Realizing 6G: The Operational Goals, Enabling Technologies of Future Networks, and Value-Oriented Intelligent Multi-Dimensional Multiple Access

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Abstract

The massive deployment of the fifth generation (5G) wireless networks are significantly accelerating the ongoing process of industrial and societal transformation. Disregard many impressive achievements, current scenario-specific, and communication-centric 5G technologies still face many challenges in empowering future applications with diverse requirements under stringent resource constraints. In this article, different perspectives of the future sixth generation (6G) networks, including the 6G operational goals, key performance indicators (KPIs), and enabling technologies, are analyzed and presented. In terms of its operational goals, we believe that 6G will serve as a holistic information and communication technology (ICT) platform by unifying the beyond communication capabilities in achieving its eventual goal of value realization by fulfilling the needs of people, industry, and society. With this understanding, the KPIs of 6G in different domains, which include capabilities of diverse and customized service provisioning, situational awareness discovery, and connected intelligence, as well as scalability, efficiency, and agility (SEA) of 6G enabled systems, are defined as 6G design objectives. Furthermore, key enabling technologies for achieving the KPIs are elaborated, including intelligent multi-dimensional multiple access, situational awareness enabled by edge intelligence and integration of communication, sensing, localization, and synchronization, as well as intelligent value-driven system orchestration and operation. Finally, our envisioned 6G concepts are exemplified by the proposed intelligent multi-dimensional multiple access, which demonstrates its effectiveness for value realization in 6G operation.

Introduction

Since the early 1980s to now, we have witnessed the dramatic revolutions in communications and computing technologies, particularly as evidenced by the different generation of wireless technologies from the first generation (1G) to 5G. Our society and lifestyle have been fundamentally transformed by the Internet, wireless communications, and pervasive computing. Emerging applications, for example, digital-twin/metaverse enabled vertical services and real-time holographic communication, are expected to enable a fully immersive and hyper spatial-temporal shared virtual space for humans to play, work, and socialize [1]. As a result, with many promising applications and the massively deployed information and communication technology (ICT) infrastructures, further bolstered by future networks and ubiquitous connectivity, we are well on our way to a hyperconnected society, where everyone and everything are connected.

However, meeting the needs of people, industry and society in a connected world goes far beyond ubiquitous connectivity, which relies heavily on intelligent operation and orchestration of the future 6G enabled integrated vertical systems for service provisioning under highly complex wireless environment, stringent application requirements, and extremely constrained communication and computing resources. As a result, 5G networks are facing many challenges on how to support tailored service provisioning, dynamic data/knowledge exchange, and intelligent collaboration among distributed machines to effectively empower diverse vertical applications.

Motivations: Limitations of 5G

The design philosophy behind the 5G networks is still primarily focused on the communication aspect, that is, data exchange, without considering the value of such data for goal-realization and vertical service provisioning. From this perspective, 5G has the following major inherent limitations in supporting diverse future applications.

Scenario-Specific Paradigms for QoS Provisioning: Given the dramatically increased variety of applications in the connected society, the communication requirements of future applications are becoming extremely diversified. In this regard, the root cause of 5G limitations is the *scenario-specific designs*. 5G focuses on supporting three typical communication scenarios: enhanced mobile broadband (eMBB), ultra-reliable and low-latency communication (uRLLC), as well as massive machine type communication (mMTC), to guide network operation and Quality-of-Service (QoS) provisioning. Although such classification significantly simplifies the complexity of

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Digital Object Identifier:
10.1109/MNET.001.2200429

5G network operation, many new applications will not be fit exactly into these three categories. Therefore, 5G networks are facing challenges for satisfying the dramatically increased service heterogeneity and diversity due to the wide variety of applications.

Communication-Centric System Design and Network Operation: While the achieving transmission rates approaching to the Shannon limit, 5G networks do not possess all essential beyond-communication functionalities to effectively support the needs of different vertical applications. For instance, many new applications, such as smart manufacturing, requires highly situation-aware, tight, and coordinated interactions among all involved entities to accomplish its operational goal in an effective and intelligent way. Achieving this often relies on the integration of sensing, localization, synchronization, communication, and control, which are well-beyond the capabilities of communication-centric current 5G networks.

Lack of Large-Scale Intelligent Interaction and System Orchestration Capabilities: With the rapid development of artificial intelligence (AI) technologies, network entities can extract descriptive knowledge (e.g., hidden network dynamics and traffic pattern) from historical data. However, 5G still primarily focuses on the conventional role of data exchange while neglecting the need and new capabilities for knowledge exchange and utilization. Given the increased complexity of network architecture, time-varying network conditions and application requirements, rapid knowledge exchange, and utilization among massive connected entities is key to achieve intelligent interaction. Meanwhile, future vertical applications require application-level, large-scale orchestration, that is, involving many connected entities by leveraging distributed information, communication, computing resources, and other capabilities which is not supported by current 5G designs.

The Scope of This Article

As we elaborated above, 5G is primarily limited by the adopted communication-centric design paradigm, in which any new improvements based on this tend to be insufficient for future applications. Therefore, overcoming these challenges in 6G has to introduce fundamental paradigm shifting on design philosophy and objectives while avoiding incremental improvement of 5G. In defining 6G in this article, we would like to answer the following key questions:

- What is the future role of 6G systems for future society and industry? What are the goals of 6G operation?
- What are the key performance indicators (KPIs) and design objectives to guide the design of 6G systems?
- What is the key enabling technologies for 6G systems to meet expectations of 6G KPIs?

The remainder of this article goes as follow: We first envision the role of 6G of future connected society based on Maslow's hierarchy of needs for human beings [2]. Then this role is used to establish the design paradigm for 6G and define the corresponding KPIs. Following that, we present a 6G system architecture. Finally, this article is concluded, and future research perspectives are outlined.

> To overcome the scenario-specific and communication-centric limitations of 5G, 6G networks will serve as a holistic ICT platform by unifying the beyond communication capabilities in achieving application-specific value realization for network operators, end-users, and vertical industries.

Defining 6G: A Value-Oriented Paradigm

Empowered by the evolution of ICT technologies, we are quickly moving to a ubiquitously networked society, with everyone and everything fully connected by Internet and wireless networks. This dramatic development and integration of wireless technologies and vertical industries rely on 6G for diverse, application-specific service provisioning beyond high speed and reliable data transmission [3]. Consequently, 6G is expected to focus on the application-specific value realization for network operators, end-users, and vertical industries.

One fundamental question to answer here is that what are future needs of connected society for 6G to support. To answer this question, Maslow's hierarchy of needs theory is considered, which includes human's basic needs, psychological needs, and self-fulfillment needs. Given the shared similarity between 6G enabled connected systems with human society, we define the goals of 6G systems at three distinct levels:

Level 1 Goal — Connected Everything: One critical foundation of the future connected world is ubiquitous connectivity, which will enable reliable, and secure connections among people, things, complex processes, and further support diverse applications of hyper-connected society.

Level 2 Goal — Connected Intelligence: The next level goal of connected intelligence for 6G is essential to enable knowledge sharing among connected entities and intelligent operation of complex systems. The embedding of AI capability into connected objects (e.g., end-users/devices, sensors, and base stations) will enable intelligent sensing of surrounding environment and meaningful knowledge exchange.

Level 3 Goal — Value realization in Hyper-Connected Systems: Our society and industry are highly integrated and connected systems of human, machine, infrastructure, and application processes. Thus, the highest level of 6G operational goal is fulfilling the needs of people, industry, and society by guiding the operation of diverse ICT systems. Technically, value realization in 6G is to observe the physical world, analyze ongoing processes, and apply our influence by generating useful knowledge, feedback, and desired operations to meet user's specific requirements at application-level.

The 5G is an era of exploring connected everything. Although 5G was promoted as an enabler of Internet of Everything (IoE) services, it is ineffective to support extreme heterogeneity QoS provisioning. However, 5G also does not realize connected intelligence since it does not integrate AI capabilities. Recently, some researchers elaborate that beyond 5G networks will support connected intelligence from the core cloud to the end-user devices. However, these works fail to show how to orchestrate and operate communication systems for objective and value realization of vertical applications.

Social needs	Current 5G	Vision of Beyond 5G	Our 6G vision
L1: Connected Everything	Partial satisfaction	✓	✓
L2: Connected Intelligence	×	✓	✓
L3: Value Realization in Connected System	×	Not considered	✓

TABLE 1. A comparison of 5G, beyond 5G, and 6G based on three-level needs for communication systems.

In achieving the overall goal of value realization in connected systems, 6G is expected to serve as a critical platform to interconnect and integrate different things, intelligence, and capabilities. 6G will integrate diverse networks to act as a coordinated holistic ICT system, following the intelligent system operation and orchestration for the value realization, that is, individualized QoS provisioning with low operation cost at end-user, as well as the high cost-effective operation for the whole network. A comparison of 5G, Beyond 5G, and 6G systems is presented in Table 1.

Realizing 6G: Multi-Dimensional KPIs for 6G Value Realization and Key Enabling Technologies

Multi-Dimensional KPIs of 6G

In realizing the value-oriented 6G systems, the defining goals of 6G discussed earlier at three levels are translated into the KPIs in three different dimensions, as illustrated in Fig. 1:

- Diverse QoS provisioning: The first KPI dimension is for the evaluation of customized diverse QoS provisioning capability of 6G while achieving connected everything.
- Situation-awareness and connected intelligence: The second KPI dimension is on the assessment of 6G situation-awareness for connected intelligence.
- Scalability, efficiency, and agility of 6G systems: The third KPI dimension is dedicated to evaluating 6G system scalabilities for value realization.

KPI Dimension 1 — Diverse and Individualized QoS Provisioning: While there are similar QoS requirements between 5G and 6G in this domain (e.g., data rate and spectral/energy efficiencies), application-specific and diverse value-oriented service provisioning in 6G calls for additional QoS indicators, including dramatically enhanced reliability, near-zero latency, highly dependable trust, privacy, and security managemen:

Volumetric Spectral and Energy Efficiency: With the deployment of satellites and unmanned aerial vehicles, 6G networks will create 3-dimensional (3D) radio environments. However, the impact of terrain, building, and even furniture inevitably induce complex 3D signal propagation and coverage holes. Thus, to quantify the spectral utilization efficiency and energy efficiency of wireless transmissions in 3D space, 6G deliver high Volumetric Spectral and Energy Efficiency (VSEE) measured in bps/Hz/m^3/Joules, rather than traditional bps/Hz/m^2/Joules in 5G. VSEE along with volumetric data rate, reliability, and latency can be utilized to evaluate 6G performance in a more comprehensive way.

Guaranteed Reliability and Latency: Emerging vertical applications usually have strict latency and reliability requirements on end-to-end connections, instead of only the radio access network itself. In detail, most end-to-end connections will go through several network domains, from the end-user device domain, through access and edge networks, toward core and cloud. However, current network systems cannot guarantee end-to-end services since controller in each network domain only focuses on its domain specific QoS requirements rather than end-to-end QoS demands of applications. In 6G, network entities in different network domains will be orchestrated to ensure guaranteed reliability of 99.9999 percent and end-to-end latency 0.1–1 ms [4].

Trust, Privacy, and Security Management: The complexity of 6G communication systems, as well as the massive number of intelligent machines and devices, bring exacerbated security vulnerability, leading to unauthorized access to network and privacy leakage [5]. Thus, future 6G has to achieve context-aware highly efficient security protection with multimodal secrecy generated within both physical and application processes.

KPI Dimension 2 — Situational Awareness and Connected Intelligence: Timely and precise awareness of network situation in spatial-temporal domains based on sensing, positioning, and network synchronization is the fundamental premise of intelligent operation and value realization of 6G systems. In detail, 6G situational awareness can be elaborated from three aspects:

Capturing the Underlying Status of Network Environments at System Level: Effective orchestration of 6G network relies on holistic understanding of network environment in both spatial and temporal dimensions [6]. Firstly, due to the varying mobility and traffic distribution in different regions, 6G network environment among different cells shows spatially heterogeneity. Secondly, many factors could contribute to the temporal dynamics of 6G, including: i) long-term fluctuations (in the level of hours) due to the fact of service traffic in a region significantly vary from different time of a day and ii) short-term fluctuations (in the level of milliseconds) due to the variation of wireless channel and interference. Therefore, it is essential to obtain the systematic knowledge of spatial and temporal network dynamics for 6G orchestrated operation.

Understanding UE-Specific Resource Conditions and Utilization Constraints: Due to dynamic end-user behavior and service traffic of UEs, 6G systems need to identify UE's intents and convert them to individualized QoS demands and further to multi-dimensional network resource requirements [7]. Meanwhile, UE's experience on the multi-dimensional radio resource utilization is highly dependent on situation and hardware-constraints. These require a contextual understanding of individual UE's resource utilization constraints, for instance, identification of the preferred and non-preferred radio resources of each individual UE.

Situational-Aware and Intelligent Knowledge Exchange Through Collaboration of Device, Edge and Cloud: Once the situational awareness is achieved at both individual and system, a following question we have to answer is how to mea-

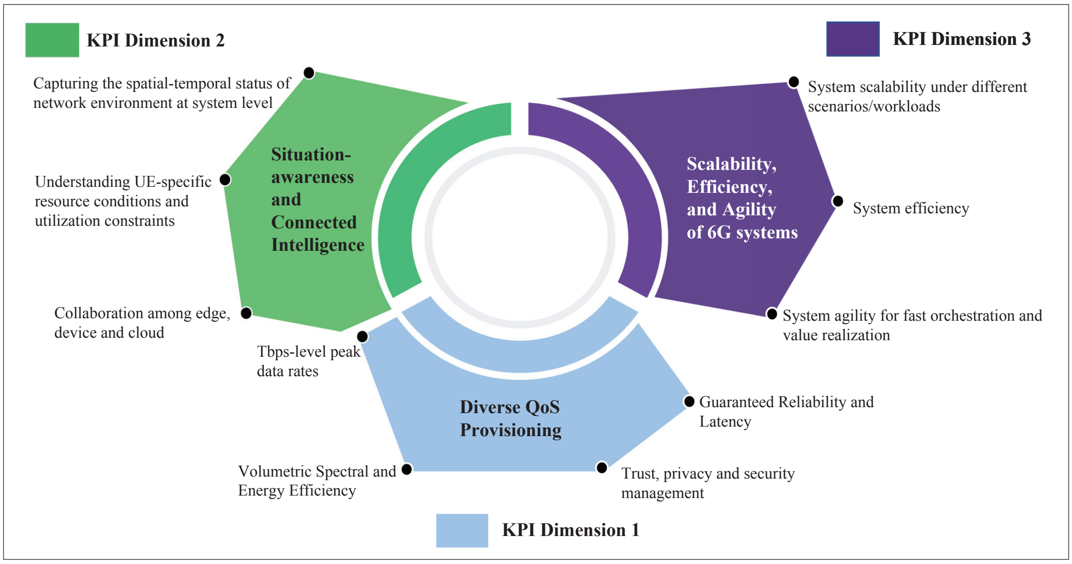

FIGURE 1. Multi-dimensional key performance indicators (KPIs) for value realization in 6G.

sure effectiveness of situational-aware knowledge exchange. Herein, we advocate to evaluate it at three aspects: i) Timeliness, which is the amount of time required for related distributed information gathering, processing, and network situation-awareness discovery, will be used for the decision-making and network operation; ii) Completeness represents the proportion of situational knowledge of the whole service area obtained at the network controller cover; and iii) Accuracy is defined as the difference between the obtained knowledge and the true status of individual user and 6G network.

KPI Dimension 3 — Scalability-Efficiency-Agility (SEA) of 6G Enabled Systems: The third KPI dimension is to evaluate the capability of 6G for supporting diverse applications with varying scale and requirements for value realization, which include system scalability under varying scenarios and workloads, overall protocol efficiency, as well as system agility for fast system orchestration:

System Scalability: This is an important indicator that describes the ability of 6G systems can seamlessly self-adapt under different scenarios and workloads. Specifically, scalability can be measured by dynamic adaptation of network structure, network resource scheduling, and communication protocol. Scalability in network resource scheduling means that network controller can flexibly adapt multi-dimensional network resources to accommodate changing traffic workload. On the other hand, scalability in communication protocol is to meet the dynamic workload/scenario by changing networking strategy and network resource management policy accordingly.

System Efficiency: 6G is foreseen as an integration of diverse ICT systems with increasing complexity. The resultant increase in system complexity creates substantial overhead in terms of signaling overhead, time cost, computation complexity, and energy cost. Furthermore, the optimal performance of value realization at an individual-level, especially in large scale network, is usually at cost of tremendous overhead. As a result, it is essential to evaluate the performance gain compared to the associated overhead. Future 6G systems must achieve high scalability with minimized overhead for high protocol efficiency.

System Agility: 6G systems are faced with ever-evolving QoS demands of end-user/application, as well as unforeseen network environment. As a result, agility is defined as the speed of 6G systems to fast re-configure and re-deploy to support the on-demand connectivity requests with diversified QoS requirements under heterogeneous conditions. Specifically, agility can be evaluated by the time required for reconfiguration.

Key Enabling Technologies for Value-Oriented 6G Systems

A variety of recent communications technologies, including non-orthogonal multiple access (NOMA), THz communication, ultra-massive multiple-input multiple-output (MIMO), re-configurable intelligent surface (RIS), and full-duplex might be useful in supporting 6G [8]. However, in achieving above-mentioned eventual goal 6G on value realization and the KPIs in three different dimensions, three categories of disruptive key enabling technologies, as shown in Fig. 2, must be integrated in 6G systems:

- The upper level technologies are for 6G system orchestration and value realization, which automatically transforms end-user's demands into individualized QoS and resource requirements.
- The middle level is the technologies for collaborative network situational awareness, which generates high accurate sensing knowledge for decision-making in value-driven 6G system orchestration and operation.
- The bottom level fundamental technologies is to enable intelligent multi-dimensional multiple access for achieving diverse and QoS/resource-aware integrated services (communication, positioning, sensing, etc.).

Value-Driven 6G System Orchestration and Operation: Intelligent orchestration of complex 6G networks will become the foundation for value-oriented collaborative communication, computing, and learning for the cost-effective QoS service provisioning.

Network Orchestration by Semantic-Empowered Understanding of Application-Level Intents: Current network operation schemes are incapable of flexibly customizing network to meet the

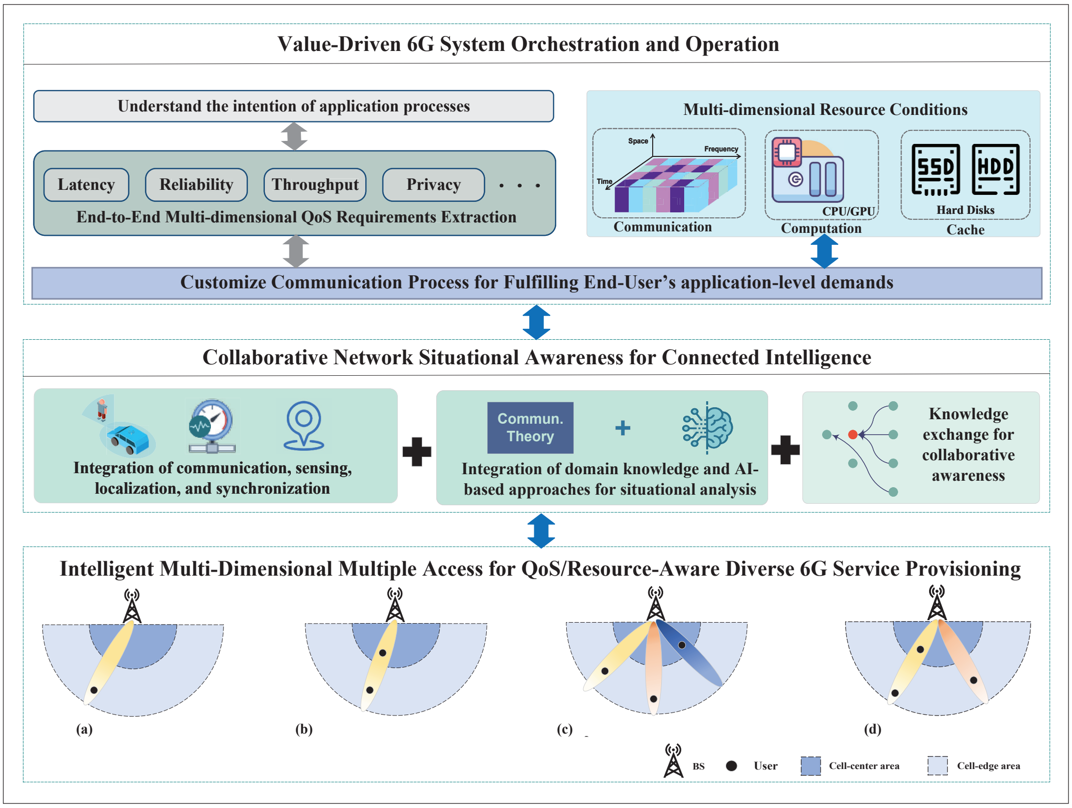

FIGURE 2. The illustration of key enabling technologies for value-oriented 6G systems. Value-driven 6G system orchestration and operation automatically transforms end-user's specific requirements at application-level into individualized QoS requirements. Then, with collaborative network situational awareness, intelligent multi-dimensional multiple access are utilized to fulfill user's specific QoS requirements.

application-level requirements and value realization. Semantic-related techniques are essential in measuring the usefulness of data packets from a communication process with respect to the value realization. It can enable the network operator to perceive the importance of the transmitted packets and customize the entire communication processes with suitable QoS requirements to better ensure the overall value.

AI-Enabled Self-Sustaining Value-Oriented Network Operation: This aims at enabling the automatic value realization at both individual level and system level. With the utilization of AI-enabled approaches, it can self-adapt configuration of 6G network, parameters of network functions, and self-management of network resources with fine control granularity under highly dynamic and complex network environments. It is an important area for further improvement since the current network framework mainly focuses on typical scenarios and always requires manual intervention under unforeseen network situations.

Collaborative Network Situational Awareness for Connected Intelligence: Situational awareness discovery based on AI-based approaches can identify underlying network's conditions [9]. In our vision, situational awareness discovery can be achieved by following key techniques.

Integration of Communication, Sensing, Localization, and Synchronization: To achieve the comprehensive situational understanding and multi-dimensional situational related awareness data at UE (e.g., channel conditions, interference) labeled with geographic location and time stamp should be collected for timely analysis. This requires unifying communication, sensing, localization, and synchronized processes to achieve efficient usage of wireless resources and to provide ubiquitous connectivity, as well as high-resolution synchronized multi-modal sensing data.

Integration of AI-Based and Domain Knowledge for Situational Analysis: Due to the high complex and varying network environments, existing AI-based approaches normally need a large amount of sensing data to achieve situational awareness, which may induce unacceptable latency for decision-making. To address this issue, we can jointly exploit AI-based and domain knowledge (e.g., models, analytical tools, and optimization frameworks) of communications and networking, in which domain knowledge is translated into "prior-expert knowledge" for initializing various learning process of AI-based approaches. This combined paradigm provides accelerated characterization of network situation, such as user behavior, spatial-temporal inference, data traffic, and network resource demand.

Collaborative Awareness Discovery by Distributed Knowledge Sharing: The situational awareness capability of single network entity, for example, base station (BS), is inherently limited due to many constrains, such as geographic locations and hardware constraints [10]. As a result, collaborative learning, such as federated and meta learning disseminate knowledge among relevant end-user devices and network infrastructure will be essential. With collaborative learning, multiple network entities with heterogeneous awareness capability could be engaged in the same situational awareness task according to user's demands under the coordination of edge servers.

Intelligent Multi-Dimensional Multiple Access for QoS/Resource-Aware Diverse 6G Service Provisioning: With increased use of large-scale antenna array and emerging physical layer techniques, for example, orthogonal-time-frequency-space (OTFS) modulation, and higher frequency bands [11], conventional time-frequency resource domains have been expanded with the addition of space, power, and code, leading to multi-dimensional multiple access (MDMA) [7, 12].

One critical challenge in MDMA is how to exploit different radio resources domains under diverse scenarios in supporting intelligent multi-dimensional multiple access while achieving the desired QoS requirements from different end-users. Consider the high-speed moving scenario, a new NOMA transmission that incorporates OTFS modulation is proposed, where end-users with different mobility patterns are grouped together for the implementation of NOMA in the Doppler-delay domain [13]. Rate-splitting multiple access (RSMA) scheme [14] have been proposed to explore additional degrees of freedom in spatial and power domains to improve spectral efficiency and system multiplexing capability. Recently, RIS has arisen as a promising technology for controlling the propagation channel of end-users, RIS-based MIMO-NOMA has high flexibility in utilizing the spatial and power domains in a non-orthogonal way as compared to conventional NOMA schemes [15].

6G relies on an intelligent MDMA that can dynamically unify different types of multiple access (orthogonal or non-orthogonal) and efficiently utilize multi-dimensional radio resources depending on the dynamic resource constraints and heterogeneity QoS requirements of end-users. Based on the observation that non-orthogonality in different resource domain will induce different level of utilization costs in different radio resource domains, our previous works have developed an MDMA scheme, which is a convergence of orthogonal multiple access (OMA), power-domain NOMA, and spatial-domain NOMA. These can select the most beneficial multiple access mode based on the radio resource utilization costs and specific QoS demands of end-users [12].

Case Study: Value-Oriented Intelligent Multi-Dimensional Multiple Access

Achieving Value Realization in 6G Through Intelligent Multi-Dimensional Multiple Access

To validate the effectiveness of value-oriented paradigm in 6G systems, we provide an illustrative use case of MDMA, in which two groups of participants are involved: end-users and network operators. Due to diverse requirements and perceived resource value, an interpretation of value by different participants, it is important to accurately define "value realization" in a more participant-specific way. In this regard, the concept of "value realization" in 6G multiple access can be defined from the perspectives of end-users at individual level and network operators at system level. The operation of 6G MDMA will be based on the overall prioritized values and needs from different participants for maximized value realization.

One critical challenge in achieving value-oriented multi-dimensional multiple access (MDMA) in 6G is how to intelligently exploit heterogeneous radio resource domains under diverse scenarios and constraints while achieving the desired QoS requirements from different end-users.

Individual Level: From the perspective of end-users, value realization means meeting the individualized QoS requirement with minimized operation cost at user side. In addition to diverse QoS requirements from end-users, different UEs normally have heterogeneous hardware capabilities, such as signal processing, computing capability, and battery supply, inducing inherent hardware constraints and disparate utilization cost in different resource domains.

System Level: From the perspective of 6G network operator, value realization is to achieve operational objectives of reducing the operational cost while improving communication effectiveness of whole network. In detail, communication effectiveness is defined by the aggregated QoS performance of all served end-users. On the other hand, the operational cost is measured in terms of network resource usage, such as energy consumption.

Implementation of Value-Oriented 6G MDMA Scheme: To concurrently achieve maximized value realization at both individual and system levels, situation-aware intelligent utilization of multi-dimensional radio resources in a flexible way is essential in the design of 6G intelligent MDMA.

Therefore, we implement a simplified version of value-oriented MDMA, considering the simulation limitations. According to the value-oriented paradigm and key enabling technologies of 6G discussed earlier, it integrates the following main technical characteristics:

- *Deep situation-awareness for customized and prioritized multiple access:* With increased resource granularity, MDMA can intelligently adjust relative importance and scheduling proprieties of different end-users to balance the individualized QoS requirements and overall network operational objectives. Specifically, deep deterministic policy gradient (DDPG) is used to adjust scheduling proprieties of different end-users by timely discovery of multi-dimensional radio resource conditions and resource utilization costs.
- *Flexible utilization of multi-dimensional radio resources with fine controlled granularity:* MDMA can intelligently multiplex end-users by OMA, power-domain NOMA, or MIMO according to scheduling priority, specific requirements of end-user, and varying resource conditions. The convex optimization algorithm with acceptable complexity is proposed to perform customized and prioritized multiple access, that is, selection of a tailored multiple access mode and multi-dimensional radio resource allocation for co-existing end-users considering user specific radio resource conditions and scheduling proprieties of end-users.

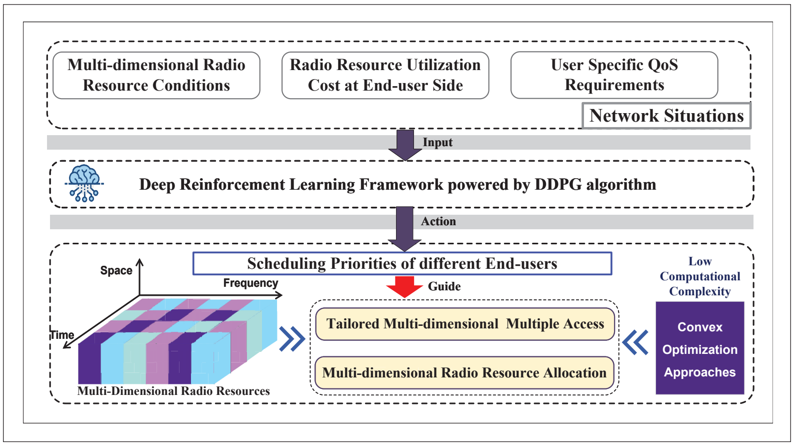

FIGURE 3. An illustration of the proposed value-oriented 6G MDMA scheme in the simulation.

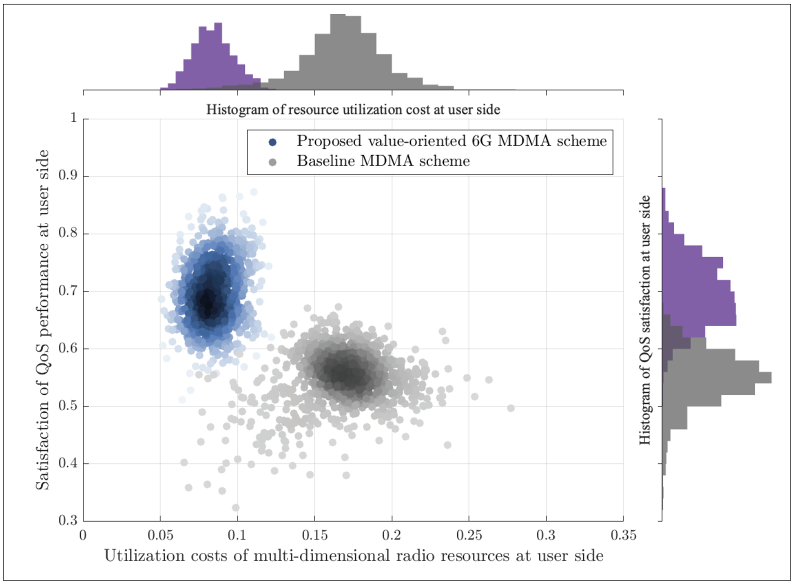

FIGURE 4. The performance of individual level value realization for each end-user, which is represented by two conflicting metrics, that is: a) User's satisfaction of QoS performance, where is modeled by the ratio of data rate and ideal data rate required by each user, denoted as function uk for user k; b) Utilization cost of radio resources in different resource domains at UE side.

Simulation and Performance Evaluation

In this subsection, we conduct a case study to evaluate the performance of value-oriented 6G intelligent MDMA scheme by numerical simulations (Fig. 3). We consider a downlink cellular network in which one BS with 64 transmit antennas and a set of 15 user equipment (UEs) with successive interference cancellation (SIC) receiver. The total bandwidth is 100 MHz, which is divided into 10 subchannels. To illustrate the effectiveness of value-oriented MDMA, we compare it with the baseline MDMA scheme in [16], which aims at maximizing the radio resource utilization efficiency of whole network without considering UE-specific resource utilization constraints. Based on technical definition of value-oriented 6G as stated above, the value realization in this case study is defined by following aspects.

Individual Level Value for Each End-User: It is defined by two conflicting metrics:

- User's satisfaction of QoS performance, which is measured by the ratio of data rate and ideal data rate. For end-user k, its QoS satisfaction is $u_k = r_k/R_k^{\text{ideal}}$, where r_k and R_k^{ideal} are the real-time achieved and ideal data rates, respectively.
- Multi-dimensional radio resource utilization cost, denoted as function g_k, that is, the processing cost of using power and spatial domain radio resources at end-user side, which is modeled in our previous work [12].

System Level Value for Network Operator: This is defined by two conflicting factors: network operational performance and cost. The network operational performance is to reflect the efficiency and fairness of all end-user's satisfaction of QoS performance, which is measured by the mean-variance theory, that is, mean(u_k) – std(u_k). Meanwhile, the network operational cost is defined as the ratio of BS's total transmit power and expected total transmit power.

Result Analysis

As shown in Fig. 4, we provide a scatter plot of individual level value realization at end-user side achieved by two schemes during simulation. In Fig. 4, the position of each dot on the vertical and horizontal axes indicates values for the QoS satisfaction ($u_k = r_k/R_k^{\text{ideal}}$) and utilization cost ($g_k$) at user-side respectively. In this figure, the darker color implies a higher probability density than that marked in light color. Compared with baseline scheme, the proposed value-oriented MDMA scheme significantly outperforms the baseline scheme with large gains. The reason is that the proposed RAN operation scheme has a situational understanding of individual UE's resource constraints and utilization costs, thus providing better quality of communication service with less resource utilization cost at UE side.

Meanwhile, the scatter plot of system level value realization for network operator achieved by two schemes is shown in Fig. 5, the proposed value-oriented MDMA scheme significantly outperforms the baseline scheme. In detail, the baseline MDMA scheme slightly outperforms the proposed scheme in term of operational cost. The reason is that the proposed scheme is prone to ensure satisfied overall level of specific QoS requirements from different end-users at cost of using more transmit power than usual at some network conditions. However, the baseline scheme only focuses on optimizing the performance of radio resource utilization in whole network.

Conclusions

The fundamental role of 6G is to interconnect and integrate different things, intelligence, capabilities, and infrastructure for value realization in applications of the future hyper connected society. In fulfilling this role, the layered goals, KPIs of 6G and value-oriented multi-dimensional multiple access technique are presented in this article. Specifically, KPIs in three domains are identified as the design objectives in achieving the value realization paradigm in 6G systems. As a preliminary example to achieve value-oriented 6G operation, intelligent multi-dimensional multiple access is elaborated by considering prioritized values from different participants for maximized value realization. Our case study on intelligent multi-dimensional multiple access demonstrates the significantly improved value realization by accommodating both individual and system level goals with situation-awareness during the operation of 6G systems.

Acknowledgment

This work was supported in part by the Discovery Program of Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Program under Grant RGPIN-2018-06254 and in part by the Canada Research Chair Program.

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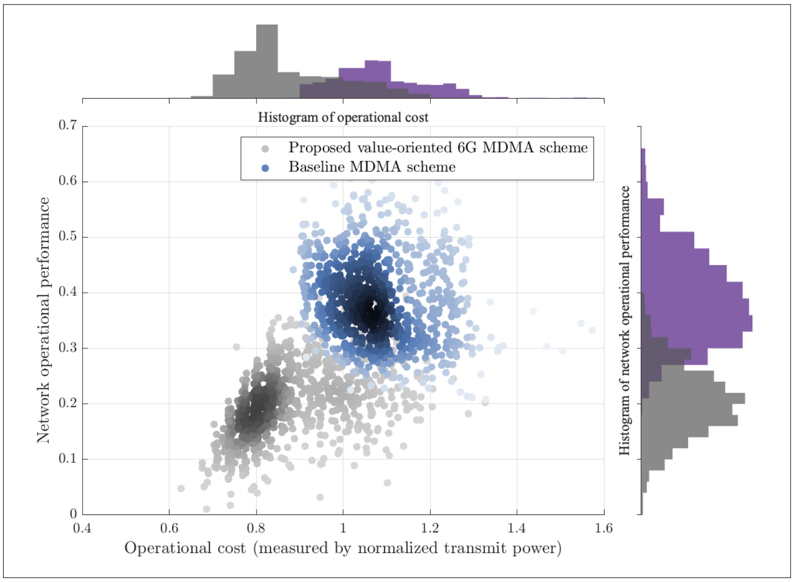

Figure 5. The performance of system level value realization at network operator, which is measured by tow conflicting factors: network operational performance and operational cost. The network operational performance is to reflect the overall level of user's QoS satisfaction in the serviced area, that is, mean(u_k) – std(u_k), where u_k is QoS satisfaction function of user k. Meanwhile, the system operational cost is defined as the normalized total transmit power of BS.

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