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Views & Comments

A Systematic Perspective on Communication Innovations Toward 6G

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The history of wireless communications can be divided into two eras. The first was a discovery-inspired era, initiated by the great physicist Maxwell's discovery of the classical theory of electromagnetism, while the second was a technology-driven era that began with Marconi's creation of the first practical world-wide radio-based wireless telegraph system, Shannon's information theory, and the later invention of cellular mobile communications from the first generation (1G) to the fourth (4G). Nowadays, the fifth generation (5G) is regarded as a leading information and communication technology. Through integration with the new generation of information technologies, such as cloud computing, artificial intelligence (AI), and the Industrial Internet, 5G has become a catalyst for the development of new technologies and a critical infrastructure for promising future applications. Under such circumstances, the issue of how to define the next-generation (i.e., sixth generation (6G)) network is a new challenge and a hot topic in both academia and industry [1]. In the recent literature, a considerable number of works have defined 6G by focusing on three main aspects: new enabling technologies, new capabilities, and new application scenarios.

At this time, perhaps we should pause and reconsider exactly what the engine of wireless communications is. We can predict that the development of any single technology will have diminishing marginal utility. In fact, the 1G–5G communication systems were all similarly derived from a particular key enabling technology, such as analog frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), orthogonal frequency division multiplexing (OFDM), or massive multiple input multiple output (MIMO), respectively. However, it is undeniable that the revolutionary 6G technology has not yet appeared—and may not appear in the foreseeable future, either. Some may consider that one of the key technologies of 6G is terahertz (THz) communication, while others may consider 6G to be based on AI, but the representative technology for 6G is still fuzzy. Nevertheless, unlike 1G–5G communication systems, which have generally provided connection-based "to consumer (2C)" services, 6G will present a service paradigm shift from 2C to "to business (2B)," as it becomes an interactive communication part in process services, enterprise organizations, and industrial applications. This systematic demand requires systems-oriented solutions. Therefore, it is necessary to interpret 6G from a systematic perspective, making it possible to create enabling technology networks and promote technical innovations in terms of need, objective, size, and cost under various application scenarios and resource constraints. As such, wireless communications may have entered a third era: the systems-oriented era.

The implications of a systems-oriented 6G can be generally summarized from two perspectives. First, from the perspective of development and evolution, it is clear that the coverage radius of each base station from 2G to 5G has become increasingly smaller [2]. Realizing such a dense deployment would inevitably incur unrealistic costs, since a considerable number of base stations must be rebuilt during each generation upgrade. Thus, for 6G, it is critical to achieve the sustainable development of future communication systems instead of depending on a resource-consuming stacked mode, while a well-ordered iterative systems-development mode is highly desirable to enable low-cost and convenient designs to be flexibly updated even without the concept of "X"G. Second, systems-oriented 6G development should allow 6G to form coupling relationships with other systems, as interconnection and interoperability are likely to be necessary among different communications systems, and to interact with these inseparable information systems including network systems, application systems, and various infrastructures. Moreover, the mutual effect of 6G and the social system cannot be ignored. For example, an appropriately designed communication system with traffic control at the entrance based on filtering and/or technologies such as the company Gartner's proposed secure access service edge (SASE) may effectively avoid a flood of social information, allowing information growth to become more rational in a way that better aligns with the basic law of knowledge growth while decreasing the cost of network operators.

1. Returning to the source of demand for 6G

For 6G, returning to the source of demand makes far more sense than a technology-driven approach. 6G should be a demand-oriented network that meets a variety of potential new demands with multiple interactive aspects, including the physical aspect, connection aspect, and service aspect. In particular, wide-area

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coverage has become a new requirement for the physical aspect of demand. For the connection aspect, higher performance continues to be pursued, with a higher bandwidth, greater number of users, and lower latency in increasingly complicated communication environments. Similarly, for the service aspect, mission-level service quality, safety, and efficiency have become emerging demands. These demands may not be accomplished by prolonging the development of traditional technologies, and their key challenges are the complexity- and uncertainty-related technical issues incurred by new scenarios such as wide-area service coverage and diverse services. In contrast, the development of 1G–5G has benefited from the architecture of cellular networks, which confines complex and uncertain communication problems to be solved via independent identical distribution (IID) through the introduction of relatively independent cells. As such, 1G–5G communications simply aimed to satisfy local independent and identically distributed demands with effectively controlled communication interference. However, 6G must meet the wide-area complex and uncertain demands caused by the various new emerging scenarios mentioned above.

In the following discussion, we provide examples to further elaborate the source of demand for 6G and new technologies for 6G that require exploration.

First, wide-area broadband coverage is one of the most critical demands on 6G. Due to various social factors and technical constraints, the phenomenon of the “digital divide” is worsening. For example, as of March 2022, China has built a total of more than 1.5 million 5G base stations, but only a few have been deployed in remote areas, resulting in a lack of broadband coverage. In addition to terrestrial wide-area coverage, achieving broadband and wide-area coverage for the vast sea areas will play a key role in future economic development, yet is still missing. Basically, improving the existing network capabilities will come at the cost of a massive increase in the number of cells. Due to the uniform and fixed-coverage characteristics of cellular-based architecture relying on optical fiber constructions, the higher the peak-to-mean ratio of the user distribution is, the higher the cost will be. Thus, it is obviously unrealistic to cover the oceans using such a cellular mode.

It is worth noting that complex and uncertain characteristics could appear in the case of wide-area coverage, such as nonuniform spatial distribution of services, long-short channel transmission delay, and various shadowing effects of wide-area environments. Accordingly, we should rethink the development direction of multiple technologies in regard to wide-area broadband coverage, as summarized in Table 1. First, the optimization goal of the massive MIMO antennas equipped by 5G base stations is to refine the signal domain by means of pre-coding and codebook design. In wide-area communications scenarios, such as wide-area elevated base station communications and the non-terrestrial network (NTN), the channel is line-of-sight (LOS) dominated, and the array scale may be up to thousands of antenna elements due to the long transmission distance. In such a case, new antenna structures (e.g., a hybrid antenna array or reconfigurable reflect-array antennas [3]) are desirable in order to realize fine-grained control of the electromagnetic domain while reducing complexity. Second, existing radio frequency (RF) technology mainly aims to improve performance in predefined frequency bands, such as power, sensitivity, and conversion efficiency, which inevitably leads to low resource-utilization efficiency. Hence, it is desirable to establish a full-band electromagnetic propagation model to predict performance under different frequencies, so as to promote the efficient utilization of all possible radio resource allocation supported by the multi-band RF front end. Third, existing baseband technologies mainly comprise application-specific integrated circuit (ASIC)-accelerated signal-processing technologies to support high-speed broadband, while the flexibility and scalability are constrained by rigid implementation. Alternatively, the use of domain-specific processors and efficient multi-tasking algorithms to support wide-range modulation and coding schemes (MCSs) is important in order to serve diverse terminals in 6G. Fourth, the number of active and standby users is the main indicator for measuring the existing protocol stack. Under wide-area coverage, however, the application scope of the protocol stack (e.g., regarding the coverage radius) is expected to be flexible and variable, and interference from different stations may be coordinated by the control plane with meticulously designed AI algorithms [4]. It is worth noting that flexible coverage may have merits in supporting an on-demand infrastructure that is adaptive to uneven traffic with fairly reduced deployment overhead. Finally, most 5G backhaul units are based on fixed platforms (e.g., communication towers) that rely on optical fiber backhauls. Wide coverage may require backhaul units to be based on movable platforms (e.g., cars, boats, and unmanned aerial vehicles (UAVs)) and to accomplish collaborative service capability under the conditions of long-delay and limited-rate satellite communications. 6G also requires more performance metrics regarding wide-area broadband coverage, such as a coverage radius greater than 100 km, a backhaul delay tolerance greater than 100 ms, and a mobility of 1000 $\mathrm{km \cdot h^{-1}}$.

Similarly, complex and uncertain issues may be raised by the diversity of services. 5G has been expected to enable various industrial applications [5] from 2C to 2B, including smart cities, smart factories, telemedicine, the Internet of Vehicles, and more. Nevertheless, 5G is only associated with one set of standards and one unified network architecture, which makes it difficult to satisfy various quality-of-service (QoS) requirements. While 6G services would presumably become more diverse, it is essential for 6G to meet the different and diverse demands of the abovementioned fields instead of blindly exaggerating unified compatibility, which

Table 1
Technology upgrades caused by the requirements of wide-area coverage.

Unit of the base station	Current technology underway	Future technology development trends
Antenna	Digital massive MIMO	Hybrid (digital/analog) antenna arrays, reconfigurable reflect-array antennas
Remote radio unit	RF device technology via various semiconductors such as GaN, GaAs, and Si	RF module-technology-based heterogeneous integration design
Baseband unit–PHY	ASIC via the integration of standard MCS for acceleration	Domain-specific processors to support wide-range MCS and customized requirements
Baseband unit–protocol stack	Static task scheduling with multi-core processors	Dynamic task scheduling via virtualization
Backhaul unit	Optical communications	Mixed transmission technologies including optical, microwave, and satellite communications

RF: radio frequency; ASIC: application-specific integrated circuit; MCS: modulation and coding scheme; PHY: physical layer.

may lead to unreasonable requirements for circuit devices and components. Technological upgrades related to the cloud, networks, the edge, and terminals should be considered, as depicted in Table 2. More specifically, cloud datacenters require the utilization of and exploration on models and knowledge for the next stage, while networks should achieve flexibly definable and guaranteed QoS. In addition, it is essential to build a new security mechanism based on coordination of communication networks and the Internet, in order to control malicious traffic from the source. Furthermore, 6G terminals should support a modular design to enable flexible upgrading and expansion, rather than just higher integration and higher computing performance. As a result, the diverse applications of 6G will have more performance metrics, including the total page load time based on https, the access success rate, and the delay for industrial control loops. It is worth emphasizing that AI will play an important role in promoting the iterative upgrading of the aforementioned technologies related to the cloud, networks, the edge and even terminals, motivating AI hardware acceleration for real-time response. Moreover, the recent hot topic of integrated sensing and communication leverages the advantages of AI in sensing, understanding, and harnessing the transmission environment, which may better support low-power consumption and high reliability.

To summarize, it is important to comprehensively consider the increasingly complex and diverse requirements of future 6G development from a systematic perspective. According to systems theory, two critical factors in determining system capability and satisfying the demands on 6G are a new architecture and the scientific resource utilization of a wireless communication system. Accordingly, an advanced layout of fundamental theoretical research on future sustainable system development should be established.

2. Network architecture evolution toward 6G

New communication demands will drive an evolution of new network architecture. As mentioned above, it is difficult for the current 5G networks to simultaneously eliminate the “digital divide,” achieve wide-area marine communications, and handle diverse communication demands (e.g., low latency, high rate, anti-jamming, and high security). In fact, the ability of the existing architecture to adapt to complex channel environments (e.g., urban, mountain, maritime, space, and outer space environments) is still relatively weak [6], while different QoS requirements (e.g., low latency, large capacity, and high reliability) have introduced great challenges to current wireless networks. As such, network architecture evolution toward 6G should be placed on the research agenda.

First and most importantly, the ongoing network architecture should be demand oriented; that is, it should meet the demands of future diverse global digital services. Take the Internet Protocol (IP)-based architecture of the terrestrial Internet. This architecture is a statistical multiplexing system that can allocate resources according to users’ demands; thus, it is *de facto* demand oriented, which indeed provides a good experience to users with on-demand services. Therefore, the terrestrial Internet has developed rapidly, surpassing previous communication systems with fixed resource allocation, such as the synchronous digital hierarchy (SDH) system. On the other hand, it should be noted that the success of the Internet architecture mainly benefits from the booming optical fiber technology, which can provide theoretically unlimited bandwidth resources. Nevertheless, when it comes to wireless communications that are limited by constrained network resources such as bandwidth and transmission power, the IP-based architecture for the terrestrial Internet may not be the best option. In fact, wireless network operators still exercise great care in applying a statistical multiplexing architecture to a wireless scenario until the operators eventually overcome the resource bottleneck with new technological revolutions.

From 2G to 5G, the bandwidth and transmission rate have tremendously increased, slackening the architecture evolution. However, this may be unsustainable, due to the inherent limitation of the bandwidth [7]. Furthermore, the coverage radius of each base station from 2G to 5G has become increasingly smaller. Realizing such a dense deployment over a vast area would inevitably incur unsupportable costs, which is again unsustainable. Therefore, it is urgent to develop a new communication network architecture for 6G that is capable of providing both broadband services and wide coverage, while considering other factors such as security, terminal size, and power consumption. To cope with the aforementioned challenges, developing a structured network inspired by the concept of mesoscience may hold promise [8]. For example, an integrated satellite-terrestrial network architecture was proposed in Ref. [9] as a structured network to provide ubiquitous network service in the future 6G. More specifically, in order to provide unified high-quality service, the integrated satellite-terrestrial network may be divided into three different levels, as shown in Fig. 1. The first and most basic level is the integration of service, through which users may be served by the same group of service providers while the two networks are operated separately. For example, the Amazon Web Services (AWS) ground station combines satellite service with a terrestrial cloud. The second level is the integration of network protocols to connect these two networks, such as by connecting on the ground through optical fibers and sharing one core network infrastructure. The deepest level is the integration of the air interface, in which unified terminal devices may seamlessly access either the satellite network or the terrestrial cellular network using the same physical-layer protocols [10], for which OFDM-based technology may be an option. In addition, the space–air–ground–sea integrated network is one of the most representative technologies for 6G, realizing seamless global coverage of communication services. Potential technologies may include software-defined wide-area networks for ensuring end-to-end QoS, and the virtualization and orchestration of heterogeneous network resources and services for enhancing network efficiency.

When integration moves from the top level to the bottom level, improved network efficiency and quality of user experience may

Table 2
Technology upgrades caused by the requirements of diverse services.

Research direction	Current technology underway	Future technology development trends
Cloud	A centralized public cloud with high-end computing/storage/communication equipment	A hybrid cloud with public/private/on-premises infrastructure supporting AI and federated learning
Network	Dense cells and standard routers	Adaptive cells and software-defined networking (SDN) routers
Edge	Mobile edge computing (MEC) to reduce delay and localize data	Mobile edge service (MES) including SASE and software-defined perimeter (SDP)
Terminal	Smartphones with fused parts	Modular phones with upgradable parts

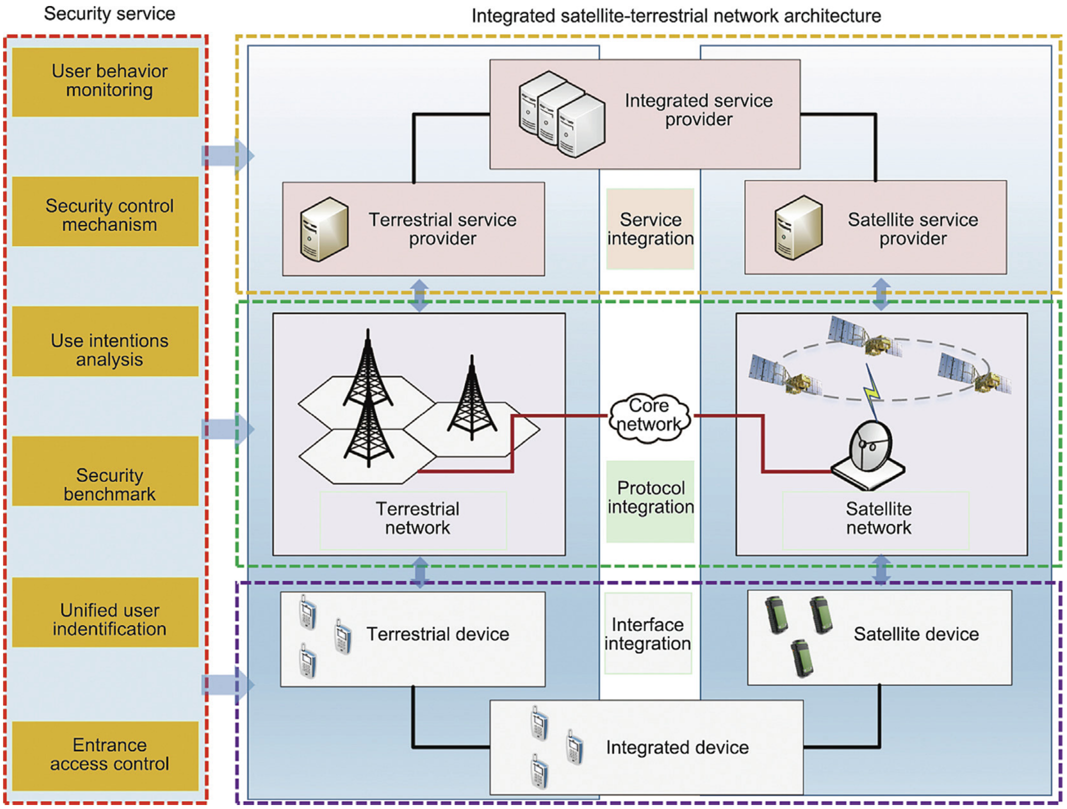

Fig. 1. Integration architecture of the satellite-terrestrial network toward 6G.

be acquired at the cost of increased implementation complexity and deployment. As such, the integration of satellite and terrestrial networks should be promoted in a step-by-step manner according to practical communication demands and fundamental principles. In addition, new issues associated with the fusion of various protocols cannot be ignored. In particular, to realize the interoperability of multiple integration levels, the protocol stack should be flexible and diverse, albeit (inevitably) with a great deal of accessorial complexity. Hence, the tradeoff between flexibility and complexity should be meticulously considered. One way to cope with this challenge is to design a structured and modularized protocol stack; it is also necessary to sort out the minimum protocol set, which will promote combination and conversion among multiple protocols to enhance the efficiency of protocol integration.

In addition, network security is essential in the evolution of network architecture. The negative impact of massive and distributed communication behaviors on network efficiency should be considered, together with the security issue presented by a new architecture. To achieve both improved security and better efficiency, the location advantage of a mobile communication network that is closer to user terminals should be brought into full play. Moreover, a security benchmark should be built for the end-user behavior of the mobile communication network. More specifically, by allowing the network to properly grasp the service types and other application information, the network will gain a deeper understanding and mastery of the application service and will then understand the characteristics of user behavior. A cross-domain collaborative network behavior management and control mechanism may also be established. In particular, by using the concept of distributed coordination, a malicious-behavior feature model can be constructed, along with methods for malicious-behavior monitoring and identification. Accordingly, at the entrance of the mobile communication network, malicious behavior will be immediately controlled or blocked once it has been identified, so as to control the scale of malicious Internet traffic and improve the utilization efficiency of network resources.

3. Frequency resources allocation and exploration

The frequency spectrum is a scarce resource, so it is always a determinant of wireless systems. Two main issues should be investigated in depth: namely, how to utilize existing wireless resources efficiently and what new resources may be used. Shall we change the fixed frequency allocation on a first-come, first-served basis? It is *de facto* that the existing communication resources are insufficient, making it difficult to meet the diverse demands placed on 6G. We have observed that, from 2G through to 5G, dedicated frequency bands have been allocated for each generation, and the bands constantly expand to grant operators a wider bandwidth. However, the existing resource allocation and utilization methods have been found to be inappropriate and inefficient for the emerging 6G application scenarios. Taking the aforementioned wide-area coverage as an example, the suitable and desirable frequency band is ultra-high frequency (UHF), such as 500–750 MHz. However, this frequency band has been allocated to other systems: The 700 MHz frequency band resource has been allocated to 5G systems, and the remainder is occupied by broadcasting systems.

To solve this dilemma, one potential solution may be on-demand resource allocation, which would allow different communication systems to dynamically share the entire suitable range of spectrums. This solution promises many benefits and innovations. First, resources occupied by the system may be dynamically adjusted according to traffic needs, so as to avoid a waste of resources on relatively light traffic. Second, from a resource pool of the entire range of frequencies, the system may select resources that are appropriate for specific application scenarios, such as mobility and reliability, with utilization occurring during the most appropriate time interval and best spatial location. Nevertheless, on-demand allocation would inevitably raise complex and uncertain issues such as matching between dynamic demands and resources. A cognitive radio concept and associated technologies have been put forward for some time, yet it is difficult for them to be widely applied in practice. This is because each current wireless system has developed in an isolated manner, which is likely to result in complicated resource coordination among different live systems.

On-demand resource allocation should be comprehensively accomplished from a systematic perspective. It is reasonable to expect that the combination explosion problem caused by multiple isolated systems can be converted into rhythmic resource allocation with reduced complexity and uncertainty. This rhythm may be produced by the discretized utilization of resources, with certain criteria aligning at multiple domains, such as space, time, and frequency domains. The concept of the multi-domain collaboration of dynamic resource allocation has been proposed as an important technical paradigm to realize highly efficient resource allocation [11]. With rhythmic utilization, on-demand resource allocation becomes multi-system evolutionary optimization. The inputs of this optimization problem should include frequency bands, platform conditions (e.g., satellite orbits and tower positions), propagation environments, interference, and various demands, while the output is the result of the resource allocation of multiple resources to multiple systems. Then, different systems would dynamically and autonomously negotiate with each other regarding resource occupation in a distributed manner, based on the changing demands of different systems. As shown in Fig. 2, resource allocation would no longer be static; rather, multiple domains would collaborate within a dynamic equilibrium among different systems.

Multi-domain collaboration would make it possible to find a way to target dynamic resource-allocation optimization. Accordingly, several issues should be considered and studied. First, it is of great importance to find a reasonable granularity of resources, such as a space–time–frequency block, as a basis with reference to the application scenario. The smaller the resource block is, the higher the utilization efficiency that may be achieved, but the more difficult the necessary technology will be. Second, it is necessary to mine resource characteristics—that is, from a channel statistical characteristics model to a refined model of the comprehensive characteristics of space, time, and frequency. In particular, electromagnetic wave characteristic maps reflecting physical properties such as propagation and interference may be constructed, such that a system design may avoid solely relying on traditional pilot design and estimation. Third, it is critical to design a rule of resource allocation with dynamic matching that solves the goodness-of-fit (GoF) problem between resources and service scenarios, while the matching includes propagation attenuation, coverage capability, anti-occlusion capability, adaptability to user dynamics, antenna size, and so forth. As a simple example, indoor communications with minor fading would use high-frequency bands to improve the data transmission rates, whereas low-frequency bands would be recommended for outdoor communications with strong fading—such as those used for high-speed rail, UAVs, and so forth—to achieve reliable communications.

Last but not least, it is desirable to explore new resources—such as the THz band—and new resource-utilization methods—such as spatial directions—for 6G. More specifically, in addition to general research on the new THz frequency band, more attention could be paid to demand-oriented research from a systematic perspective, such as combining THz with other bands to satisfy systems-level requirements. Therefore, it is necessary to clarify the application scenario first, such as indoors high-speed multimedia interconnection (augmented reality (AR)/virtual reality (VR)). Then, the technical requirements of the transmitter, receiver, and antennas can be further analyzed, based on the specific scenario. For example, high-gain dynamic directional antennas hold potential to be a breakthrough technology for THz indoors applications. Spatial direction is also worthy of attention as a new form of resource utilization. Current terrestrial mobile communications involve many non-LOS propagations, which can realize cellular communications with spatial reusing. As LOS propagations become dominant, the dimension of spatial direction can be explored in order to expand system capacity. Still, numerous problems regarding resource exploration for 6G remain for consideration and study.

4. Fundamental research with a paradigm shift

For the systems-oriented era, associated fundamental research may require a new paradigm. In fact, the detrimental effects of complexity and uncertainty will inevitably arise in 6G from a systems point of view [12]. Many aspects such as the transmission environment, spectrum resources, and signal format deeply interact with each other, while difficult problems have accumulated and been formed along with the long-term development of communication systems. In particular, ten major challenges with mathematics have been identified by Huawei [13], and fundamental research on physics and materials science has become ever more critical for further development toward 6G. It is recognized that fundamental research on 6G should address problems from a systematic perspective.

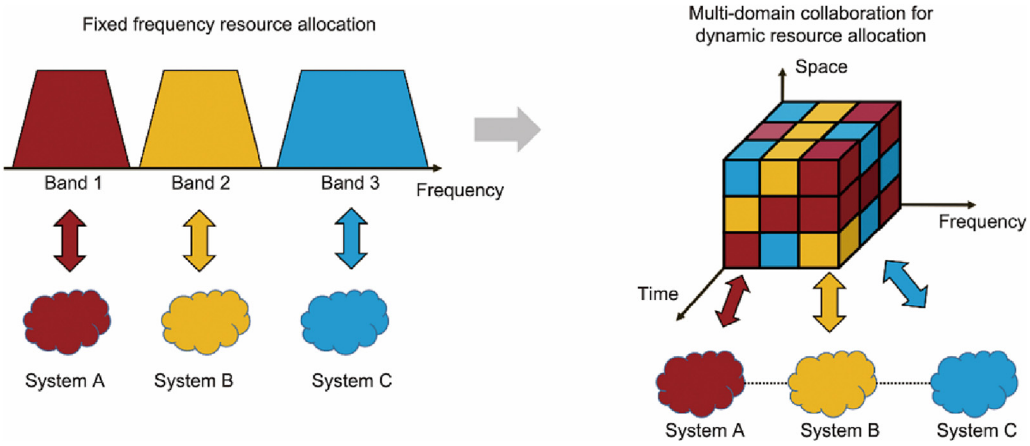

Fig. 2. Illustration of the collaborative utilization of multi-domain resources.

Problems may be identified in three main areas. First, in terms of systems, where problems have been raised by more diverse applications with more complex communication networks, a systematic solution is desirable in order to achieve user-centric development and provide information services with differentiated quality of experience (QoE) for users. Second, in terms of technology, as the monopolizing tendency of technology is likely to affect scientific judgment and innovation in the scientific method, a change should be made in systems design with the selection of technology being based on the expected application demands instead of just commercial interests. Third, in terms of theory, where the systems paradigm development is likely to be restricted by a patching of the traditional Shannon's framework, new ways should be found to revolutionarily form new systems. As such, a new paradigm for research development should be seriously considered. In general, most previous methodologies have been bottom-up—that is, going from monopoly technologies to systems. This is the right time to call for a paradigm shift to top–down methodologies in the systems-oriented era, following a top-level design with well-directed research development from technologies to systems, along with pertinent theoretical exploration.

Fundamental research currently emphasizes a demand-oriented approach, which may be exemplified by the semantic communication research that is presently underway [14]. The rationale behind this approach is that the object being transmitted and processed in a communication system will eventually evolve from a data bit to semantic content. A blue-skies approach might not be the best option for the semantic communication related research. Since we have observed that the demand for large-capacity multimedia services is increasing daily, especially in application fields such as security surveillance, video command, and conversational video, the contradiction between the increasing multimedia data and the limited wireless bandwidth is becoming particularly prominent. It is of primary importance for semantic communication to mitigate this contradiction—that is, the demand orientation. Within fundamental research, a new path could be sought from the perspective of prior knowledge to allow the transmitted content to be significantly reduced. Accordingly, researchers can investigate computational communications, intelligent communications [15], and so on, whose transmission and processing are based on knowledge instead of raw data. Furthermore, by analyzing the essential characteristics of human visual perception and introducing new assessment criteria with QoE, traditional "point-to-point" communication may be transformed into a new closed-loop architecture based on a network-shared prior knowledge including a dictionary, attention model, semantics, and so forth. In this way, instead of transforming the bit stream by an encoder, only the specific parameters that are significant to QoE improvement will be transmitted, which can be expected to reduce the bandwidth requirement tremendously [14].

Furthermore, there are challenging systems-level issues to be addressed in the development of 6G in the fields of wide-area covered cross-domain transmission and cross-media transmission. The goal of the former is to realize interconnection and interoperability among different communication systems such as those of sea, land, air, and space. Since multiple systems differ greatly in terms of waveforms, protocols, and so forth, the key to achieving this goal is to establish a unified specification and verification method in order to enable integration, conversion, and adaptation to become concise and efficient. The purpose of the latter—that is, cross-media transmission—is to accomplish the transmission of physical-layer signals (e.g., electromagnetic waves) from one medium to another, such as the transmission of electromagnetic waves from air to sea, or from air to underground. However, existing communication systems are likely designed for a specific channel environment and will fail to support cross-media transmission at the physical level. Therefore, more fundamental research should be conducted on cross-media channel models, cross-media signal processing, and so forth.

Overall, fundamental research in this systems-oriented era should be planned based on the development demands of future communication networks. We suggest not only focusing on a single technology but also paying attention to systematic issues and striving to establish an associated technology support net. In general, it will probably be difficult to replicate previous successful cases, such as the optical fiber communication technology that determined a new era of communication systems. In addition, it is inadvisable to focus on theoretical research while waiting for others to discover and use the practical applications of such research later, which may result in losing a hard-won development opportunity. In other words, we recommend that fundamental researchers in this field become involved with industrial chains in order to obtain a better understanding of system requirements and their specific corresponding positions on the chain. In this way, fundamental research will be able to play a greater role in the accelerated development of society—truly implying a paradigm shift.

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