtual gaming experience to enable users better transaction with improved QoI.
Meebits [22]	Larva Labs	To attract crypto-buyers by creating a virtual world with video games virtual reality and high-speed networks	2021-present	\$3,300	Features avatar characters that powers the NFT project and attracts buyers to invest.	Improvement in speed through 5G network helps to achieve QoE in Gaming experience and mapping into the real-world experience.

B. SURVEY MOTIVATION

The motivation behind this paper is described as follows.

- Recently, AR and VR technologies have been implemented in various sectors such as education, medical treatment, construction, military affairs, entertainment, and industrial research. As AR/VR deployments would drive the future industry verticals, BC can assist in the security and uniqueness of assets to its users. Furthermore, BC-based AR/VR is implemented in cyber-physical ecosystems to support trusted ledgers and automated SCs among AR/VR stakeholders.
- 6G networks improvise upon 5G networks via increased reliability and high bandwidth channels. In the future, 6G is designed to support low-latency industrial IoT (IIoT), deep-sea and sky networks, and massively connected nodes for ubiquitous AR/VR experience.
- Thus, the integration of BC and 6G would address secured protocols and assisted networked infrastructures, virtualization, privacy, and integrity of remote computational AR/VR resources.

C. KEY TAKEAWAYS OF THE SURVEY

- The proposed survey presents the coalition of 6G network services at the communication plane, with support of BC at the application plane to provide dense real-time connectivity, high bandwidth, and secured data transfer among AR/VR applications. Table 3 presents real-world industry projects that have deployed BC-based AR/VR *DApps*, that are supported through current LTE networks. However, with the advent of 5G/6G network services, AR/VR applications are expected to have high connectivity at extremely

low latency. The key takeaways of the survey are highlighted as follows.

- We present a proposed architecture that supports decentralized system architecture that supports responsive edge-service communication, smart parking, vehicular networks, and industry 4.0 productions. The architecture highlights the applicability of BC to enforce security and privacy over 6G-assisted massive connected AR/VR networks. Through 6G, QoI among AR/VR users is enhanced, and BC maintains secured and chronological transactional ledgers.
- Through a proposed review method and designed research questions to be addressed by the survey, a solution taxonomy of 6G-assisted BC-based AR/VR is discussed in terms of security and communication perspective, and different use-cases of AR/VR are discussed.
- Open issues and challenges of the possible integration of 6G and BC in AR/VR are discussed, and an interesting use-case *BvTours* is presented that presents a 6G-assisted virtual home-tour service, that provides a 3D AR/VR based real-estate industry view to prospective buyers, presented by real estate agents. A flow scenario is discussed, and the performance analysis of the case study is presented in terms of network-based parameters like packet loss rate, packet miss probability, and BC-based transactional throughput.

D. EXISTING SURVEYS

This subsection presents the discussion on the existing surveys that have discussed in isolation the key principles of integration of 5G/6G networks and BC as a potential solution

TABLE 4. Comparative analysis of the proposed survey with existing state-of-the-art surveys in AR/VR.

Author	Year	Objective	1	2	3	4	Pros	Cons
Zhang <i>et al.</i> [26]	2019	The paper conducts a survey on various issues the industry faces which can be tackled with BC under IoT, 5G and industrial applications	Y	Y	N	Y	Integrates BC and IoT as blockchain-of-things (BCoT) exploring its architecture, limitations and applications	challenges to BCoT such as security vulnerabilities, privacy leakage and resource management and their solutions are not discussed
Olga <i>et al.</i> [27]	2019	The paper summarizes different challenges faced by the internet services and securing them using BC integration which will help create a decentralized internet service	Y	N	Y	N	It combines many research works and gives opportunity to BC-based applications and to foster the development of more realistic BC-based systems	BCs are classified and described but their limitations are not discussed
Yang <i>et al.</i> [28]	2019	The paper aims in finding new technical applications of BC by creating new dimensions of BC-based systems	Y	N	N	Y	Precise outlook on BC-based networks and the challenges faced which BC can resolve making it a secure and trustworthy internet	Different aspects of BC involving networks are discussed but their challenges and issues are not shown
Fraga <i>et al.</i> [25]	2019	To give a review on BC which helps industrial developers in cybersecurity, augmented reality and cryptocurrency. It also helps in deploying specific hardware infrastructure	Y	N	Y	Y	a Higher degree of the industry considered with automation, security, trust and immutability with BC	Cost-effective solutions for the industries are not discussed in particular
Hewa <i>et al.</i> [29]	2020	The paper explores the role of BC which address many crucial issues and challenges existent in 6G and it also predicts future directions	Y	Y	N	Y	The design of 6G networks is discussed which gives rise to new business ventures and shows how BC can change and improve the domain	Communication cost in 6G is already higher and integration with BC would cause economic and financial issues
Willis <i>et al.</i> [30]	2020	The paper shows performance analysis on latency aspects of networks and demonstrates integration of IoT and BC	Y	Y	N	Y	Studies network stability and latency across platforms and nodes in detail in smart contracts	Ineffectiveness in terms of cost of IoT based BC technology is not discussed
Dabbagh <i>et al.</i> [31]	2020	The paper surveys the empirical performance of different BC applications using certain criteria	Y	Y	N	Y	Figures out the performance characteristic of each BC platform which helps identify and discuss major factors	Performance of top BC companies in the world is not discussed along with the actual challenges faced by them
C. Fan <i>et al.</i> [32]	2020	To determine important criteria which can be then used to evaluate the performance of BC systems and compare it	Y	Y	N	N	Empirical and analytical evaluation is performed which suggests practical changes to be made in existent BC systems	Empirical and Analytical models do not propose practical solutions for mentioned problems under performance analysis
Liao <i>et al.</i> [33]	2021	To build an IC-mIoT network to achieve ubiquitous VR/AR services with the help of 6G network. A new consensus mechanism proof-of-contribution (PoC) protects various types of content and resource transactions in information-centric (IC) based massive IoT (mIoT)	Y	Y	N	N	The paper designs a perfect consensus algorithm for index selection and discusses optimal cache offloading strategy between nodes	Challenges of 6G networks could cause disadvantages in the algorithm and its applications
Proposed	2021	A comprehensive survey that presents the integration of BC and 6G into AR/VR, with a discussion of possible use-cases and applications	Y	Y	Y	Y	reference architecture of the possible integration is presented, along with a discussion of open issues and future directions. The integration of BC and 6G is backed through a proposed case study <i>BvTours</i> that highlights the benefits	

1 - Decentralized systems, 2 - Latency, 3 - Taxonomy, 4 - Financial Benefit, Y-shows parameter is considered, N - shows parameter is not considered.

to address network latency, bandwidth, security, and trust issues in AR/VR ecosystems. Table 4 shows the relative comparison of the proposed survey with the existing state-of-the-art surveys. Tahir *et al.* [34] presented an overview BC-assisted solutions for B5G networks. Dai *et al.* [26] presented the survey on IIoT issues and presented key principles of BC-based solutions to address trust and interoperability issues among different stakeholders. Alrubei *et al.* [30] presented a brief review by analyzing several latency aspects and also demonstrated the integration of BC and IoT.

Labazova *et al.* [27] developed a detailed taxonomy that demonstrates areas of BC in six different applications based on eight characteristics (reading access, writing access, anonymity, level, main consensus mechanism, event handling, data exchange type, encryption, and history retention). The taxonomy presents twenty-five applications bifurcated in twenty-one technical areas. Yang *et al.* [28] presented a survey that integrates BC framework for future internet-based services to aim security and development of decentralized, trustworthy service. The authors also present a case study for BC applicability in IoT-based neuro-informatics.

Fernández-Caramés and Fraga-Lamas [25] provides a detailed guide for most relevant blockchain-based applications for Industry 4.0 technologies and enhance the next generation of cyber-secure industrial applications like IIoT, cyber-physical production system (CPPS), big data analytics, industrial AR/VR, autonomous robots and vehicles, 3D printing, and assisted cybersecurity. Hewa *et al.* [29] explained BC-based interfaces and protocols in future 6G networks. The authors depicted future applications and service opportunities via BC in 6G systems.

Dabbagh *et al.* [31] presented a survey on empirical performance evaluation of different permissioned BC platforms on different frameworks (Libra, Ethereum, Parity, Geth, Quorum, Hyperledger Fabric) and demonstrated the performance of these frameworks according to ten different selection parameters. The proposed framework also facilitates the identification of factors that impact performance on the different platforms. Fan *et al.* [32] presented a systematic survey that covered BC-based performance evaluation in terms of empirical and analytical parameters. The authors derived that performance monitoring is the best empirical

analysis for public BC and analytical modeling is suitable for selecting BC. Liao et al. [33] introduced new technologies for AR/VR applications viz. BC for information-centric massive IoT devices (IC-mIoT) and Proof-of-Cache-Offloading (PoCO) consensus mechanism. The analysis proved the efficacy of the proposed scheme.

Till date, existing surveys have highlighted the key technologies, protocols, and implementations related to 6G communication in massive IoT (mIoT), IIoT, healthcare, AR/VR, and other verticals. The surveys have also focused on integrating secured data sharing and provenance through BC (security perspective) or network-based orchestration through 5G/6G networks (network-based perspective). However, a unified vision that holistically presents the integration of 6G and BC in AR/VR is not presented. Thus, a protocol reference architecture is required to address the end-to-end solution through communication and security-based layered stack architecture. Thus, the presented survey addresses the gap in earlier surveys through a proposed integration of 6G and BC in AR/VR ecosystems to cater to massive IC-mIoT, industry 4.0, finance, and healthcare application and render real-time analytics, responsive communication, and massive connectivity bandwidth through a secure and private network in open channels.

integrative solution taxonomy supported and validated through a designed case study.

E. ORGANIZATION AND READING MAP

FIGURE 2 presents the organization and survey reading map. Section II presents an overview of augmented and virtual reality and their applications, as well as the utility of blockchain and 6G network in AR and VR. Section III briefs the review methodology opted for the proposed paper. Section IV shows the existing centralized and BC-based decentralized architecture to support secure information sharing in AR/VR. Section V discusses the proposed solution taxonomy of 6G and BC in AR/VR applications. Section VI presents the open issues and challenges in 6G-assisted BC-based AR/VR applications. Section VII presents a proposed case study, *BvTours*, which presents a layered architecture for a 6G-assisted virtual real-estate touring service, and is supported through BC for transactional ledgers. For payment ecosystems, SCs are executed between buyer and seller nodes. Section VIII presents the performance evaluation of the proposed case study. Finally, section IX concludes the article.

This section gives glimpses of AR, VR, 6G, and blockchain (BC) technology. We explained the emergence of 6G and BC, potential benefits of BC and 6G in AR/VR space, and recent industry use-cases. The section intends to provide the readers with the motivation of the potential of BC and 6G in AR/VR and highlights the contributions of the article.

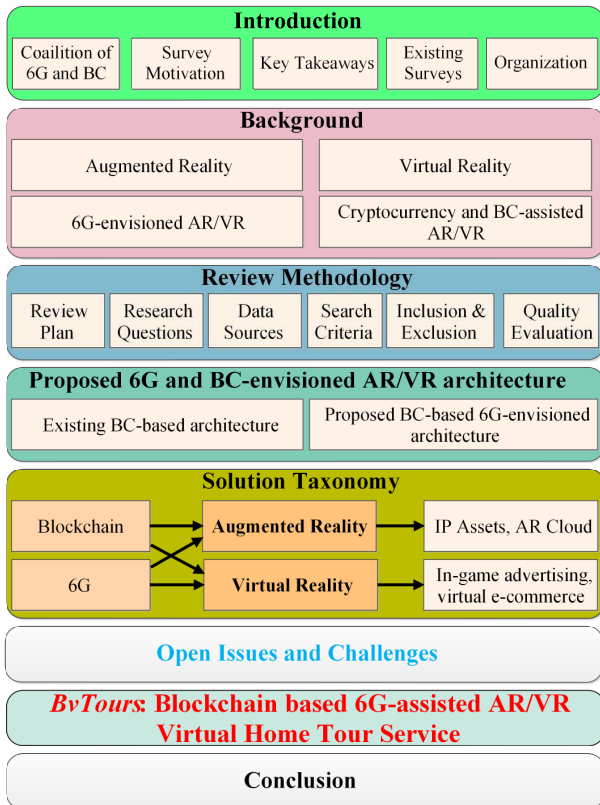


FIGURE 2. Organization and reading map.

In the survey, we present the key principles, reference layered architecture, and a possible discussion of an

II. BACKGROUND

The section is divided into four subsections. The first two subsections discuss AR and VR basics. The third subsection discusses features of 6G and its potential vision to support AR and VR applications. Finally, the fourth subsection delves into the integration of BC into AR and VR applications. The focus of the background section is to present useful insights to the readers about the key technical drivers like AR, VR, 6G, and BC to address the security and communication perspectives. The section thus addresses research questions RQ 2 and RQ 3, which are put forward in the review method section. RQ 2 is addressed through a coherent discussion on the integration between AR, VR, and MR technologies and their applicability in concerned user applications. RQ 3 is addressed through effective discussions on the integration of AR/VR with 6G communication networks.

A. AUGMENTED REALITY

AR can be thought to be a *middle-ground* between the VR and the real-world space. AR can be explained through the reality-virtuality continuum (RVC). FIGURE 3 depicts the continuum timeline. RVC presents the transition of reality to virtual space. As presented in FIGURE 3, at different points in RVC, the different degrees of interaction with AR/VR users

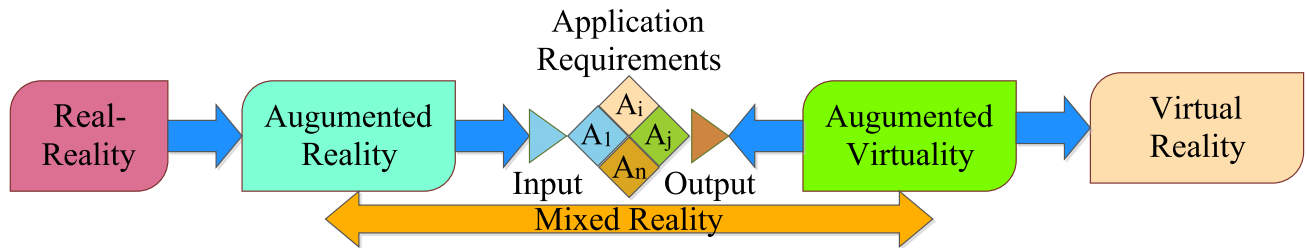


FIGURE 3. The reality-virtuality continuum of AR and VR.

changes. At the extreme left point in the RVC, we have real reality (RR), which represents the actual real world and its associated objects. This is the world that we humans know and interact. At the extreme right end of the RVC, we have VR applications that create a perfect simulation environment of the RR space. The VR space enables users to interact through perceptual and sensory elements with the objects in the RR space. At the middle points, we have AR and augmented virtuality (AV) space between RR and VR. AR superimposes and emulates multimedia elements like images, videos, audio as perceptual elements for AR users to interact with RR. Still, there is a distinct separation of VR and RR space. Thus, an observer in AR can experience both RR and VR in real-time but cannot interact with both worlds simultaneously. AV superimposes RR on VR, but current deployments are not matured enough to address the superimposition in a complete sense. Thus, we have a middle-ground between AR and AV, denoted as MR, that presents a near-close enough experience of AV. Through MR, both virtuality and actuality can closely interact in real-time, enabling MR users to interact with both virtual and physical environments and objects through high-level imaging and sensing technologies. Thus, MR can potentially digitally transform the entire RR workspace and apply digital user content to the MR space. This enhances user QoE, with enhanced capacity to apply digital information directly to a worker's real-life experience. Thus, MR applications have been an emerging trend in diverse application sets for business logistics. Extended reality (XR) covers the entire umbrella of the MVC and allows the superimposition of different applications $\{A_1, A_2, \dots, A_n\}$ to interact, play, and share content. The input depends on application requirements, and the preferred output is the user requirements, which enhances the QoI at the user end.

In practicality, AR and VR are developed before MR developments. The potential applications of the AR/VR space are the entertainment, print media, and gaming industries. The potential industries have driven a range of business, educational, and informational users and have allowed mapping of a virtual object in a real space [35]. In present-day mobile applications, key elements of AR are increasingly used to improve the user experience of interaction with applications. AR also helps in the improvisation of knowledge dissemination, mainly through interactive educational apps and healthcare apps. Broadly, AR is classified into four types,

namely, *Marker Based* (Image Recognition), *Marker Less* (Location-Based), *Projection Based*, and *Superimposition Based*. Aggarwal and Singhal [36] presents AR as an interesting use case of intelligence amplification (IA), which allows the usage of computers as a tool to make interactive and intelligent human experience to perform day-to-day practical tasks.

B. VIRTUAL REALITY

VR presents the virtual experience of the real world, which presents the dynamic views of the RR in terms of created virtual objects. VR is highly dependent on four technologies: visual displays, graphics, tracking systems, and database construction and maintenance. For an effective VR experience, rendering engines play an important factor in managing the moving and tracking speed by measuring device processing latency. VR finds interesting use-cases to support different application areas like vehicle simulation, entertainment, vehicle design, architecture design, microscopy, and many more. VR has improved the user experience and real-time control; however, VR expansion in industrial deployments is challenged due to high-end communication latency, mass rendering of large simulated models, and effective scalability of VR objects in real-world space [37]. VR presents the virtual superimposition of real-world objects of RR, and enhances the immersive content to support key technologies like IoT, enhanced 3D-modelling, virtual education, and many more [38].

However, VR is challenged by interfacing the real objects at present acceptable scenes with ultra-low latency. Thus, VR requires effective network management to ensure high-quality video content streaming, perceptual movements, and multi-mode interfaces. In gaming, VR requires 3D-joysticks to support the integrated natural language processing libraries and hand-gesture movements. As speech and motion are primary interfaces, there have to be real-time movements to ensure avatars' smooth and streamlined motion in the VR world. Moreover, it requires heavy rendering and graphic engines to support the environmental conditions, such as sounds, removal of second-order noise, echo-cancellations, to add a personalized user experience. To cite an example, VR can support the environmental conditions that are exactly similar to a hot summer environment in a desert land

and the feel of a sea breeze. To ensure effective rendering, AI-supported engines can drastically learn from the local environment, set-up patterns, and responsive agent functions that provide the real experience of RR in the virtual world. To ensure user data privacy, cryptographic primitives are used for the encryption of data. With the emergence of quantum computers, privacy through quantum-key distribution is used to ensure the perfect secrecy of the user. Quantum computers work on associated *qbits* that can exist in multiple non-deterministic states to support parallelism in tasks. This reduces the overall computational complexity of hardware engines and mitigates the security vulnerabilities [39].

C. 6G-ENVISIONED AR/VR

6G communication is envisioned to support dense-network connectivity, massive coverage, low-powered nodes, and effective AI-capability that supports mIoT. 6G is capable of supporting $< 10^6$ parallel sensor connections per sq. km range. 6G allows computational intelligence to enhance AR/VR perception models at extremely high reliability and coverage range. 6G is envisioned to support smart city verticals like vehicular-to-anything networks, internet-of-bio-sensory things, supermassive edge computing, AR/VR use-cases (for example, remote surgery, holographic mind-mapping, immersive gaming experience, haptic communication through sub-millisecond (< 1 ms TI service), optical radio access cores with photonic communication for super-dense visible light communication [40]. 6G support virtualization through SDN and does not require manual orchestration of nodes. Thus, it addresses the limitations of 4G-LTE and 5G-RAN cores in manual optimization and task configurations. 6G networks operate services in virtualized containers to provision resource requirements to nodes. 6G-based TI service enables haptic human-to-machine interactions and is predicted to drive industry 4.0 to encompass an entire cyber-virtual space, where physical objects and processes would be in close interaction with humans, sensors, through touch and perception. The generated digital content would be transferred through intelligent physical and MAC layers through edge nodes. It would support diverse applications at the user level with a real-time AR/VR experience.

In summary, 6G is envisioned to provide the following services to industry 4.0 and telemedicine.

- 6G-TI services would strengthen the entire IIoT control systems to replace the legacy industrial ethernet communication with a new diverse set of 6G-enabled IIoT protocols. The latter would offer responsive automation of physical processes.
- 6G would kick-off IIoE revolution, led by immersive XR, digital twin processes when coupled with holographic communication, complex machine learning, and deep learning models that would train sensors, robots to perform day-to-day tasks. Furthermore, due to intelligent AI-based learning techniques, the massive training data would be densely interconnected to support extreme low-level device offloading latency.

- In healthcare 4.0 ecosystems, 6G would revolutionize telemedicine/healthcare through interactive and haptic AR service. For example, robots would communicate with remote doctors to operate telesurgical operations, which would be supported through responsive 6G-based tactile internet services. In addition, VR service would allow doctors to feed and precisely examine, enlarge, and view 3D models of body parts through 6G-based remote networks. This would enable doctors to practice medical procedures without requiring physical presence at the hospitals and carry out complex surgery procedures through surgical robots.

D. CRYPTOCURRENCY AND BC-ASSISTED AR AND VR

Cryptocurrency gained prominence through Satoshi Nakamoto bitcoin ledgers and has transitioned today as digital asset forms that are shared and distributed across multiple P2P nodes. It laid the starting foundation of blockchain 1.0, through which digital transactions are performed without the requirements of a third-party financial intermediary [41]. Cryptocurrency-based transactions are immutable ledgers, where a virtual amount is deducted through the sender's financial wallet and credited to the receiver's wallet. Once the transaction is completed, the record is added to a particular block, which is mined after sufficient transactions are added to the block. Once the block is mined, the transaction ledger state is reflected across all nodes in the P2P network. A recent Markets & Markets report indicates that the cryptocurrency market in 2010 is approximately \$3 billion, and it is expected to rise to \$39.7 by 2025, at a CAGR of 67.3% [42]. The adoption of cryptocurrency has also increased, seen in market capitalization, users, and transaction volume. The cryptocurrencies operating in decentralized nature also put trust into users [43].

Blockchain 2.0 introduced Ethereum chains and presented the design interface for the realization of SCs. As financial markets evolved, BC gained prominence into a range of vertical applications, and the need and requirement of decentralized applications, or *DApps*, came into view. This led to the inception of blockchain 3.0, or the design of *DApps*, to support BC-based applications other than finance. Some notable applications include healthcare records storage, secured asset transfers, loan and credit operations [44], and many more. Some of the notable cryptocurrencies include bitcoin, ethereum, peercoin, dogecoin, auroracoin, and permacoin [45].

BC, on the other hand, differs from basic cryptocurrency primitives and is defined as a distributed, timestamped, and chronological ledger, where appended transactions cannot be modified. In case of modification, the block hash changes, and thus it invalidates the entire chain. In the case of bitcoin cryptocurrency, the block size is 1 MB. A block consists of the block header and the body. The block body consists of the list of added transactions to the block. The block header contains the current block hash, the previous block hash, block timestamp, nonce, and the Merkle

TABLE 5. Research questions to support the proposed study.

Q. No.	Research Question	Objective
RQ 1	What are the challenges in BC adoption in AR/VR applications?	To get an overview of BC technology and its major challenges and adoption issues in AR/VR applications.
RQ 2	How AR/VR applications can provide user interactive experience?	This question aims to explore the applications of AR/VR to improve QoI in smart city environments.
RQ 3	What are the visions and applications of 6G to provide network orchestration in AR/VR?	To discuss 6G key principles, features, and underlying protocols in designing interactive AR/VR applications.
RQ 4	What are the challenges of BC in security and data handling in 6G?	This question helped to study the BC architecture for massive data management, interoperability, automatic interaction and transactions among devices as well as reliability with open issues and challenges.
RQ 5	What are the key benefits of 6G in an overall superior AR/VR user experience?	To discuss and implement 6G communication technical parameters in a use-case scenario.

hash value. BC has evolved to support trusted transaction exchange among many finances, education, edge networks, AR/VR, and many more applications. The issues and challenges faced by AR and VR in different industry verticals are discussed in the article. We present the emergence of decentralized and trusted AR/VR through BC that ensures immutable, timestamped, and chronological ledgers. For persistent connectivity, we propose the benefits of 6G networks as key drivers in AR/VR [46].

This section details the background of AR, VR. We subsequently envisioned the importance of 6G and BC. After reading this section, the readers can understand AR, VR concepts for visualization of their requirements in various applications and industry verticals.

III. REVIEW METHODOLOGY

The section presents the review methodology and is centered around the regulations proposed by Kitchenham et al. [47], [48]. The complete review is partitioned into six logical strategies mentioned below.

A. REVIEW PLAN

The proposed survey was outlined systematically. Following steps are followed for literature (i) Determine the research questions, (ii) observe sources of data, (iii) apply constraints for search on collected data, (iv) apply criteria for inclusion and exclusion, and (v) Assessment of quality. This literature survey includes different publications such as research papers, books, and articles in a relevant domain such as AR/VR, 6G, and BC. The gathered material was analyzed for quality, and then the relevant data for the topic was retrieved from the survey. A well-planned and systematic review can assist researchers in producing fair results without any biasing.

B. RESEARCH QUESTIONS

We have provided the outline of existing literature on 6G and BC in the field of different reality systems and networks. We have also identified and listed some research questions in Table 5 along with their objectives to support the carried out survey.

C. DATA SOURCES

We have identified digital libraries (data sources) like *IEEEExplore*, *Springer*, *ACM*, *Science Direct*, *Elsevier*, and many more. These academic libraries provide a rich and diversified literature that we explored to carry out the proposed survey. Kitchenham et al. [47], [48] also recommends usage of electronic data sources for literature survey. We have also referred to other resources like articles, technical reports, and blogs, books, patent contributions to carry out an exhaustive survey in our related field.

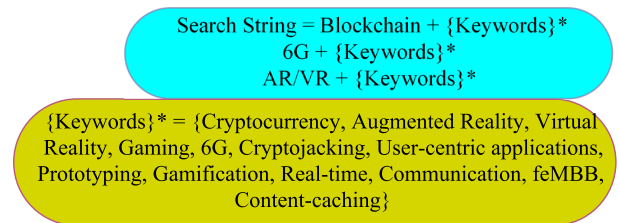


FIGURE 4. Search Strings.

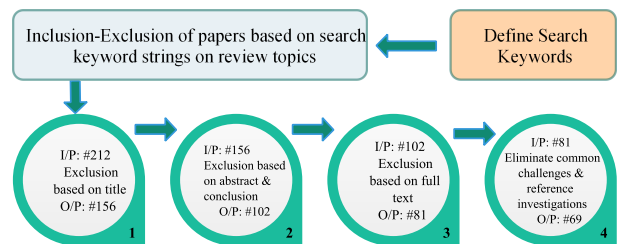


FIGURE 5. Inclusion and exclusion criteria.

D. SEARCH CRITERIA

The papers related to BC and its current and future implementation and integration in AR, VR underlying 5G/B5G/6G networks have been considered for the survey. FIGURE 4 refers to the keywords and search strings utilized for relevant topic search. We progressed in our search by also considering online articles as well as references to the collected papers.

E. INCLUSION AND EXCLUSION

We start the process by filtering papers according to the topic's relevance. Initially, we scanned the academic repositories for the papers that are centered around the search string

that combines *BC AND AR/VR*. Next, we selected the papers with the keywords *5G with AR/VR*, an *6G with AR/VR*. Next, we use the *OR* keywords to increase our academic database. We also collected papers centered with the keywords *Cryptocurrency AND AR*, *Cryptocurrency and VR*, and used 6G service names like *FeMBB in AR/VR*, *muRLLC in AR/VR*, and others. Then, we excluded the papers that were not of potential interest for our survey article. FIGURE 5 depicts the inclusion and exclusion criteria for the proposed survey.

F. QUALITY EVALUATION

We have assessed quality evaluation on the reference literature as per standard guidelines provided by Database of Abstracts of Reviews of Effects (DARE) and Center for Reviews and Dissemination (CRD) [47].

This section discusses the review methodology. We discussed the research steps as per defined guidelines and regulations to fulfill subsequent research requirements.

IV. PROPOSED 6G AND BC-ENVISIONED AR/VR ARCHITECTURE

In this section, we present the existing architecture that caters to AR/VR technology requirements. First, we present the details of decentralized 6G-envisioned BC-secured AR ecosystems. Then we present a more holistic picture covering different use-cases of smart city technologies centered around decentralized AR/VR applications, namely smart wearables, edge server computing, and smart parking. We highlighted the key fundamental of 5G/6G communication aspects to support the network management issues in these applications. Finally, the section addresses RQ 1, as the section addresses the potential benefits and reference architecture of the BC-envisioned AR/VR ecosystem in massive IoT environments.

A. EXISTING BC-BASED AR/VR ECOSYSTEM

This section presents a use-case of the industry 4.0 automation ecosystem and focuses on the automatic inspection of machines and processes to automate the in-site monitoring process. The collected data from in-site monitoring systems are analyzed through supportive AI techniques and are passed to different supply-chain stakeholders. To support massive bandwidth requirements, we assume communication through 6G-FeMBB service to leverage real-time automation and control. Once the data is presented to different stakeholders in the supply-chain ecosystem, BC is used at different supply chain points to ensure consistency and timestamped chronology among users. FIGURE 6 shows the architecture of a decentralized system along with AR and VR.

- *Utilizing AR in Industry 4.0 process cycle:* We discuss AR as a key driver for the industry 4.0 automation cycle that supports manufacturing, robotics, and automated

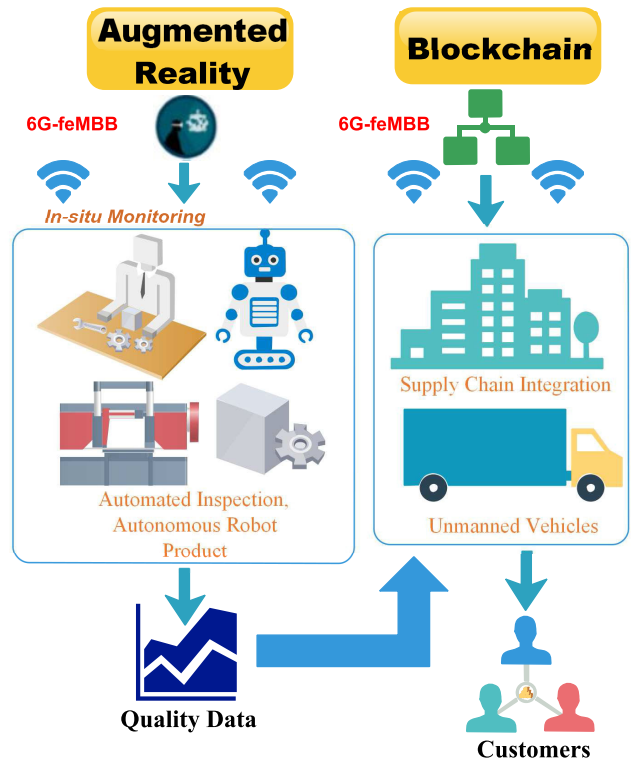


FIGURE 6. The decentralized system architecture in AR.

inspection of products. In the existing scenario, the industrial machines are sensor-driven and are networked to support different processes in action. At the in-site architecture, robots are employed to monitor and physically inspect the different processes. Through robots, human intervention is minimized and is particularly useful in hazardous industries like petroleum, chemical, natural gas, and oil industries where boring and drilling operations involve significant risk to human life. The robots collect sensor data, and the collected data is aggregated and sent to the cloud server for analytics. To improve robots' learning, reinforcement learning is a suitable choice as it ensures a reward-penalty-driven mechanism so that robots can learn and adapt to external environments. The functioning of the sensors and robots can be viewed through AR-driven interactive controls, and robotic gestures can be monitored visually. AR systems consume a lot of bandwidth, and thus network management is a critical aspect. In the industrial process, real-time automation is required in critical applications like bomb disposal, driving vehicles, heavy-weight lifting, assembly pipelines, and many more. Thus, 6G-FeMBB networks can support the real-time bandwidth, which ensures precision and a consistent network. For low latency, services like TI, muRLLC, and mMTC (for sensor-to-sensor communication) are preferred.

- *Data Analytics:* AR collected data such as high-resolution videos and images of the day-to-day process are used for *Ground-Zero* analytics. A back-end data

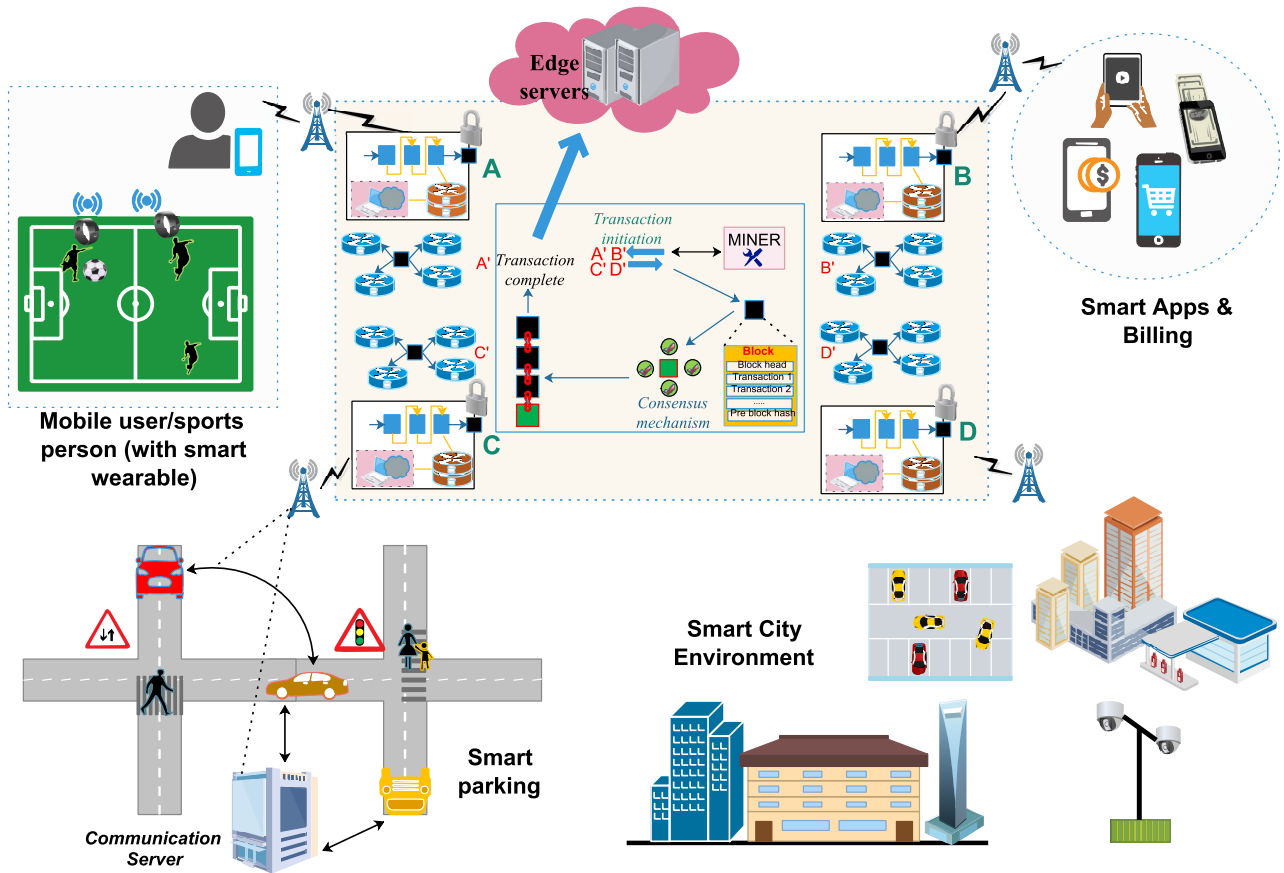


FIGURE 7. A proposed reference architecture of BC-based 6G-envisioned massive IoT-supported AR/VR ecosystem.

visualization engine would process the data and provide the required visuals. BC ensures decentralization and encryption and provide data access to authorized people.

- **Supply Chain Integration:** In supply-chain ecosystems, BC-ensures chronological and timestamped points between every stakeholder in the chain, that starts from the manufacturer, the supplier, logistics, warehouse storage, buyers, and the users. Thus, at each key point, trust is required. BC leverages the required trust among all points in the supply-chain ecosystem and ensures automated funds transfer between every stakeholder through associated SCs. Thus, manual intervention is reduced, middle-men and third-party intermediaries are removed, and black-marketing, and hoarding of products are eliminated. This ensures a complete and transparent end-to-end ecosystem. BC allows all users access to the same state of the ledger, thus improving errors' traceability. BC also improves the quality and proper access-control on shared data that reduces the production cost. Working machines and fault isolation in AR and VR supply-chain systems becomes easy as machine models can be easily viewed through realistic 3D modeling. Thus, AR/VR supported the supply-chains result in higher production, minimized cost, reduced machine downtime, and increased profits.

B. A PROPOSED REFERENCE ARCHITECTURE OF BC-BASED 6G-ENVISIONED MASSIVE IoT-SUPPORTED AR/VR ECOSYSTEM

This subsection proposes a reference architecture for a smart city ecosystem that supports different IoT verticals like smart vehicles, smart parking, interactive XR, smart wearables, factory automation, and many more. FIGURE 7 presents the key details of BC-leveraged 6G-envisioned massive IoT-supported AR/VR ecosystems.

In the proposed architecture, we envision the use-case of a massive information-centric IoT ecosystem, with services orchestrated through 6G communication systems. IoT encompasses millions of connected sensor devices that constantly interact and interplay with 6G edge and cloud nodes and requires high data ingestion and ultra-low latency nodes. 6G offers ubiquitous connectivity and access to different IoT verticals like smart automation, smart homes, smart industries, and smart playgrounds, with interactive AR/VR experience embedded with the nodes. AR/VR nodes are expected to transition massive IoT data and require high data-rate support for the peak bandwidth scenarios to address 6G-access nodes bottlenecks. In 6G networks, due to high demand by AR/VR users, we envision a massive-IoT framework where the services and demands are fully mobilized through an array of a 6G-based integrated network of airspace, land, sea, and

TABLE 6. Low-powered consensus approaches suitable for IoT envisioned AR/VR platforms [49].

Consensus Protocols	Blockchain Type	Category	Performance Indicators	Storage Overhead	Miner Selection	Attack Perimeter	Platforms	Limitations
Proof-of-Elapsed Time (PoET)	Both Permissionless Permissioned	Proof-of-Work (PoW) with low energy consumption	S-Medium, Lt-Low, T-Medium	High due to timer based executions	Random miner selection based on a waiting time	Less as executed in trusted scenarios	Hyperledger-Caliper, Sawtooth, Trusted execution environments (TEEs)	Dependent of Intel software guard extension (SGX) proprietary solution
Delegated Proof-of-Stake (DPoS)	Permissionless	Proof-of-Stake (PoS) based representative democratic	S-High, Lt-Low (≈ 1.5 secs for block addition, T-High (10^6 bps)	High due to vote results stored in addresses	Stakeholders vote to choose witnesses and delegates	> 51% attack by witnesses	Bitshares Cryptocurrency	Dependent on monetary stakes to choose the witnesses and delegates during mining, hence trust and transparency is reduced
Proof-of-Importance (PoI)	Both Permissionless Permissioned	Reputation-based PoS	S-Medium, Lt-Low, Th-High	High overhead to maintain reputation scores	Node with high reputations are called for mining	> 51% importance	NEM Cryptocurrency	Monetary dependent on nodes
Practical Byzantine Fault Tolerance (PBFT)	Private, Permissioned	BFT family	S-High, Th-High, Lt-Low	Low due to effective node agreements	2/3rd of nodes agreement	> 33% malicious or faulty nodes	Hyperledger controlled by third party	Only applicable to small-sized IoT design, not scalable for large networks
Stellar	Permissionless	BFT variant-based on federated BFT	S-High, Th-High, Lt-Low	Medium due to construction of quorum slices	Nomination and ballot protocol	Variable as it uses federated nodes to form PBFT	Micro-finance service	Not scalable for large scale IoT networks
Tendermint	Permissioned	A hybrid variant of PBFT and PoS	S-High, Th-High, Lt-Low	High due to storage of voting results	Voting power is determined and is proportional to the probability of leader selection	> 33.3% voting power	Cosmos software development kit, Binance, Inter BC communication (IBC) Protocol	Relies on monetary concepts and is thus not suitable for low-powered IoT
Raft	Permissioned	A variant of PAXOS, non-PBFT	S-High, Th-High, Lt-Low	High due to maintenance of logs at multiple sites	Leader election and log replication	> 50% faulty replicas	Atomix, Dotnext, Rafty, Microraft	Low security, and thus with an increase in security, throughput decreases
Tangle	Permissionless	Directed acyclic graph (DAG)-based consensus	S-High, Th-High, Lt-Low ≈ 10 ms	Low due to DAG paths	Leader election and log replication	> 33.33% computing power and 50% faulty nodes	Corda, Quorum	Node corruption rates are higher, hence secured exchange requires validator overheads
Omniledger	Permissionless	Verifiable random function (VRFs)	S-High, Th-High, Lt-Low	High as validators are required to store full transaction history	Committee selection and VRFs for miner election	> 25% faulty nodes	ByzCoinX	Large communication overheads not suitable for constrained IoT

massive wireless TI networks. Moreover, 6G is envisioned to employ edge intelligence schemes like machine learning and deep learning algorithms, for example, computer vision algorithms to detect vehicle movements, deep-sea sightings, and others. In this scenario, the content services provided by AR/VR are expected to communicate with vehicular networks, UAVs, user nodes, NFV-supported routing nodes, and production systems to involve the immersive XR. Some notable use-cases include AR/VR supported UAV monitoring; AR/VR assisted autonomous driving, and AR/VR-based plug and play user services.

To leverage the supportive AR/VR integration with 6G-envisioned massive IoT at low latency, trusted content-caching is critical. The shared data of multiple users and requests for data access have to be secured to ensure privacy, trust, and security from malicious attackers. Thus, we ensure BC as decentralized and traceable ledgers in the ecosystem to mitigate the attack vectors. Also, SCs can be

executed on-demand to ensure the automated flow of funds among different nodes involved in transactions. To ensure the key potential of BC in 6G-envisioned information-centric IoT, we assume that edge routers have to build local BC ledgers and verify the local transactions through elected nodes. Thus, a permissioned BC is more suitable, where the access and control rights are only with the authorized stakeholders. The permissioned BC nodes would record the local transactions, collaboration contracts in 6G-massive IoT, including paid content AR/VR service, paid edge-resource transactions in terms of computation, bandwidth access, and communication-related services. There are two major constraints to deal with massive IoT communication, viz. energy consumption, and latency. BC records the world-state ledgers for all the transactions and forms the respective endorsements in the permissioned ledger.

Table 6 presents the power and latency efficient consensus mechanisms proposed for massive IoT AR/VR space.

TABLE 7. 6G and BC as key-drivers for AR applications.

Perspective	Key Benefits in 6G	Key Benefits in BC
Security	The network used by AR developers needs to be strong and secure to which they can sign up and use their GPUs to render the latest applications	Scaling AR where developers can contribute their system power and can earn tokens with cryptocurrency which can be redeemed for credits
	For creating IP-protected digital assets, BC, AR, and computer vision require large bandwidth and a strong network	BC helps create and provide identity to assets so that they cannot be replicated. For example, CryptoKitties using the Ethereum BC network
Communication	BC companies requiring cryptocurrency with online transactions require huge speeds and reliable networks. 3D objects and data also require large bandwidths.	Apart from providing authenticity and verifying the assets, BC solutions and cryptocurrency are aiding many companies like Microsoft, IBM, and FedEx.
	Entities in AR are 3D in nature which requires dealing with big data and brands, which has led to a surge in AR app development and market fragmentation.	BC secures ownership rights and aggregates AR experience for multiple organizations simultaneously.

TABLE 8. 6G and BC as key-drivers for VR ecosystems.

Perspective	Key Benefits in 6G	Key Benefits in BC
Security	Digital worlds that use VR from live entertainment to gaming and virtual software need secure and high-bandwidth networks.	BC helps to verify the copy of an item, irrespective of its form, to avoid stealing and preserving the identities of VR users identities and establishing ownership.
	Seamless networks across countries provide uniformity and ease of sharing and the universal nature of the content, establishing global connectivity.	BC helps develop a single technological platform that would act as a transmission mode and standardizes fragmentation.
Communicative	The modern gaming landscape requires effective networks that allow the users to connect and the servers in real-time	BC-linked coins can help users interact with advertisements and also links information based on the interests the users show through ads.
	When consumers need to travel to a specific location, a network of relatively high bandwidth is recommended that keeps them secure	BC provides authentication and stores with the copyrights of digitally created entities and keeps them secure.

Certain IIoT devices rely on batteries also to operate; they require a low-powered consensus approach to reduce mining time and complex cryptographic computation overheads. Along with energy-saving, multiple IoT networks and nodes communicate with each other in real-time. These nodes typically rely on intermediate gateways for mining, increasing overall latency during critical AR/VR applications. As depicted, the choice of a particular consensus protocol depends on the type of supported application. In industrial IoT networks, there is a trade-off in scalability and associated cost to support the high transaction rate. Some consensus protocols like Practical Byzantine Fault Tolerance (PBFT), Tangle, and Raft are suitable in IoT due to low costs but are not scalable for large networks. On the other hand, Delegated Proof-of-Stake (DPoS), Proof-of-Importance (PoI), and Omniledger are more apt for large-scale IoT ecosystems but would require high storage overheads. The choice of an optimal consensus thus requires a careful study of the network requirements, and tailor-made consensus are leveraged for respective networks [49].

For content services in 6G-massive IoT, we propose a content-centric IPv6 network that would replace the legacy IPv6 and IP router nodes. The content-centric IPv6 would be controlled through NFV-state, and thus, it would effectively decouple the IP address with the content location and form an effective content address. The routers are envisioned to support the content-addressing scheme. Through a unified content name, the edge router closest to the content would service the required user. Thus, it would drastically reduce the high-end latency requirements of sending the content request to cloud-based services. Based on the user behavior, recommender systems can be built on the router as an additional service that can cache content from local edge

routers or send the request to the cloud servers to gather similar contents. The nodes can request cache offloading from edge-IoT nodes based on an agreed resource pricing mechanism.

In case of cache-offloading request, the requested AR/VR content, the nodes would check its local cache list to inform the user whether the content is available or has to be serviced through a pricing model. In case the content is present, a 6G-FeMBB service is set up to download the content. The cache list consists of an index-pair address of the actual stored content and gets updated if the content is modified. When the latter happens, the cache list is *not-authoritative*, and a fresh copy of content has to be fetched. The content request is forwarded through NFV-flow table requests to the 6G-access nodes.

This section discussed the existing BC-based AR/VR techniques deployed and their limitations. Subsequently, we presented reference architecture based on BC and 6G for the massive IoT AR/VR ecosystem. The readers can understand the difference between existing and proposed architecture and the implied advantages.

V. SOLUTION TAXONOMY

In this section, we present a solution taxonomy based on the coalition of BC and 6G in AR/VR ecosystems. FIGURE 8 shows the proposed solution taxonomy. We present the key benefits of BC integration in AR and VR ecosystems. Table 7 presents the key benefits in the AR ecosystems, whereas Table 8 presents the benefits in VR. The technical perspective are presented as follows.

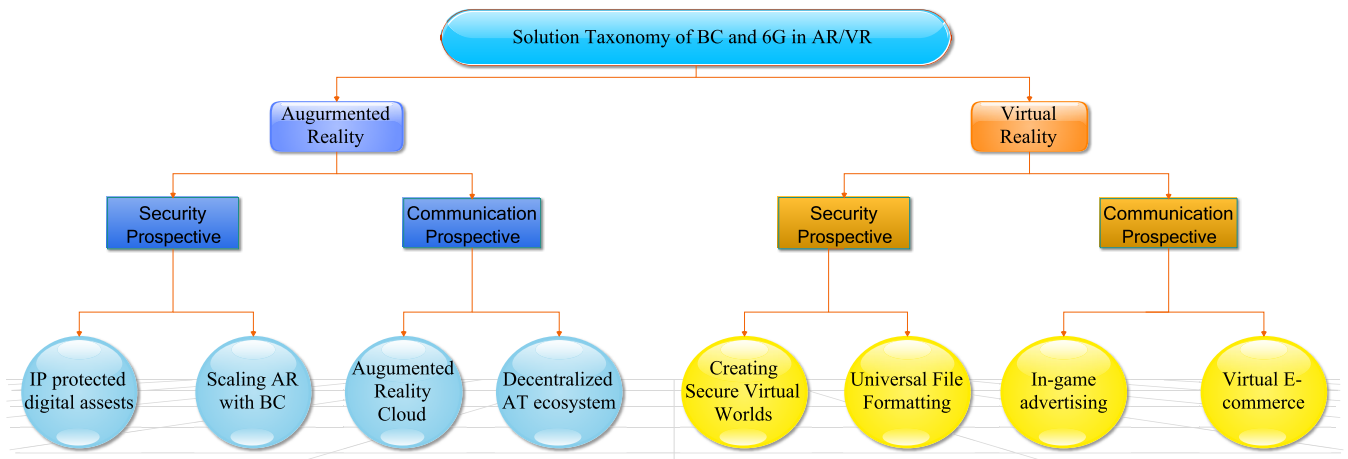


FIGURE 8. The proposed solution taxonomy of coalition of 6G and BC in AR/VR ecosystems.

A. AUGMENTED REALITY

There are several scenarios where AR-based systems can obtain huge credibility from BC. The details are presented as follows.

1) SECURITY PERSPECTIVE

In this section, we talk about the applicability of BC and 6G in AR to show how the latter would benefit applications that require high data rate handling and processing at desired levels of security, trust, and access control. Thus, we form the creation of a decentralized framework for assets identification.

a: CREATION OF IP-PROTECTED DIGITAL ASSETS

When it comes to digital assets, verifying whether they are unique or replicated is a difficult task. For creators of digital assets in VR or AR, BC allows the virtual items unique and non-redundant properties. This application of BC increases the privacy and security amongst users and their creations. Some companies combine BC and VR to sell virtual real estate in which the uniqueness and validness of the asset are the keys. For example, *Lampix* combines BC, AR, and computer vision to track virtually represented data at various places. With BC-driven intellectual property, there are many advantages. BC holds the values of IP assets that are owned by different businesses and companies across the world. Licensing and authenticating these agreements can be made easy with SCs, and it would provide definite evidence of ownership for virtual and real assets. Thus, in the legal sense, BC has the potential to drive matters that involve jurisdiction as easy to proof systems as it can assert the ownership of digital assets stored in the distributed chain ledgers. Thus legal disputes are resolved easily [50].

b: SCALING AR WITH BC TECHNOLOGY

A new use-case of AR technology is the virtual try-on, which allows consumers and shoppers to try new outfits at home

easily, and look and feel the outfits on their bodies. The try-on facility is expanded to design homes as paint colors, fittings, and other materials, and thus extracts huge revenue in the interior design sector. However, the current cloud infrastructure is not mature enough to handle these applications' high bandwidth and latency requirements. To address the issue, a decentralized peer-to-peer network is more applicable. Thus, the render network (RNDR) aims to address the issue by creating an extensive peer-to-peer network that consists of graphical processing units (GPU). After this network is ready, any GPU can power this network which can be utilized by AR applications to render their updated applications. In return, owners of these GPUs earn render tokens that can be redeemed for cash or render their graphics. As this network progresses, the entire system changes and upgrades into a decentralized marketplace. Hence, this network would help and aid the distribution and monetization of immersive, interactive XR, and light-field media on thin client devices like AR glasses, light-field displays, and mobile untethered VR headsets [51].

2) COMMUNICATIVE PERSPECTIVE

This subsection discusses the applicability of BC and 6G in AR through a high-speed, reliable network for 3D interaction and security of ownership.

a: AR CLOUD

The AR Cloud is a real-time mapping of the world object, which is cast on the RR. It connects the physical and digital worlds using spatial computing technology. It acts as a digital twin to provide real-world experience to users from any device, location at any time. As the BC technology helps the user verify the authenticity of the digital asset being sold, it can prove hugely profitable, especially in situations where the asset is region-specific in the case of video games where actual profit can be made considering the rarity of the asset. This, in turn, influences the AR applications and turns them into profitable ventures. Companies across the world can

create their custom version of AR Cloud, and it can open up a new stream of interactive market [52].

AR Cloud, when integrated with various technologies such as computer vision, localization, mapping, and 6G connectivity, can deliver persistent content. Google's AR-based navigation uses Google's visual positioning service (VPS) and AR cloud to increase accuracy.

AR Cloud also has a huge potential in gaming. For example, Google's *Just A Line* game allows people in the real world to draw collaboratively in a virtual world together. This could allow engineers and architects to design and create internal structures of places in the future. With AR Cloud, coaches in sports could provide live feedback, ease judgments, and speed-up updates. AR Cloud could solve the problem of buying real-world 3D objects based on 2D images available on the website.

b: UTILIZING BC TO POWER A DECENTRALIZED AR ECOSYSTEM

AR can be used to run marketing campaigns and advertising. It can directly help users find their required product with ease. As AR is a 3D map, consumers can be guided to specific shops where required brands or products are offered. Different apps can be made for public places like parks, and museums [53]. To simplify the union between BC and AR, one can consider the game *Pokemon Go* for real where every *Pokemon* collected is unique, and each has its own set of distinct abilities. Hence, the rare ones could make the fans or customers hunt and trade them in reality, using real money. This would create a very different dynamic which would be profitable [54].

B. VIRTUAL REALITY

In this subsection, we present the key directions of different VR applications. We present the solution in two parts- the security perspective and the communication perspective. The details are presented as follows.

1) SECURITY PERSPECTIVE

Here, we talk about the applicability of blockchain and 6G in VR, which benefits from the seamless transmission of digital data in real-time while preserving users' identities through BC-based fragmentation.

a: CREATING SECURE VIRTUAL WORLDS

There is a huge demand for VR-based systems and applications like entertainment and gaming; at the same time requires security against malicious activities, viz. hacking, duplication, destruction. BC helps in the verification of the actual copy of VR software and avoids forgery. In addition, BC helps in maintaining the identities of VR users and helps them establish item ownership [55].

b: UNIVERSAL FILE FORMATTING

Application of BC helps in normalizing fragmentation, file formatting, and mode sharing of data to avoid global

connectivity issues and ensure maximum security, privacy, and verification of identity. BC-based peer-to-peer distribution systems exist that assist people in collaborating by sharing the same virtual spaces through the latest AR applications [55].

2) COMMUNICATIVE PERSPECTIVE

Here, we discuss the applicability of blockchain and 6G in VR, where VR deals with the gaming industry and incorporates BC to create large-scale advertisements using tokenization. With 3D experience, VR can boom the e-commerce industry.

a: IN-GAME ADVERTISING

A recent Research and Markets report states that the global gaming market shot up to USD 173.7 billion in 2020 and is predicted to go as high as about USD 314.4 billion by 2026 with a compounded annual growth rate (CAGR) of 9.64 % [56].

With the increased demand in the gaming arena, advertising plays a profitable role as the former and latter are interlinked. All popular games advertise in-game purchases based on the gamer's interest. VR would help creators indulge in advertising with more potential and help create effective interactive models. Cryptocurrency can also be used by users and gamers when they interact with advertisements. BC can compensate users possessing coins to interact with advertisements for logging information about their activities [57].

b: VIRTUAL COMMERCE

Evolution of VR in e-commerce would attract more consumers and promote its popularization. A combination of VR and 3D modeling in software could help e-commerce revolutionize user interfaces and renew ideas. VR treats users and computers as a whole through which people will be able to directly feel information and objects, which would give them a greater sense of control [58].

C. 6G NETWORKS

This section highlights the key benefits of 6G networks in scaling secured and trusted AR/VR applications. Table 9 presents the key research directions of the coalition of BC and 6G-envisioned AR/VR in different industry verticals. Some of the potential 6G applications are presented as follows.

1) SCALABILITY

End-to-end latency in 5G and 6G networks is less than 1 millisecond, allowing extremely high transaction throughput rates. Bitcoin and Ethereum, two major BC networks cryptocurrency networks, only manage to add $\approx 10 - 14$ transactions per second. On the other hand, private and consortium BC can add up to 22000 transactions per second. As a result, 6G architectures and algorithms are continuously being studied to boost the throughput of BC networks [59].

TABLE 9. Key research directions on BC and 6G-envisioned AR/VR in different industry verticals.

Taxonomy Parameters	Ref. No.	Year	Objective	Main Contribution	Limitations
BC-based AR/VR	[25]	2019	To demonstrate how modern industries can sustain on BC, IoT and AR	Discusses the benefit BC can bring to the industry and challenges	Hypothetical paradigm is considered and real scenario is not
	[60]	2019	To understand the collaboration of BC with many industrial technologies, systems and AR	Shows how BC secures identities, transactions, and detects frauds	Challenges such as BC interoperability, security and privacy not discussed
	[13]	2020	To observe how VR, AR, and BC have integrated allowing companies and industries gain opportunities	Immense potential of BC is seen as it eliminates the necessity of a third party	Use cases in the scenario are limited
	[61]	2020	To see the practical interaction with BC involving virtual devices using mobiles and AR	Efficiency of VR with BC and AR	Disadvantages of AR not taken into account
5G/6G-enabled AR/VR	[62]	2020	To observe the convergence of BC in 5G networks and beyond for development of decentralized, distributed and immutable smart applications	Practical overview and solution on increasing BC implementation in comparison to AI	Does not highlight problems existent in 5G networks
	[4]	2020	To implement BC and AI for countering problems arising in 5G networks	Provides high-level taxonomy of BC and AI for 5G	Problems faced by AI and 5G networks are not discussed
	[63]	2020	To demonstrate authentication and key agreement protocol involving BC and 5G networks	Statistics and data analytics of various situations in application of BC are observed	Security threats of BC are not discussed

2) CROWDSOURCING

In 6G networks, small infrastructure investors would be able to roll out cellular towers that would play a key role in reducing operators’ infrastructure costs. The concept of investors gains related to the phenomenon of crowdsourcing. These investors must be both registered and verified. In a decentralized, trustworthy manner, BC and SC can provide a key role in registering towers and managing used resources. BC can form ledgers that would include the operational charges like billing, maintenance, and service charge of the towers, and SCs would automate the fund clearance based on a specified set of logistics. This ensures transparency and auditability in payment ecosystems, and the payments are managed through crypto-tokens. The tower owner can register important attributes regarding the tower’s capabilities, hardware, pricing, availability, attestation and certification, and reputation history through the infrastructure company. Information is then sent to all mobile providers once the tower is registered to the owner name [59].

3) INFRASTRUCTURE SHARING

The mobile network operator (MNO) provides telecom services in various ways, including active and passive sharing. BC is helpful in the management and tracking of resource distribution and consumption. With SCs, an immediate and safe agreement for sharing and secure payment is established among all stakeholders [64].

4) SPECTRUM SHARING

Spectrum sharing is a costly feature in 6G or lower cellular networks, as substantial sums of money are paid to spectrum regulators. The operator buys bands and sub-bands and then utilizes or leases them to other operators. BC technology can be used for license shared access (LSA), and cognitive radio networks (CRN) can be integrated with BC to provide a distributed medium access control (MAC) protocol for the networks’ secondary users. In addition, spectrum sharing based on BC would allow for the virtualization of network

resources. The federal communications commission (FCC) has suggested that BC-based spectrum sharing service can be embedded easily in the 6G protocol stack as BC-is the integral component of 6G stacked applications [65].

5) NETWORK SLICING

Localization of the physical infrastructure or the underlying network services and capabilities is referred to as network slicing. It enables the operator to set up a division and serve a diverse range of users, services, and applications while maintaining the same internal network infrastructure [66]. Spectrum and infrastructure sharing would also benefit from network slicing. The slicing is done by a network slicing broker (NSB), which considers all of the network’s service capabilities. An SC with decentralized storage can be used to replace practically all NSB functions in its place. BC would also authenticate network slices, and secure payments [67].

6) INTERNATIONAL ROAMING

In international Roaming, third parties are involved, which causes changes in rules and payments among the users. Several drawbacks exist in present conditions, such as (i) A single point of control that could fail, (ii) Expenses that go to intermediaries, and (iii) Insecure and fraudulent activities. SCs can secure payments and remove the involvement of third parties, thereby reducing expense, tracking, and auditing all analytical factors. SCs reduce the litigation costs, and parties that abide by the contracts are committed to binding to the rules defined in the contract.

This section discussed the solution taxonomy proposed for integration of BC and 6G in the AR/VR ecosystem. The taxonomy detailed the benefits in the latter from a security and communication perspective. At the end of this section, the readers can get the highlights of various real-world applications in AR/VR systems utilizing 6G and BC.

TABLE 10. Open issues and challenges.

Key Drivers	Parameters	Open Issues and Challenges	Deployment scenarios
Blockchain	Scalability	It can affect adoption regarding thousands of transaction that take place per second	Protocols where transactions can be off-loaded from the main BC to save space and reduce network congestion
	Interoperability	Lack of universal standards deprive BCs from consistency and security	Industry-wide standards would ensure uniformity
	Security	Smart contracts and Transactions lack good protocols which ensure security and privacy	Privacy protocols and good identity initiatives.
	Integration	Time and resources required to restructure systems and integrate with legacy systems	Database oriented solutions that help legacy system connect to BC back end
	Decentralization in modern systems	Designing anonymous authentication and validation with encryption schemes	Cryptographic encryption schemes that are certificate-less.
6G	Network Security	6G wireless networks are vulnerable to access control attacks	Physical layer security protocols can be extended
	High Frequency Bands	Use of sub-mmWave and THz frequency bands requires high sensitivity and low noise transmitter	Network layer protocols and new connections can enhance frequency resources
	Radio Access	Cell size plus carrier frequency may limit the orthogonal frequency division multiplexing (OFDM) numerology option	THz bands can be explored further, protocols can be altered
	Low Latency Communication	Several requirements and protocols required for transmissions and networks	Effective schemes and protocols would help
	End-user vulnerabilities	Individuals can lose keys due to lack of protocols, compromising their BC stored assets	Proper security and privacy protocols

VI. OPEN ISSUES AND CHALLENGES

This section presents the open issues and challenges of the integration of BC and 6G in AR/VR applications. The section address the RQ 4 question as it highlights the challenges of BC in security and data handling in 6G-envisioned AR/VR ecosystems. Table 10 presents the key parameters and highlights the open issues and challenges of the coalition of 6G and BC in AR/VR deployments. It is known that BC suffers from limitations of network bandwidth, transactional throughput rate, and scalability. The issues are intensified when we move to public BC ledgers. Thus, the integration of BC to manage the transactional ledger states of AR/VR contents requires effective design platforms. Moreover, SCs, if executed in public environments, are vulnerable to contract-based attacks like gas attacks, re-entrancy attacks, dead code attacks, and many more. Thus, adopting BC and SC for AR/VR data requires effective principles and implementation strategies.

6G ensures benefits of KPIs. However, the latter is in the developmental phase; as a result, a coalition of BC and 6G in decentralized AR/VR ecosystems to drive various use-cases requires common formats for communication protocols and globally structured standards.

- *Flow-rate control:* In distributed networks, peer-to-peer networks are limited in terms of bandwidth, with bottlenecks in peak data rate duration. With 6G infrastructure, and FeMBB service, the available bandwidth is improved, but the end-devices have to map to the defined baud rate of communication to manage the flow control of 6G-access nodes. Currently, electronic devices would face a bottleneck in maintaining flow mechanisms to cope with the FeMBB service. Due to a mismatch in baud rates, the data transfer rate would be high in the core networks, but due to the low line rate, the benefit would be compromised at end-systems; thereby, the potential QoI of immersive AR/VR would be limited.

- *Real-time Avatars:* In 6G, holographic communication requires sub- μ latencies for a successful realization. To design a real-time avatar design, the hardware rendering engines have to update the user information in real-time over a peer-to-peer network. With the current deployments, a large amount of computing resources and power is required to satisfy the requirements of real-time avatar movements.
- *Non-conformant standards:* 6G networks protocols and mechanisms are in developmental phases, and most defined protocols are proprietary-based. Thus, realizing the full potential of AR/VR applications in diverse industry verticals would require uniformity in standard and protocol designs.
- *Variable QoI:* In 6G networks, each user is serviced differentially, and the provided service depends on the user pricing and pay-per-demand mechanisms. Thus, the core 6G-enabled routers have to be designed with sufficient maturity to handle the variable application services and differential provisioning for heterogeneous users and networks. This might result in connectivity and variable delays at the end-user, thereby it reduces the QoI provisioning of the AR/VR users.
- *Scalability and high latency:* In BC networks, the scalability of users is a critical problem. The issue is further intensified in public BC networks, where the mining time is quite high than permissioned networks. However, 6G nodes can service the mining-as-a-service mechanism through edge nodes. Still, the resource transfer and transactional record deployment have to be managed through the BC network itself, further jeopardizing the latency at end-users, thereby affecting the overall scalability of mined blocks.
- *Government regulations:* In many countries, still cryptocurrency transfers are not considered legal tender. Thus, in the case of inter-country payments, government regulations play a critical role in designing

a cryptocurrency exchange server that would facilitate seamless inter-country payments through a regulated network.

- *Illegal cryptocurrency markets:* Owing to the anonymous nature of cryptocurrency payments, it is heavily used by malicious entities like hackers and criminals for the supply of restricted goods inside a country. Due to a low level of clarity and lack of cryptocurrency regulations, the cryptocurrency markets are not regulated, and thus there are illegal e-commerce supplies. The nature of such supplies is not traceable to the original supplier, and thus fairness in chronological supply-chain movements is a critical challenge to be addressed.
- *SC executions and vulnerability:* SCs executed in permissionless environments like ethereum and bitcoin are susceptible to various insider and outsider-based malicious attacks by an adversary. Even in permissioned environments, the security of data flow is dependent on the authenticating stakeholders. If the majority of the stakeholders perform collision-based attacks, they can control the overall consensus of the permissioned ecosystem, and thus SCs are vulnerable in such scenarios. Common attacks include gas-based attacks, contract-flow attacks, injection-based attacks, code re-entrancy problems, and mining pool attacks that can disrupt the entire working state of SC execution. The solution to such attacks is to design SCs in isolated containers or dockers, but it adds up to the overall design cost. Therefore, the address of open SCs execution and contract execution frameworks is a critical issue.
- *Issues in privacy-preservation of AR/VR users:* In different countries, the rules of privacy-preservation of AR/VR users are different. Hence privacy-preservation mechanisms like differential privacy, K-anonymity, I-diversity, and t-closure have to be designed to conform to the global legislation rules. Therefore, the conformance of privacy-preservation schemes for AR/VR users and the definition of a similar set of privacy for all users is a critical challenge that needs to be addressed in the future.

This section highlighted the open issues and challenges of the integration of 6G and BC in AR/VR ecosystems to address the implementation requirements of full-fledged end-to-end ecosystem deployment.

VII. BvTours: BC-BASED 6G-ASSISTED AR/VR VIRTUAL HOME TOUR SERVICE

In this section, we propose an AR/VR based, 6G and BC-assisted smart home buying application scheme, named as *BvTours*. The above technologies help in transforming people from the conventional way of buying real estate properties these days. A recent research estimation from Goldman Sachs reports that VR in real estate alone can

maximize the generation to as much as \$2.6 billion by 2025 [68]. In a traditional workflow, a real estate agent provides the client a long list of properties (such as apartments, large living penthouse, duplex, row-house, etc.). This follows a series of explanations, negotiations, and finally the real-life visits to houses and apartments. This process consumes a considerable amount of both estate agents' and home-buyers time, especially when properties are far, which needs a long journey and becomes expensive. In addition to the above, the on-site construction projects often change, thereby inculcating them in the model apartment is a costly process.

AR/VR technology provides virtually anytime/anywhere real-estate solutions and proves to be fast, efficient, and an easy way for people to get a real sense of home. AR/VR integration in real estate provides advantages viz. saves time and money, builds emotional connections, offers global reach, bridges connection and ownership, provides virtual staging, architectural visualization, and virtual commerce. Typically two 3D virtual tours are popularly used by real estate companies, viz. interactive visits, and guided visits. In guided visits, it resembles commercial video, a virtual video, or 360-degree form (a type of VR). It is best suited for fixed properties as it can be captured through a panoramic camera. In interactive visits, the person chooses where to move within a property by spotting special hot spots in the field of view (FOV). It is more interactive and efficient than guided visits as it can lure maximum clients.

Traditionally, commercial real estate (CRE) technology is concerned with listings and connecting buyers and sellers. BC technology can potentially transform home-buying operations such as property transactions like purchase, sale, financing, leasing, and management transactions. The BC-leveraged system would provide verifiable, and censorship-resistant options, provides secure and tamper-resistant shared databases, enhance transaction process quickly and economically, eliminating the need for intermediaries (such as brokers, companies, banks). SCs in BC tokenize the property, enabling buyers to trade their assets like stocks and facilitate online transactions (like earning a certain amount of money after the liquidation of property through a token).

The extremely large data flow among interconnected devices up to the end-users requires guaranteed QoS requirements. Due to ubiquitous AR/VR communication in 6G, it is very important to provide the former with the required resources (e.g., high computational processing capabilities and power, storage, graphics processing, communication assets) through a chain of massive devices to achieve the feasibility enhancement. IC, a decentralized network architecture, has been adopted to cope up with large-scale content distribution in 6G, which enables network caching in AR/VR content [33]. Because of the very high data rate and usable bandwidth requirements, there is tremendous pressure on the network and security to potential threats to IC routers. Integration of BC is a possible fit and would enable trust

TABLE 11. 6G channel models for diverse communications to support AR/VR.

Channel Models	Frequency bands	Application Scenarios	Models		Channel Properties
			Deterministic	Non-Deterministic	
mmWave/THz channel [69]	26/28, 32, 38/39, 60, 73 GHz for mmWave, and 300 GHz for THz channels	vehicle-to-vehicle, vehicle-to-infrastructure	Ray Tracing, Map-based	Propagation Models, geometry based stochastic models (GBSM), quasi-deterministic model	Directed channels with high bandwidth, high blockage and diffuse scattering
Optical Wireless [70]	380-780 nm	Underground sensor networks	Recursive, Geometric, Ceiling-bounce, DUSTIN	GBSM, non-GBSM	Material based scattering, non-linear induced noise at transmitters, high delay spread
Acoustic [71]	2-32 KHz	Underwater Networks/UAV-to-maritime	Ray Tracing (two and three ray models)	GBSM	time varying, sparse scattering
Satellite [72]	Ku, Ka, K, V band regions	geosynchronous earth orbit, low earth orbit, and medium earth orbit	Analytical, Ray-Tracing	GBSM, non-GBSM	High-frequency shift, climatic attenuation in case of fog and mist, Large coverage
High Speed Rail Transmission channel [73]	Sub 6-GHz/mmWave bands	Hills, terrains, highways, urban areas, open areas, and UAV-to-rail networks	Ray Tracing	GBSM, non-GBSM	Large Doppler spread, trajectory varying effects, non-stationary
Ultra-massive MIMO [74]	Sub 6-GHz/mmWave bands	Indoor and outdoor	Ray Tracing	beam domain channel model (BDSM), correlation based stochastic models (CBSM)	Spherical wavefronts, non-stationary
Industrial IoT [75]	Sub 6-GHz	IoT, automation	Ray Tracing	GBSM	Non-stationary path losses, random movements, non-directed line-of-sight (NLOS) propagation, multimodal

and co-operation among massive AR/VR nodes, distribute the content caching of nodes, and ensure sharing of resources.

To amortize the overall buyer requirements in AR/VR applications, we propose *BvTours*, a reference architecture in a modern buyer-seller scenario for CRE environments. The proposed case study integrates 6G and BC for providing an incredible virtual tour experience without affecting QoI and security requirements. FIGURE 9 shows the three-tier architecture of *BvTours* which is explained in subsequent sections.

A. AR/VR SENSING LAYER

At the sensing layer, we assume a composition of apartments, buildings, homes (view of the garden, lake, shopping malls, etc.) that spreads in an area of interest. These places are equipped with static cameras and flying drones equipped with a high-speed video imaging system and GPS to capture the complete view in 360 degrees of freedom. Furthermore, the realtor bench is equipped with AR/VR reception system integrated with the software. It provides a platform to create personalized design portraits, staging, decorations to the chosen property to increase the relationship between the user and a virtual environment. It is also equipped with specialized user apps to customize different buyer-oriented items and facilitates the former and investors to see inside premises from their computer screens, gaining a sense of the building’s space, style, and atmosphere.

B. 6G INFRASTRUCTURE LAYER

At the 6G infrastructure layer, we envision that AR/VR applications are connected to millions of user nodes. 6G access nodes control the inflow and outflow of data with extremely low latency, high reliability, and network rate and improve the QoI. The layer also supports AI-assisted intelligent computing, cognition, natural language processing, libraries to support audio, video content (for example- convolutional neural nets, single-shot detection, and many others). The overall integration ensures a highly effective user experience and connectivity for interactive AR/VR applications like holographic teleportation, immersive XR, real-world audio-video perception and experience, 3D-object location identification, high precision, and control mapping. The 6G infrastructure is layered in three planes: communication plane, service plane, and information plane.

1) CHANNEL MODELLING

Table 11 presented a comparative analysis of different channels and associated models. In the proposed case-study *BvTours*, we consider the integration of satellite and ultra-massive MIMO channels at the infrastructure layer. As satellite channels would be stable in diverse topological conditions, it maintains a consistent user bandwidth during the AR/VR session. As a model, we integrate GBSM to model the satellite channel, mainly the regular shaped GBSM.

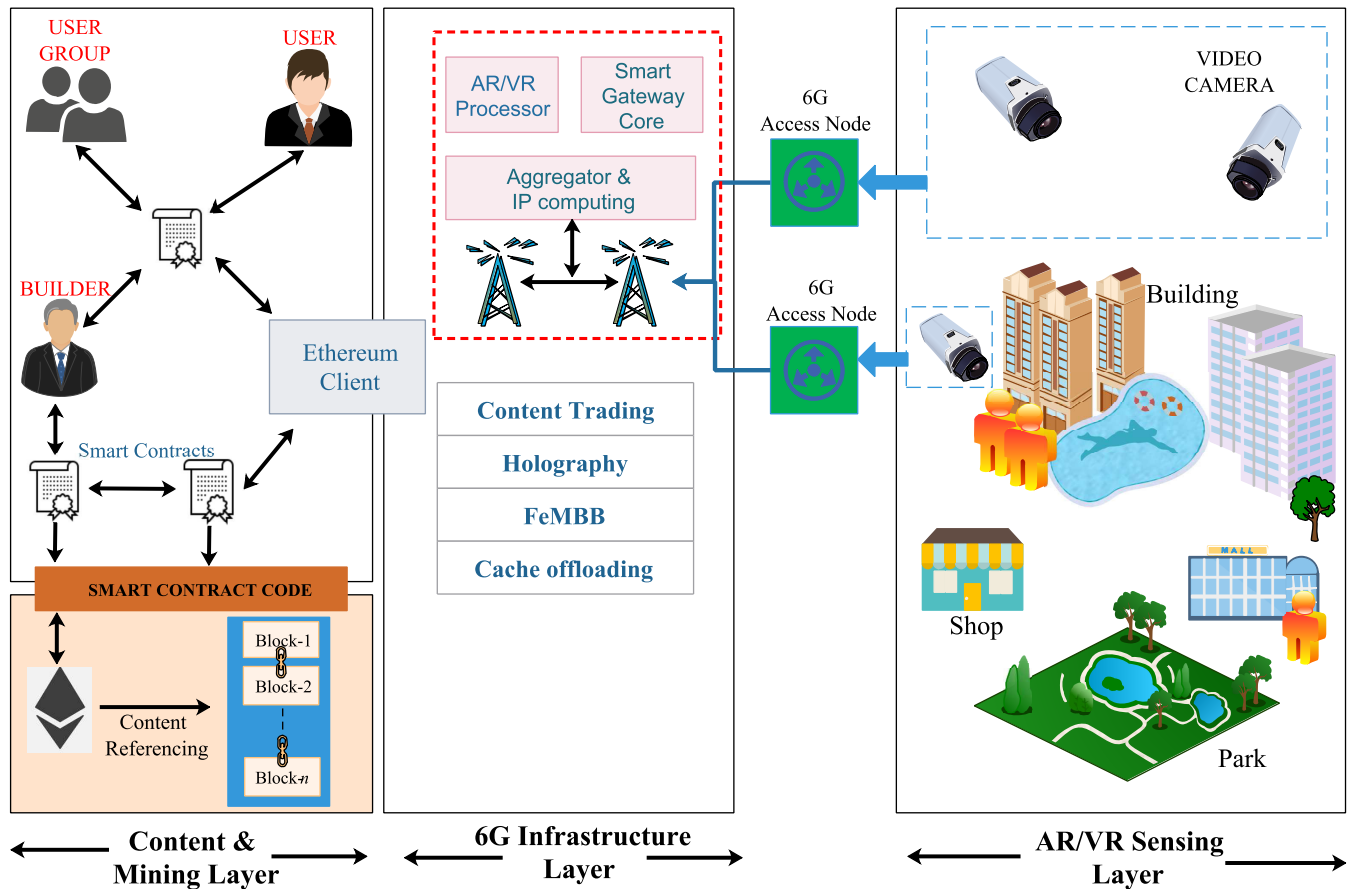


FIGURE 9. BvTours: The proposed integrated scheme.

It supports high accuracy in the processing of link frames in both large and small-scale fading channels.

2) COMMUNICATION PLANE

This plane consists of different service classes of 6G that support high data rate, extremely low latency and power, and long-distance communication. 6G protocol stack includes services like FeMBB, eRLLC, ultra-massive machine-type communications (umMTC), long-distance and high-mobility communications (LDHMC), and extremely low-power communications (ELPC) to improve the AR/VR experience. FeMBB is responsible for extremely high data rates and broadband services. A peak data rate of ≥ 1 Tbps for ultra-resolution and 4K video transmission is fixed through FeMBB. In support, at the communication plane, 6G-enabled TI communication leverages fully sensory digital sensing and reality, haptic interactions to cater to sub-millisecond round-trip-time delay requirements for various holographic and society applications.

3) SERVICE PLANE

This plane incorporates holographic communication services and cache offloading phenomenon for efficient distribution and security of private data. Holographic communication creates 3D visualization and transmits close-to-real

virtual vision sights of people and surrounding environments. It employs access to multiple-view cameras and streams high-definition videos. It also ensures very low latency for real-time voice and intermediate control response.

The data transmission latency is related to delay between the network core and installed base station. Under large AR/VR user requests in peak traffic conditions, the network caching philosophy can be utilized to reduce latency by storing the latest data at the edge of the network. Caching is featured architecture that improves the consumer-experienced QoS and reduces overall network traffic, network congestion, prevention of denial-of-service (DoS) attacks, and content availability enhancement.

The network caching constituted four solutions viz. caching placement, content delivery, centralized caching, and distributed caching. The service plane is inherent in-network content caching placement mechanism, consisting of 1) content placement and 2) content replacement. In content placement, the network selects a node for caching the required content, while in content replacement, the node decides the latest content to be kept in case of memory overflow. During the content delivery phase, each node caches the content and serves it for the future. The caching approach is selected based on the trade-off between high-end data and induced latency which can be evaluated by employing

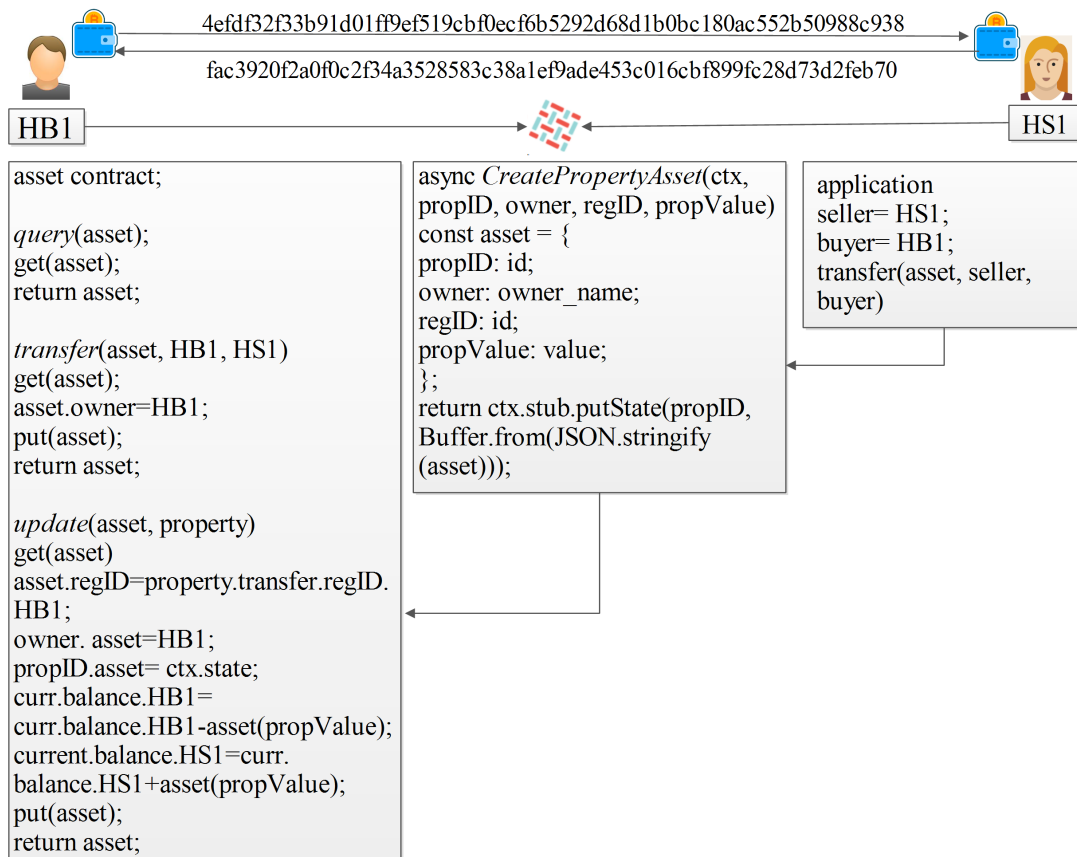


FIGURE 10. Contract policy and endorsement in permissioned ecosystems.

various process control parameters. The centralized and distributed caching schemes are popular in 6G-based networks. In a centralized caching strategy, a server/controller selects a controlled group of nodes and caches replica versions of content to reduce network delay and improve memory resources. In distributed strategy, the centralized controller is not present, and nodes decide caching based on the utilization of local factors and metrics. This improves bandwidth requirements and increases network efficiency. The adopted policy is primarily governed by the computational complexity of the algorithm and timing overheads due to central base nodes.

4) INFORMATION PLANE

This plane incorporates enhanced intelligent estimation solutions to handle losses, anomaly detection, and understanding of key performance indicators (KPI) trends for heterogeneous and dense 6G channels. This incorporates machine learning (ML) techniques along with deep reinforcement learning (DRL) to improve the decision-making process, management of resources (power, frequency bands), intelligent aggregation, self-configuration, and context awareness as per user requirements.

The data from access points is sent to cloud computing and storage. The network nodes incorporate computing and data aggregation features, i.e., the processing is done locally at the edge/fog devices. These edge computing facilities are controlled using NFV and SDN-controlled network entities. They are equipped with the intelligent decision and learning models that grab knowledge of resource allocation, network slicing, handover, etc. A distributed AI-enabled edge architecture is considered that provides facilities such as storage, processing, optimization, user management. The intelligent core is the gateway of edge servers close to the users to provide a real-time response with reduced response time.

C. CONTENT AND MINING LAYER

At the content and mining layer, the home buyer closes the property’s AR/VR virtual tour session and sends a close session request to the infrastructure builder. The session channel close request is forwarded to the AR/VR controller at the 6G-service plane, and the 6G- access node closes the session. The home buyer presents its purchase request to the builder of the property, and the legal agreement draft is set up between the buyer and the builder, which mentions all the terms of the agreement. We initiate an SC between the stakeholders

(buyers and sellers) of the property, and the contract is executed through the content and service management function. The SC includes the details of the real estate property purchase price, and the associated terms of payments (either in full or in parts) are set up in the contract. In the case of loans, the contract would ensure the involvement of the associated bank, which funds the prospective buyer the loan for the property and associates the repayment tenure in the contract and the equated installments. Once the contract conditions are fixed, it is executed in permissioned mode only between the authorized stakeholders associated with the contract.

In permissioned network, we design the operational set of procedures through an operational agent. The main function of the agent is to listen to the set of events defined in the contract, and the nodes in the permissioned network establish a consensus for executing the contract based on the defined operational policy [76]. In Hyperledger fabric, we define the executable logic through the ledger state. FIGURE 10 shows the defined contract and endorsement policies between the home buyer and home seller. To implement the same, we consider chaincode execution environments, where we consider home buyer entity as HB1 and home seller entity as HS1. We define a contract asset that represents the real estate that HB1 wishes to buy from HS1. To invoke the chaincode, we agree on the transfer ownership of asset from HS1 to HS2, through three invoked functions, namely, *query*, *transfer*, and *update*. The asset contract is packaged into isolated dockers as chaincodes to be deployed on the low-level fabric. As the dockers assure isolation property, the privacy of owner and seller details is preserved. A world-state is defined as the fabric that holds the cache of current asset states, and get, put, and update states are saved in the world-state. The *CreatePropertyAsset* creates a new asset object for real-state, and we define the set of endorsement policies for SC that defines the communicating stakeholders involved in the chaincode operation. In the endorsement policy, we consider two entities HB1 and HS1, and execute the contract. Once the endorsement policy is valid, it executes a peer node in the BC network, takes the input of the transactional proposal from the world-state as a response, and updates the read-write buffers. In case of invalid transactions, the read-write buffers are not executed. The communicating fabric channels are invoked in case of a multi-transaction environment between buyers and sellers. For each communication, a separate channel is invoked so that the privacy of data is maintained. The channel state contains the ledger instance, chaincode object, and details of world-state ledgers. Once the contract is executed, the miner node is selected in the permissioned network to mine the block, and add it to the on-chain ledger.

D. WORKFLOW OF BvTours

FIGURE 11 shows the main workflow diagram of the proposed study architecture for AR/VR sharing. The user (HB) and the real-estate management (IB) layers an important constituents for end-to-end secured access using 6G communication network. The architecture assumes entity set

represented by $E = \{E_{HB}, E_{IB}, E_{AR/VR}, E_{6G}, E_{CSM}\}$ where E_{HB} represents the client or home buyer, E_{IB} represents the real-estate developer or builder (IB), $E_{AR/VR}$ is the defined AR/VR controlling module between builder and client that connects services like content processing, service request and grant, caching and ultra-low latency data transfer. For AR/VR service, the process initializes when E_{HB} (user/home buyer) forwards a virtual tour request to E_{IB} . Here, we assume a set of k buyers, represented by $E_{HB} = \{HB_1, HB_2, HB_3, \dots, HB_k\}$ related to a set of m builders, represented by $E_{IB} = \{IB_1, IB_2, IB_3, \dots, IB_m\}$ defined through a relational set $M : E_{HB} \implies E_{IB}$. Any HB_k forwards virtual tour request VT_{req} to E_{IB} that comprises of various parameters viz. location of apartment, apartment entity identification, apartment size and apartment cost. The above parameters can be set represented as $VT_{req} = \{L_I, E_I, S_I, C_I\}$. If the parameters of VT_{req} relates to E_{IB} , the corresponding request will be accepted and E_{IB} calls $E_{AR/VR}$ for content transfer. $E_{AR/VR}$ is supported by three planes viz. communication plane (P_C), service plane (P_S) and information plane (P_I) as explained in 6G infrastructure layer. P_C delivers FeMBB services and supports bandwidth B_{sup} . The content delivered to the user (or home buyer) consists of n video frames represented as $V = \{F_1, F_2, \dots, F_n\}$. The calculated latency for the n^{th} frame can be written as follows.

$$L = \frac{\text{Framesize}}{\text{Bandwidth}} = \frac{F_n}{B_{sup}} \quad (1)$$

For processing video frame content, the demanded channel bandwidth $B > B_{sup}/F_n$. AR/VR controller ($E_{AR/VR}$) sends FeMBB request $FeMBB_{req}$ to 6G interface (E_{6G}). FeMBB service is then initiated and grants $FeMBB_{req}$. At $E_{AR/VR}$ end, intelligent caching service starts to transfer the contents with high speed to grant VT_{req} to the home buyer (HB). HB and IB allocate the resources on the channel through an access scheme (typically time-division multiplexing (TDM)) technique to multiplex data packets for virtual tour requests between them. Once the channel access is permitted, the session starts between the former and latter, and massive data in the form of packets will be transferred to E_{HB} with ultra-low latency. Once E_{HB} finished the virtual tour, the session and occupied channel will be closed. At E_{6G} end, FeMBB service stops and acknowledges all the entities. At this point, E_{HB} completes the virtual tour experience. E_{HB} initiates purchase request to E_{IB} and latter contacts E_{CSM} for creating smart contracts. E_{CSM} completes the task and sends back smart contracts to E_{IB} that is finally forwarded to E_{HB} . The payment process initiates between E_{HB} and E_{IB} , both entities represents wallets W_{HB} and W_{IB} respectively, where data set W_{HB} contains information such as amount, userID, cryptocurrency, hash, Merkle root, and timestamp denoted by $W_{HB} = \{A, ID(HB), B, H_T, MR, T\}$ and data set W_{IB} contains information such as contact information, payment, userID, cryptocurrency, hash, and Merkle root denoted by $W_{IB} = \{CI, P, ID(IB), B, H_T, MR\}$. Once E_{CSM} validates the token transaction through a trusted collaboration, the payment amount is transferred from E_{HB} to E_{IB} to ensure the

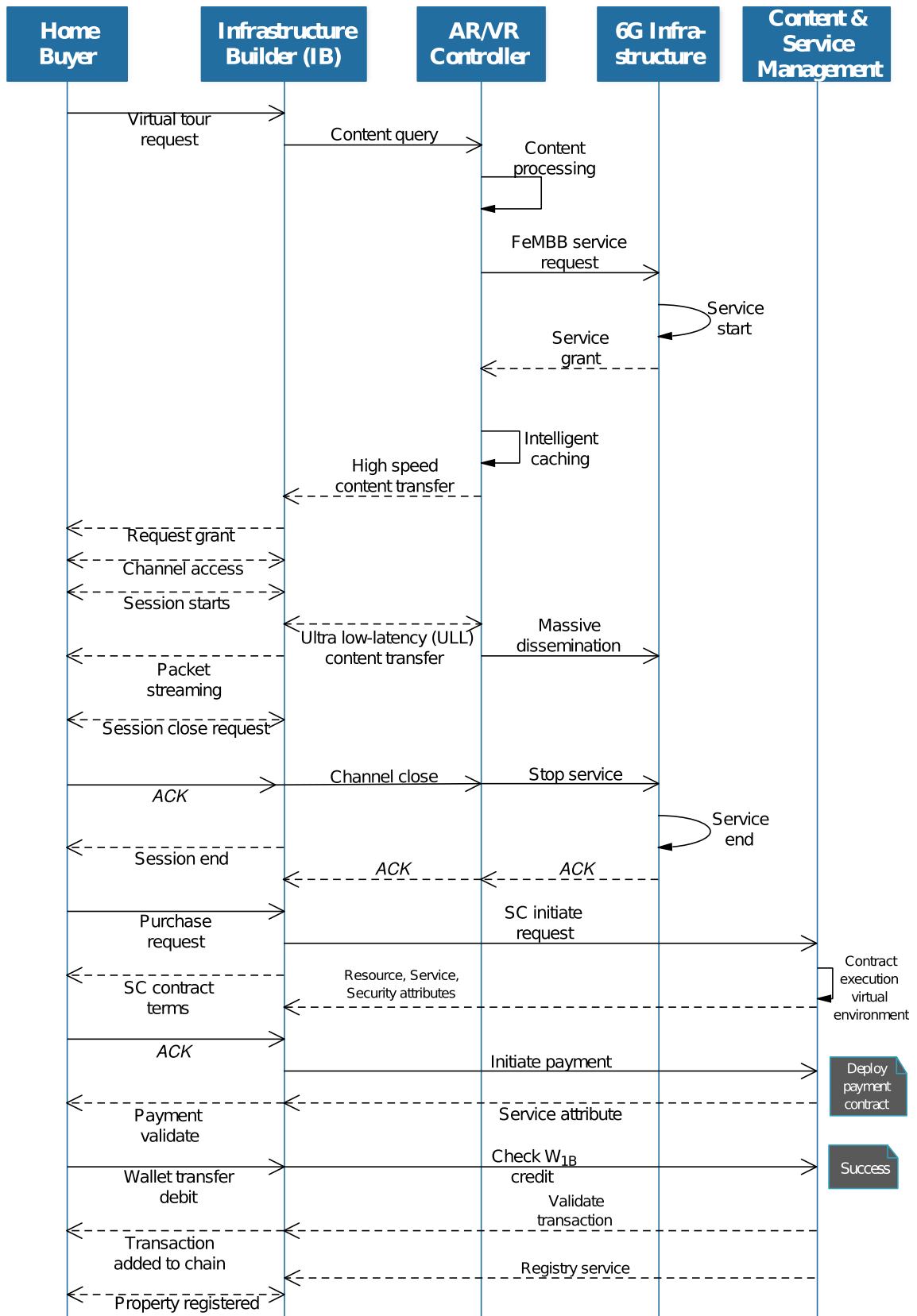


FIGURE 11. Sequence of workflow of BvTours.

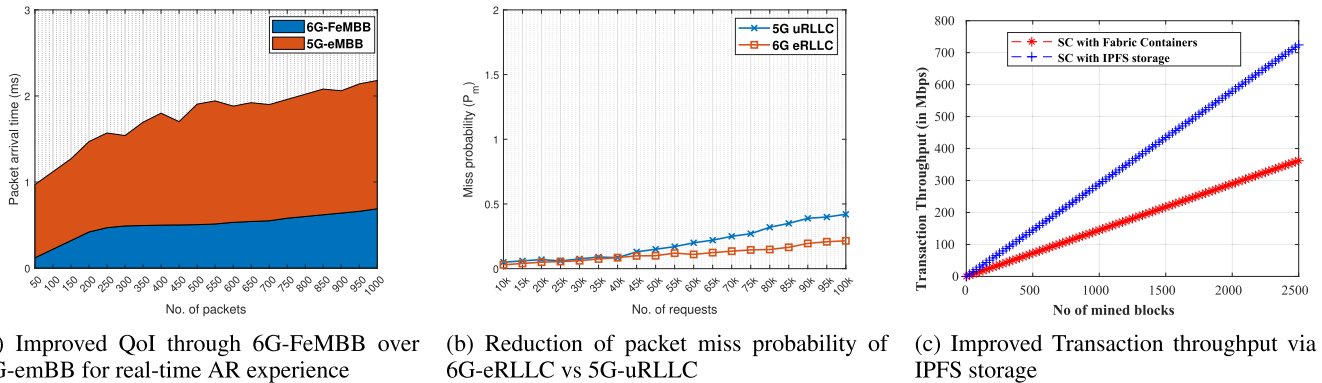


FIGURE 12. *BvTours*: Improved AR/VR content sharing and automated SC flows.

legality of actions. All the transactions will be thus guaranteed and protected by BC.

This section proposed a case-study *BvTours*, and presented a 6G-envisioned BC-leveraged virtual home tour service. We presented the layered architecture, the components, the smart contract and the workflow interactions of the case-study.

VIII. PERFORMANCE EVALUATION

In the performance evaluation, we address RQ 5 through the presentation of the results for *BvTours* in terms of user welfare or QoE that provides rich experiences from 6G technology. The analysis would provide a broad comparison and advantages of 6G over 5G networks.

QoE defines a high QoS and user-centric communications achieved by holographic communications, AR, VR, and TI service, which requires a very high data rate with extremely low latency. 6G focuses on QoE; to provide high QoE, it demands low end-to-end latency. The evaluation is done in terms of latency and miss probability of the arrival of the processed packet. To improve memory limitations and enhance the overall transactional performance of BC decentralization, distribution off-chain IPFS storage is used compared to conventional frameworks.

AR/VR packet transmission requires reliable transmission over the channel with low latency since a very high data rate is involved. The transmission channel adds impairments such as network delay, jitter (variation in propagation time), packet loss. 5G-URLLC AR/VR QoS requirements has bit error rate of the order of $10^{-3} - 10^{-5}$ and latency of 5 – 10ms [77]. Compared with traditional video streaming, AR/VR involves 360-degree video scene streaming with much lower packet delivery latency with varying environment dynamics and user viewing behaviors. The latter will affect user QoI and requires a much higher network bandwidth. We define QoI in terms of induced network jitter for 5G and

6G protocols. We assume 4K UHD (3840×2160) video with 120 Hz scanning rate with 360° spherical coverage to transmit hologram for a fully immersive VR experience. The network latency affects the transmission of video packets and results in poor reception quality and jitter under peak/experienced data rate conditions. 6G network over-the-air latency being two orders better than 5G counterpart ($10\mu s$ compared to 1ms), the former will induce fewer glitches in packet arrival time. FIGURE 12a depicts the area under the curve of variation of packet arrival time vs. number of transmitted video frames for an effective AR/VR experience. It can be seen that the trend of inter-packet latency is constant using 6G-FeMBB service and shows an improvement of almost 60% compared to 5G-eMBB service, which shows a highly interactive and real-time feasibility of AR/VR experience of the proposed scheme.

In 6G networks, network heterogeneity, exists to connect a plethora of vertical applications exercising extremely large data and varying QoS. Intelligent AI/ML-based estimation algorithms are embedded at the core and edge networks to carry out functionalities like content caching, sensing, resource allocation, network slicing, and control. As mentioned previously, we assume 4K (3840×2160) 24-bit color representation of VR video transmission packetized with an average IP packet size of 576 bytes. The packet also contains the header and destination information. At any instance, t , access point (AP) or e-NB transmits 43,200 packets to edge computing or storage. These are deployed with NFV and SDN-controlled intelligent agents to provide learning and decision-making caching mechanisms. Assuming a cache size of 2.5GB, both 5G and 6G transmission networks will satisfy the request size of 43,200 packets. Beyond it, 5G network will be insufficient to cache incoming requests due to higher latency, and packets will be missed at a cache with probability p_m . FIGURE 12b shows the comparison of miss probability vs. no of the request transmitted for 5G & 6G network with defined cache size. It can be seen that the 6G-eRLLC network shows almost 43% improvement in caching excess incoming packets at the edge layer.

At a certain threshold T_r , network congestion due to very high delay results in excessive loss of requests, and p_m is close to 1, and almost all packets start to miss. However, the increase in p_m will occur at a higher value, and the threshold difference will be greater in 6G networks than the 5G counterpart.

Finally, we present the analysis of the execution of SC in terms of chaincode storage and the SC execution stored in IPFS ledgers. FIGURE 12c shows the comparative analysis in terms of obtained transaction throughput in terms of mined blocks with SC execution. In *BvTours*, in the content and mining layer, once E_{HB} completes the virtual tour request VT_{req} through the 6G-FeMBB, a SC is executed between E_{HB} and E_{IB} . The SC is executed in a permissioned environment as it includes the private details of E_{HB} and is deployed on a hyperledger machine. As the SC execution requires a legal home purchased agreement and licensing, the transactional wallets are instantiated once all the contract conditions are met and property is registered in the name of E_{HB} . The results are stored in BC as an immutable and registered block. As more such blocks are added, the main chain transaction throughput drops due to increased mined blocks. Once possible, optimization is publishing the contract details on IPFS ledgers, where registered E_{HB} and E_{IB} can access the property records through the IPFS hash key. The hash of the IPFS main block is stored in the main BC as the address to refer to the IPFS block, and thus more transactions are added per block, which improves the block transactional throughput. At 1000 block additions, for example, the hyperledger based SC execution has a transaction rate of 144.871 Mbps. Compared to this, IPFS published off-chain has a better transaction rate of 289.722 Mbps, and thus the latency in SC executions and payment delays are minimized, which improves the real-time payment service in *BvTours*.

This section discussed the performance evaluation of the case-study *BvTours* in terms of quality of interaction, reliability and transaction throughput.

IX. CONCLUSION

With the proliferation of massive connectivity in IoT, technologies like AR and VR have emerged as disruptive technologies to drive a range of verticals in the Industry 4.0 sector. The emergence of data-driven AR/VR applications has forced networks to be highly resilient, massively connected, ultra-low latency, with real-time experience. Coupled with this, incorporating security and trust in decentralized data dissemination among heterogeneous stakeholders is challenging. Thus, the article presents a novel and systematic survey that presents the coalition of BC and 6G networks to support AR/VR verticals. The article summarized the challenges of integrating BC and 6G in AR/VR and presented a solution taxonomy to address a range of different applications. We presented the key concepts, architecture, protocols, and technologies that addressed various facets of the

BC-envisioned 6G scheme for AR/VR. A solution taxonomy is presented, and a BC-based decentralized architecture is proposed. The open issues and challenges of the integration are presented. Finally, a case study *BvTours* is presented that discusses a 6G-based virtual tour service with secured BC-based service. The workflow and interaction flow among stakeholders is discussed. The adoption of case-study is validated through performance evaluation in terms of packet arrival time, packet miss probability, and BC-based throughput is presented. The article lays a building foundation for trusted 6G-based AR/VR decentralized applications.

In the future, the authors would like to investigate the impact of BC-based trusted 6G service for mIoT applications.

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