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6G AND ONWARD TO NEXT G

THE ROAD TO THE MULTIVERSE

MARTIN MAIER

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THE ROAD TO THE MULTIVERSE

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"We shape our tools and then our tools shape us …
We become what we behold."

Marshall McLuhan
(1911–1980)

Canada's eminent media theorist and philosopher:

Credited with predicting the rise of the Internet and phrasing the term global village in *The Gutenberg Galaxy*

CONTENTS

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Maier is a full professor with the Institut National de la Recherche Scientifique (INRS), Montréal, Canada. He was educated at the Technical University of Berlin, Germany, and received both MSc and PhD degrees with distinctions (summa cum laude) in 1998 and 2003, respectively. He was a recipient of the two-year Deutsche Telekom doctoral scholarship from 1999 through 2001. In 2003, he was a postdoc fellow at the Massachusetts Institute of Technology (MIT), Cambridge, MA. He was a visiting professor at Stanford University, Stanford, CA, from 2006 through 2007. He was a corecipient of the 2009 IEEE Communications Society Best Tutorial Paper Award. Further, he was a Marie Curie IIF Fellow of the European Commission from 2014 through 2015. In 2017, he received the Friedrich Wilhelm Bessel Research Award from the Alexander von Humboldt (AvH) Foundation in recognition of his accomplishments in research on FiWi-enhanced mobile networks. In 2017, he was named one of the three most promising scientists in the category "Contribution to a better society" of the Marie Skłodowska-Curie Actions (MSCA) 2017 Prize Award of the European Commission. In 2019/2020, he held a UC3M-Banco de Santander Excellence Chair at Universidad Carlos III de Madrid (UC3M), Madrid, Spain. He is coauthor of the book "Toward 6G: A New Era of Convergence" (Wiley-IEEE Press, January 2021) and author of the book "6G and Onward to Next G: The Road to the Multiverse" (Wiley-IEEE Press, January 2023).

PREFACE

Global crises such as the Covid-19 pandemic highlighted the fragility of our current approach to globalized production, especially where value chains serve basic human needs. On the flip side, however, virtual experiences such as Zoom's cloud-based video platform for online meetings and events have skyrocketed in popularity as the Covid-19 pandemic's online-everything transformation took place. With the mass digital adoption of remote work and online social activities accelerated by a global pandemic, we may finally find ourselves on the verge of something big and potentially paradigm-shifting: *The Metaverse* – the next step after the Internet, similar to how the mobile Internet expanded and enhanced the early Internet in the 1990s and 2000s.

The Metaverse will be about being inside the Internet rather than simply looking at it from a phone or computer screen. With the rise of the Metaverse, the Internet will no longer be at arm's length. Instead, it will surround us and will radically reshape society. Importantly, the Metaverse is not only based on the social value of today's *Generation Z* that online and offline selves are not different; this is because the younger generation considers the social meaning of the virtual world as important as that of the real world since they think that their identity in virtual space and reality is the same. But it also aims at realizing the *fusion of digital and real worlds across all dimensions* created and delivered by non-traditional converged service platforms of future 6G and Next G networks, where developers do not hesitate to use technologies from as many disciplines as possible. They do not discriminate whether services and applications will be used by human beings or by physical, digital, or virtual objects.

The Metaverse, underpinned by decentralized Web3 technology, is widely seen as the precursor of the *Multiverse*. While the Metaverse primarily focuses on virtual reality (VR) and augmented reality (AR), the Multiverse offers eight advanced types of extended reality (XR) realms, which together span the entire reality–virtuality continuum, including but not limited to VR and AR. This book is a sequel to our last book titled "Toward 6G: A New Era of Convergence" (Wiley-IEEE Press, January 2021), in which we briefly touched on the Multiverse and argued that 6G should not only explore more spectrum at high-frequency bands but also, more importantly, converge driving technological trends such as multisensory XR applications, connected robotics and autonomous systems, wireless brain–computer interaction (a subclass of human–machine interaction), as well as blockchain and distributed ledger technologies.

The purpose of this book is to complement our prequel book by describing the most recent progress and ongoing developments in the area of the Metaverse and Multiverse. Specifically, the book aims at weaving the following *emerging themes* carefully together in future 6G and Next G networks and the enhanced services they offer to disruptive applications in order to enable peak-experiences and human transformations: (i) touch-screen typing will likely become outdated, while wearable devices will become commonplace, enabling future communication technologies that are anticipated to fold into our surroundings, thereby helping us get our noses off the smartphone screens and back into our physical and biological environments, (ii) human transformation through unifying experiences across the physical, biological, and digital worlds, (iii) seamless convergence and harmonious operations of communication and computation to provide user-intended services and change or even transform the behavior of humans through social influence, (iv) creation of new virtual worlds to create a mixed-reality, super-physical world that enables new superhuman capabilities, and (v) rise of a new regime that connects all humans and machines into a global matrix, which some call the global mind or world brain, leveraging on the collective intelligence of all humans combined with the collective behavior of all machines, plus the intelligence of nature, plus whatever behavior emerges from this whole.

Despite the current lack of compelling use cases and potential pitfalls of the Metaverse, a rising number of organizations are searching for ways to use the Metaverse. This book points to three spheres of contexts, in which we outline different narratives for the year 2030 and beyond. Due to their striking similarities, we select *Society 5.0* as the frame story or, if you will, *meta narrative*, in which the Metaverse as well as Multiverse can be embedded naturally. Taking into account our meta narrative as well as the fact that future 6G and Next G networks are anticipated to become more human-centered than previous generations of mobile networks, cross-disciplinary research is necessary, involving not only communications and computer science but also cognitive science, social sciences, psychology, and behavioral economics. In addition, as we shall see, neuroscience and psychological approaches should be used to better understand humans and thus build a *deeper Metaverse*. This book aims at providing the reader with new complementary material, putting a particular focus on 6G and Next G networks in the context of the emerging Metaverse as the successor of today's mobile Internet and precursor of tomorrow's Multiverse. We hope that this book will be instrumental in helping the reader find and overcome some of the most common 6G and Next G blind spots.

Montréal, 24 August 2022 *Martin Maier*

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M. M.

ACRONYMS

3GPP	Third Generation Partnership Project
4G	fourth generation
5G	fifth generation
6G	sixth generation
ABI	application binary interface
ACC	access control contract
ACP	artificial societies, computational experiments, parallel execution
ADC	analog-to-digital converter
AGI	artificial general intelligence
AI	artificial intelligence
AI4Net	AI for communication network
ANN	artificial neural network
API	application programming interface
AR	augmented reality
ARG	alternate reality game
ARIB	Association of Radio Industries and Businesses
ATIS	Alliance for Telecommunications Industry Solutions
AV	augmented virtuality
AWS	Amazon Web Services
B5G	beyond 5G
BIoT	blockchain-based Internet of things
BS	base station
BUMMER	behaviors of users modified, and made into an empire for rent
CAS	complex adaptive system
CI	collective intelligence
CIA	Central Intelligence Agency
CIC	Central Intelligence Corporation
CoC	computation oriented communications
CoZ	Crowd-of-Oz
CPS	cyber-physical system
CPSS	cyber-physical-social system
CPU	central processing unit
DAC	digital-to-analog converter
DAO	decentralized autonomous organization
DApp	decentralized application
DL	deep learning

DLT	distributed ledger technologies
DNA	deoxyribonucleic acid
DNN	deep neural network
DSOC	decentralized self-organizing cooperative
DSP	digital signal processing
DWE	digital world experience
ECDSA	elliptic curve digital signature algorithm
EOA	externally owned account
EPON	Ethernet passive optical network
ERC	Ethereum Request for Comments
ESF	edge sample forecasting
ESP	extrasensory perception
ESPN	extrasensory perception network
ETH	ether
ETSI	European Telecommunications Standards Institute
EVM	Ethereum virtual machine
F5G	fifth generation fixed network
FBT	fitness-beats-truth
FCC	Federal Communication Commission
FG-NET	Focus Group Technologies for Network
FiWi	fiber-wireless
FN	future networks
f-NFT	fractionalized non-fungible token
FTTE	fiber-to-the-everywhere-and-everything
GDP	gross domestic product
GFT	Google Flu Trends
GMPG	Global Multimedia Protocol Group
GPS	global positioning system
GPT	general-purpose technology
GPU	graphics processing unit
HART	human–agent–robot teamwork
HCI	human–computer interface
HetNet	heterogeneous network
HIN	hyper intelligent networks
HIT	human intelligence task
HITL	human-in-the-loop
HMD	head-mounted display
HMI	human–machine interaction
HMN	Harmonized Mobile Networks
HO	human operator
HSI	human–system interface
HTC	Holographic-type communication

HTML	Hypertext Markup Language
I2V	invisible-to-visible
IA	intelligence amplification
ICT	information and communications technologies
IEN	intelligence-endogenous network
IFrame	inline frame
IMT	International Mobile Telecommunication
IoE	Internet of everything
IoT	Internet of things
IPFS	inter-planetary file system
ISAC	integrated sensing and communications
ISACC	integrated sensing, communications, and computing
ISG	Industry Specification Group
IT	information technologies
ITU	International Telecommunication Union
ITU-R	ITU-radiocommunication sector
ITU-T	ITU-telecommunication sector
JC	judge contract
KPI	key performance indicator
LED	light-emitting diode
LOS	line-of-sight
LTE-A	long-term evolution advanced
M2M	machine-to-machine
MEC	multi-access edge computing
MIMO	multiple-input and multiple-output
ML	machine learning
MMORPG	massively multiplayer online role-playing game
MPP	mesh portal point
MR	mixed reality
MTurk	mechanical turk
MU	mobile user
MWI	many-worlds interpretation
NbS	nature-based solutions
NDE	near-death experience
Net4AI	communication network for AI
NFT	non-fungible token
NGMN	next generation mobile networks
NG-OAN	next-generation optical access network
NG-PON	next-generation passive optical network
NOMA	Non-orthogonal multiple access
NSF	National Science Foundation
OFDM	orthogonal frequency division multiplexing

OLT	optical line terminal
ONU	optical network unit
OTT	over-the-top
OWC	optical wireless communication
P2P	peer-to-peer
PC	personal computer
PDA	perceive-decide-act
pHRI	physical human–robot interaction
PMN	perceptive mobile network
PON	passive optical network
PoW	proof-of-work
QIT	quantum information technology
QKD	quantum key distribution
QoE	quality-of-experience
QoS	quality-of-service
QR	quick response
RAN	radio access network
REN	resource efficient networks
RFID	radio-frequency identification
RGB	red green blue
RIS	reconfigurable intelligent surface
RPC	remote procedure call
SAGSIN	space-air-ground-sea integrated network
SDG	sustainable development goal
SDO	standard development organization
sHRI	social human–robot interaction
SLAM	simultaneous localization and mapping
STER	selflessness, timelessness, effortlessness, and richness
TBSN	trust-based secure networks
TDM	time division multiplexing
TOR	teleoperator robot
TRC	TRON request for comments
TV	television
UAV	unmanned aerial vehicle
URL	Universal Resource Locator
URLLC	ultra-reliable and low-latency communication
V2X	vehicle-to-everything
VC	venture capital
VPN	virtual private network
VR	virtual reality
VUCA	volatile, uncertain, complex, and ambiguous
WDM	wavelength division multiplexing

WiFi	wireless fidelity
WLAN	wireless local area network
WoZ	Wizard-of-Oz
WRC	world radiocommunication conference
XAI	explainable artificial intelligence
XR	extended reality

CHAPTER 1
Introduction

"Computers are useless. They can only give you answers."

Pablo Picasso
(1881–1973)

1.1. Toward 6G: A New Era of Convergence

This book is a sequel to our last Wiley-IEEE Press book titled "Toward 6G: A New Era of Convergence," which was authored together with Amin Ebrahimzadeh and was the first published book on future 6G mobile networks [1].

In our prequel book, we argued that 6G should not only explore more spectrum at high-frequency bands but, more importantly, *converge driving technological trends*. Our applied approach was in line with the bold, forward-looking research agenda put forth by Saad et al. [2], which intends to serve as a basis for stimulating more out-of-the-box research that will drive the 6G revolution. Specifically, Saad et al. [2] claim that there will be the following four driving applications behind 6G: (i) multisensory extended reality (XR) applications, (ii) connected robotics and autonomous systems, (iii) wireless brain–computer interaction (a subclass of human–machine interaction), and (iv) blockchain and distributed ledger technologies. Among other 6G driving trends, they emphasize the importance of edge intelligence and the emergence of smart environments and new human-centric service classes, as well as the end of the smartphone era, given that smart wearables are increasingly replacing the functionalities of smartphones. They argue that smartphones were central to 4G and 5G. However, in recent years there has been an increase in wearable devices whose functionalities are gradually replacing those of smartphones, ranging from integrated headsets to smart body implants that can take direct sensory inputs from human senses.

6G and Onward to Next G: The Road to the Multiverse, First Edition. Martin Maier.

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These emerging smart wearables may bring an end to smartphones and potentially drive a majority of 6G use cases.

One of the most intriguing 6G visions out there at the time of writing our prequel book was outlined by Harish Viswanathan and Preben E. Mogensen, two Nokia Bell Labs Fellows, in an open access article titled "Communications in the 6G Era" [3]. In this article, the authors focus not only on the technologies but they also expect the human transformation in the 6G era through *unifying experiences across the physical, biological, and digital worlds* in what they refer to as the network with the sixth sense. Combining the multi-modal sensing capabilities with the cognitive technologies enabled by the 6G platform will allow for analyzing behavioral patterns and people's preferences and even emotions, hence creating a sixth sense that anticipates user needs and allowing for interactions with the physical world in a much more intuitive way.

Furthermore, Viswanathan and Mogensen [3] claim that new themes are likely to emerge. Specifically, the future of connectivity is in the creation of *digital twin worlds* that are a true representation of the physical and biological worlds at every spatial and time instant, unifying our experience across these physical, biological, and digital worlds. Digital twins of various objects created in edge clouds will form the essential foundation of the future digital world. Digital twin worlds of both physical and biological entities will be an essential platform for the new digital services of the future. Digitalization will also pave the way for the creation of new virtual worlds with digital representations of imaginary objects that can be blended with the digital twin world to various degrees to create a mixed-reality, super-physical world, enabling new *superhuman* capabilities. Augmented reality (AR) user interfaces will enable efficient and intuitive human control of all these worlds, whether physical, virtual, or biological, thus creating a unified experience for humans and the human transformation resulting from it. Dynamic digital twins in the digital world with increasingly accurate, synchronous updates of the physical world will be an essential platform for augmenting human intelligence.

Importantly, Viswanathan and Mogensen [3] outlined a *vision of the future life and digital society* on the other side of the 2030s. While the smartphone and the tablet will still be around, we are likely to see new man–machine interfaces that will make it substantially more convenient for us to consume and control information. The authors expect that wearable devices, such as earbuds and devices embedded in our clothing, will become common. We will have multiple wearables that we carry with us and they will work seamlessly with each other, providing natural, intuitive interfaces. Touch-screen typing will likely become outdated. Gesturing and talking to whatever devices we use to get things done will become the norm. The devices we use will be fully context-aware, and the network will become increasingly sophisticated at predicting our needs. This context awareness combined with new man–machine

interfaces will make our interaction with the physical and digital world much more intuitive and efficient. The computing needed for these devices will likely not all reside in the devices themselves because of form factor and battery power considerations. Rather, they may have to rely on locally available computing resources to complete tasks beyond the edge cloud. As consumers, we can expect that the self-driving concept cars of today will be available to the masses by the 2030s. They will be self-driving most of the time and thus will substantially increase the time available for us to consume data from the Internet in the form of more entertainment, rich communications, or education. Further, numerous domestic service robots will complement the vacuum cleaners and lawn mowers we know today. These may take the form of a swarm of smaller robots that work together to accomplish tasks.

In fact, according to [4], nothing has happened yet in terms of the Internet. The Internet linked humans together into one very large thing. From this embryonic net will be born a collaborative interface, a sensing, cognitive apparatus with power that exceeds any previous invention. The hard version of it is a future brought about by the triumph of a superintelligence. According to Kelly, however, a soft singularity is more likely, where artificial intelligence (AI) and robots converge – humans plus machines – and together we move to a complex interdependence. This phase has already begun. We are connecting all humans and all machines into a global matrix, which some call the *global mind* or *world brain*. It is a new regime wherein our creations will make us better humans. This new platform will include the collective intelligence (CI) of all humans combined with the collective behavior of all machines, plus the intelligence of nature, plus whatever behavior emerges from this whole. Kelly estimates that by the year 2025 every person will have access to this platform via some almost-free device.

Our prequel book described the latest developments and recent progress on the key technologies enabling 6G mobile networks, paying particular attention to their seamless convergence. Among other potential research directions, 6G will take cloud services to the next level by moving many of the computational and storage functions from the smartphone to the cloud. As a result, most of the computational power of the smartphone can focus on presentation rendering, making virtual reality (VR), AR, or XR more impressive and affordable. Furthermore, 6G will transform a transmission network into a computing network. One of the possible trademarks of 6G could be the seamless convergence and harmonious operations of transmission, computing, AI, machine learning, and big data analytics such that 6G is expected to detect the users' transmission intent autonomously and automatically provide personalized services based on a user's intent and desire.

In the final chapter of our prequel book, we took an outlook on how future profound 6G technologies will weave themselves into the fabric of

everyday life until they are indistinguishable from it. As a result, the boundary between virtual (i.e. online) and physical (i.e. offline) worlds is to become increasingly imperceptible, while both digital and physical capabilities of humans are to be extended via edge computing variants with embedded AI capabilities. More specifically, we elaborated on the implications of the transition from the current gadgets-based Internet to a future Internet that is evolving from bearables (e.g. smartphone), moves toward wearables (e.g. Google and Levi's smart jacket or Amazon's announced voice-controlled Echo Loop ring, glasses, and earbuds), and then finally progresses to nearables (e.g. intelligent mobile robots). Nearables denote nearby surroundings or environments with embedded computing/storage technologies and service provisioning mechanisms that are intelligent enough to learn and react according to user context and history in order to provide user-intended services. While 5G was supposed to be about the Internet of Everything (IoE), to be transformative 6G might be just about the opposite of Everything, i.e. Nothing or, more technically, No Things. Toward this end, we introduced the *Internet of No Things* as an extension of immersive VR from virtual to real environments, where human-intended Internet services – either digital or physical – appear when needed and disappear when not needed. In doing so, the Internet of No Things helps tie both online and offline worlds closer together for the extension of human capabilities and experiences, ranging from conventional VR and AR to advanced XR and even more sophisticated cross-reality environments that involve various types of physical and digital realities.

Figure 1.1 depicts our proposed architecture of the Internet of No Things, which integrates the following three evolutionary stages of mobile computing: (i) ubiquitous, (ii) pervasive, and (iii) persuasive computing. Ubiquitous computing is embedded in the things surrounding us (i.e. nearables), while pervasive computing involves bearables and wearables. Persuasive computing aims at changing or even transforming the behavior of human users through social influence. As explained in technically greater detail in Chapter 5, the Internet of No Things will be instrumental in not only establishing XR as the next-generation mobile computing platform for the extension of human capabilities and experiences but also enabling future communication technologies that are anticipated to fold into our surroundings, thereby helping us get our noses off the smartphone screens and back into our physical and biological environments. The Internet of No Things represents an important stepping stone toward ushering in the 6G post-smartphone era and its underlying fusion of digital and real worlds created and delivered by non-traditional converged service platforms.

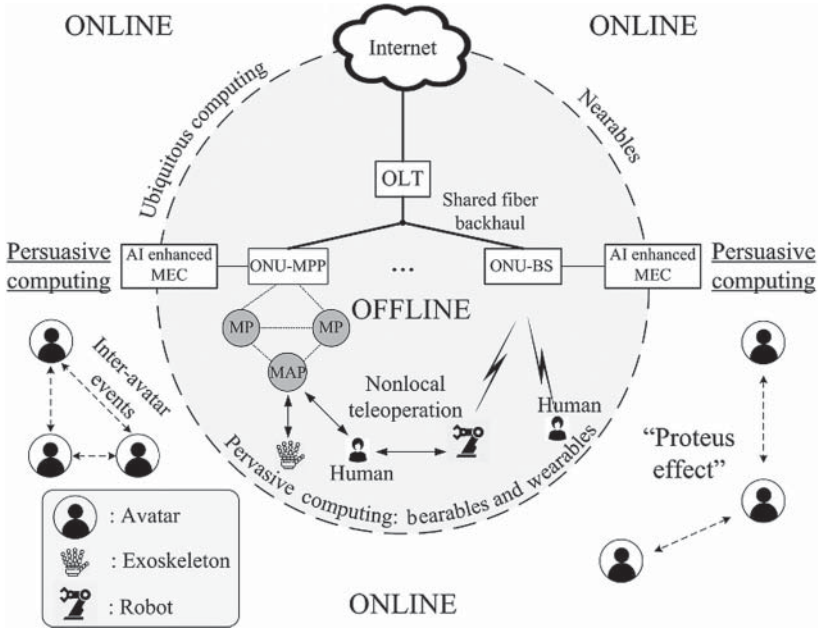

Figure 1.1 Internet of No Things: Integrating ubiquitous, pervasive, and persuasive computing for the extension of human capabilities and experiences.
Source: Maier et al. (2020). © 2020 IEEE.

1.2. Fusion of Digital and Real Worlds: Multiverse vs. Metaverse

In May 2019, the ITU-T Focus Group Network 2030 (FG-NET-2030), an initiative focusing on the fixed networks domain, published the first white paper on their Network 2030 vision [5]. Network 2030 is an abstraction of network technologies required to deliver advanced applications in 2030 and the decade after. It aims at coexisting with deployed infrastructures, incrementally inserting new capabilities in both public and private fixed (wireline) networks. According to [5], the next frontier in multimedia after VR and AR will include holographic media and multi-sense network services, e.g. haptic communication services. Soon our experiences with VR/AR will determine that they are not real enough, calling for new media, unencumbered by today's head-mounted displays (HMDs). The fusion of digital and real worlds across all dimensions is the driving theme for Network 2030, created and

delivered by non-traditional converged service platforms, where developers do not hesitate to use technologies from as many disciplines as possible. They do not discriminate whether services and applications will be used by human beings, or by physical, digital, or virtual objects.

The European Telecommunications Standards Institute (ETSI) launched its Industry Specification Group (ISG) fifth generation fixed network (F5G) initiative, which aims at promoting the expansion of fixed networks to as many sectors as possible via fiber-to-the-everywhere-and-everything (FTTE) [6]. F5G also considers complementary wireless technologies, most notably WiFi 6, for the last meters to enable use cases such as cloud VR, online gaming, smart factory, and the support for the evolution of 5G networks. According to [6], F5G is the foundation of the new digital age and is a prerequisite for the digital transformation of the whole society. F5G is just the beginning and a first step for more generations to come. The evolution of F5G, together with that of mobile 5G and 6G, is expected to support new application scenarios involving digital avatar life, full sensory (including tactile and haptic) Internet, and a ubiquitous intelligent society in this new era of convergence.

In the final chapter of our prequel book, we also introduced the concept of the so-called *Multiverse* as an interesting attempt to help realize the fusion of digital and real worlds. The Multiverse offers eight different types of reality, including but not limited to VR and AR, as explained shortly. A term closely related to the Multiverse is the recently emerging *Metaverse*. According to [7], the Metaverse will be the precursor of the Multiverse. Specifically, the Metaverse might be viewed as the next step after the Internet, similar to how the mobile Internet expanded and enhanced the early Internet in the 1990s and 2000s. The various adventures that this place has to offer will surround us both socially and visually. The Metaverse is unique in that it spans a wide range of interconnected platforms as well as the digital and physical worlds underpinned by decentralized *Web3* technology.

As shown in Figure 1.2, while the Web1 (read-only web) and Web2 (read-and-write web) enabled the knowledge economy and today's platform economy, respectively, the Web3 will enable the *token economy* where anyone's contribution is compensated with a token. The token economy enables completely new use cases, business models, and types of assets and access rights in a digital way that were economically not feasible before, thus enabling completely new use cases and value creation models. Note that the term token economy is far from novel. In cognitive psychology, it has been widely studied as a medium of exchange, and arguably more importantly, as a positive reinforcement method for establishing desirable human behavior, which in itself may be viewed as one kind of value creation. Unlike coins, however, which have been typically used only as a payment medium, tokens may serve a