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Review paper

Ubiquitous information service networks and technology based on the convergence of communications, computing and control

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Abstract: The rapid development of the IoT (Internet of Things) is bringing about a functional change of communication networks from "information transmission" to "information service". First, the conception and characteristics of the IoT are introduced, i.e., an Internet of humans, machines, and things meant to achieve smart information services. Then, the technology requirements for realizing ubiquitous and smart information services are described. The corresponding key technologies are also discussed, including the integration of communications, computing and control technology (3C), heterogeneous network fusion theory and technology, intelligent sensor technology and short-distance networking theory, large-scale network transmission theory and technology, the network virtualization and intelligent computing technology geared toward information service, and the collaborative network system and service model geared to the application of the IoT. Finally, the development trends of information technologies and information networks in the next five to ten years are analyzed, and give some suggestions for main research areas to be explored and key issues to be resolved.

Key words: Internet of Things, ubiquitous and smart information service, 3C integration, development trends of information networks, research suggestions

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1 Introduction

With the development of globalization, information does not only support economies, it is the engine that determines the success or failure of economic development. With the rapid development of the IoT and the "Internet +", traditional information network technology, which takes interpersonal interaction and information transmission as the target function, cannot meet the growing new demand for social development. The rapid development of the IoT is promoting revolutionary changes in the area of information technology, including the following: 1) The characteristics of information networks will strategically shift from connecting human to connecting everything-including humans, machines, and things; 2) The development of the information industry will strategically shift from "information

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transfer" to "information services"; 3) Research in information technology will strategically shift from the "information transmission technology" to the "smart service technology"; 4) For the information community, the evaluation of social contributions will strategically shift from their value to the community's own networks to their peripheral effects and marginal value[1-3].

The goal of the IoT is to realize a strategic shift in the development of information network technology from an "information transmission system" to an "information service system". The key idea of the IoT is to connect everything (physical or virtual) including humans, machines, and things-using information networks together with modern sensing technology to implement sensing, exchanges and transmission of information data. In this way, the IoT can build a new generation of production and service environments, realizing real-time dynamic interactions of humans, machines, and things. The data collected from network peripherals will be intelligently analyzed, processed, and controlled through a brain-like cloud platform. Therefore, a SIS (Smart Information System) and its architecture, based on the convergence of communications, computing, and control will be built, making physical and virtual things implement smart, human-like service[1-3].

Accordingly, the wireless communication networks are no longer just the information transmission channels, but infrastructure and technology platforms supporting information services. The object of information services for communication networks is no longer just human, but gradually extended to all things including humans, machines, and things. Future wireless communications networks will become wireless service networks connecting humans, machines, and things, called the IoT. The core characteristic of this networks will be achieving massive complex real-time information collection, efficient transport, and smart services, which pose severe information-carrying and processing challenges for a network. In the foreseeable future, the computing ability of wireless networks and mobile nodes will grow rapidly following the Moore's Law[4], and implementing ubiquitous information service based on the convergence of communications, computing, and control is the inevitable trend.

In 1999, Aston first proposed the concept of "Internet of Things", "Yet today's information technology is mainly dependent on data originated by people that our computers know more about ideas than things. The problem is that human information is affected by limited time, attention and the accuracy. We need to empower computers with their own means of gathering information, so they can see, hear, and smell the world for themselves, in all its random glory..."[5]. This concept opens the prelude of Information Service to so-called ubiquitous information services, meaning building heterogeneous fusion networks, taking advantage of the computing power of network nodes, achieving the ubiquitous connections and smart interaction of humans, machines, and things, and providing any type of information services for any user located anywhere.

The IoT is a typical network achieving information services, whose core features are that it is appreciable, connectable, communication-capable, and controllable. The rapid development of IoT promotes the convergence of computing, communications, and control, and this convergence promotes the rapid development of the ubiquitous information services.

2 The development and the analysis of the current situation

Recently, the research on ubiquitous information services has become a hot topic in the wireless communications community. Domestic, research in this area has focused on two aspects: first, how to implement the convergence of communications, computing, and control-namely 3C convergence; the second is how to implement smart information services based on 3C convergence.

2.1 The deep convergence of communications, computing, and control

The development of communication networks and services is a process that is changing from "analog" to "digital" and "computation". From the initial artificial switching to program-controlled switching and soft switching, and from voice services to the current diversified and personalized value-added services based on IMS, computing technology has played a crucial role in the development of communications. Due to the introduction of large amounts of computing technology, the differences in hardware, software, and protocol are gradually blocked, end users must only focus on what they need and how to get the appropriate resources and services through the network. It is also easier for the communication network itself to achieve dynamic, telescopic extension. From data exchange, video conferencing, and business development platforms, we can see communication networks utilize more and more computing technologies to meet the needs of the public services, and to provide users with fast, high quality and comprehensive services. Today, communication technology and business are moving toward the application of computing technology and toward network and service provision, CT and IT are really moving toward fusion. From the communication network itself to its business, more and more characteristics of cloud computing are appearing[6].

As computing and communications technology get into perfect harmony, control technology and the development of information services have integrated with them. Similarly to communications and computing technology, control technology is also a science based on mathematics, that expands research on common problems of communications, computing technology, biotechnology, and other disciplines to reveal the commonalities between machine-to-machine communications and the human nervous and sensory systems. A typical system with deep convergence of computing, communication, and control is the CPS (Cyber Physics System), which implements the interaction of physics process through human-computer interaction interfaces, utilizes network space to manipulate a physical system in a remote, reliable, real-time, secure, and collaborative way, so that the physical system is provided with computing, communications, precise control, remote collaboration, and autonomous function. This means that intelligence is given to a machine, which is one of the key technologies required for the IoT and ubiquitous information services for humans, machines, and things.

Academician He Jifeng believes that the sense of CPS is in connecting physical equipment by a network, in particular, connecting to the Internet, so that the physical device has five functions in computing, communications, precise control, remote coordination, and autonomy. The United States NSF (National Science Foundation) believes that CPS will interconnect the whole world. NSF Computer and Information Science and Engineering Director Branicky said, "As the Internet has changed human interaction, CPS will change our interaction with the physical world." Realizing the significance of the convergence of communications, computing, and control, in 2006 the United States first released the "American Competitiveness Initiative", which takes the CPS to be an important research projects. In July 2007, the Presidential Commission on Aviation Security and Terrorism reprot entitled " Leadership Under Challenge: Information Technology R&D in a Competitive World", lists eight key information technologies and ranked CPS as the most important. From 2007 to 2013, the European Union invested over 7 billion Euros in the development of CPS-related technology and industry, in order to become a world leader in smart systems.

From an industry perspective, CPS covers smart home networks, national and even world-class applications in industrial control systems, and smart transportation systems. This not only connects the existing equipment simply together, but has also spawned numerous systems with computing, communications, control, coordination, and self-performance functions that gives physical devices "wisdom". As a network form of CPS, the market scale of the IoT has reached trillions of yuan.

2.2 The implementation of SIS based on ubiquitous wireless technology

The key technologies involved in the realization of ubiquitous information service include: heterogeneous fusion network theory and technology, intelligent sensor technology and short-distance networking theory, large-scale network transmission theory and technology, network virtualization and intelligent computing technology geared to information service, and the collaborative network systems and service models geared to the application of the IoT.

2.2.1 The theory and technology of heterogeneous fusion networks

Building a heterogeneous convergence network is the basis of realizing seamless information service. Currently, wireless access networks of different types coexist, e.g., wireless LAN, global microwave internet access network (WiMAX, World Interoperability for Microwave Access), 3G networks, 4G networks, and WiFi. These networks have obvious differences in all kinds of aspects, such as access technology, coverage scope, network capacity, and transmission rate. Any singular wireless access network cannot meet the ubiquitous information service required by mobile users. It is an important challenge faced by the next generation of networks to converge these overlapping and heterogeneous wireless networks to provide multi-service seamless information service for users[7].

Research on heterogeneous networks can be traced back to the BARWAN (Bay Area Research Wireless Access Net-work) program sponsored by the University of California-Berkeley in 1995; R.H. Katz, the project director, was the first in the literature[8] to converge different overlapping networks to construct heterogeneous networks to meet diversified requirements of services in the future terminal. Later, international standardization organizations developed research on the coordination and convergence of heterogeneous network and put forward different convergent network standards, among which are the 1900.4 standard from IEEE, which formed the frame of resource management for heterogeneous network and defined the ports and agreements of resources in convergent management[9] and 3GPP, which put forward the concept of a heterogeneous cellular network, that can supply service with a high data rate for users through deploying in heterogeneous residential areas with low power dissipation and small coverage areas[10].

The research of domestic scholars on heterogeneous wireless network started around 1997. With the development of this research, the state scientific plan also gave great support to heterogeneous networks; the 973 program "the basic research of the theory of wireless communication of poly-domain collaborative width", was approved in 2007 and develops research aiming at joint scheduling and optimization problems of multidimensional resources such as time, frequency, air, and code domains, for example, so as to realize the impressive promotion of network volume. The 973 program "acknowledges the basic theory of wireless network and research as key technologies" reaches the aim of the convergence of heterogeneous networks through researching the adaptive features of cognitive network system structures, cognitive feature of wireless network multidomain environments, and autonomy of wireless network management and control. The 973 youth program “Basic theory and key technology of collaborative heterogeneous cellular overlapping network” researches channel characteristics, jamming modeling, the capacity domain of in-formation theory, transporting mechanisms and processing methods of network adaptive signals, cross-layer re-source management and optimization mechanisms, and the network system frame of overlapping heterogeneous networks.

So far, scholars have developed rich research into the collaboration and convergence of heterogeneous networks, for example, the selection of heterogeneous networks[11-14], network switches[15-18], network frameworks[19-21], coordination and management of disturbances[22-25], distribution of wireless resources[26-30], load balancing[31-35], and network selforganization[36-38]. The existing results of research on the convergent mechanisms of heterogeneous wireless networks form different perspectives and push the realization of ubiquitous convergent networks to some extent, but two main problems still exist: 1) the disturbance coordinate problem between heterogeneous networks is hard to resolve, so it restrains the improvement of the effectiveness of heterogeneous networks and 2) the existing framework of heterogeneous networks is static, which causes inflexible utilization of network resources. The key to solving these two problems lies in uniform network management and control systems. It is possible to build control platforms for heterogeneous convergent networks based on the idea of computer communication convergence to optimize computer resources and communication resources to decrease the disturbance between heterogeneous networks and to optimize the utilization of network resources. This platform should have functions such as monitoring, analyzing, coordinating, controlling, and managing, the nodes and resources of heterogeneous networks to realize real-time collection and high speed analysis of network information and flexible adjudication of resources. It is obvious that the platform needs the support of strong computing capacity to exchange high utilization of communication resources through computing resources.

2.2.2 Smart sensing technology and short-range networking theory

Dynamic networking to intelligent sensors and information terminals is necessary realizing seamless information services. As mentioned earlier, the service objective of information in the future will be transformed to people, machines, and things, and it will become necessary to collect mass information of mass objectives. Starting from information transmission, the peripheral sensor network should have large-scale self-organization capacity, low power consumption, mobility, reliability, and stability. Starting from the perspective of information processing, the peripheral network needs to transmit data that is collected with as low a time delay and as reliably as possible.

At present, the communication technologies of sensor nodes used frequently in peripheral network include Zig Bee, WiFi, Bluetooth, and UWB, among which the applications of WiFi and ZigBee are the widest[39]. They do not only have low deployment, distribution, and maintenance costs, but can also supply the same data rate as wired connections. With the scale of wireless sensor networks becoming bigger and bigger and the type of sensors increasing the network frame must be able to supply networking for large-scale heterogeneous terminals. New technologies appearing in the environment of the IoT also put forward new challenges to peripheral networks, such as D2D (Device-to-Device)[40] communication, M2M (Machine-to-Machine)[41] communication, and networking of HetNet (Heterogeneous Networks)[42].

D2D demands high transmission rate when the distance (between the devices that are moving) is small. The key of M2M communication is that the network nodes must deal with large amounts of short data packages. The main target of HetNets is to decrease the disturbance between residential areas. However, the short-distance networking technology that is popular at present did not consider these requirements at the time of design, so they can not supply corresponding service stably, reliably, and comprehensively[39]. Generally speaking, peripheral sensor networks have characteristics such as huge network scale; restrained nodes, energy, and resources; and data concentration, that are different from the existing self-organized networks.

The short-distance networking problem refers to many aspects of technologies, such as network framework, addressing mechanism, and network deployment under energy restrainsc. Research aiming at network connection methods, topological structure, and agreement layer in network frameworks include WINS, Pico Radio, AMPS, Smart Dust, and SCADDS[43]. Research literature aiming at addressing this mechanism includes algorithms based on different network topological structure such as SAR, Directed Diffusion, GEM, LEACH, Tree Cast, PEGASIS, and AODV[44]; algorithms based on geographical location information such as GLB-DMECR, GPSR, GRID, GEAR, GEDIR, DREAM, PALR, CR, LBM, LAR, and Geo GRID[43]; and algorithms addressing methods concentrating on data, such as CAWSN, Directed Diffusion, and CBP. Research in sensor deployment includes incremental node deployment algorithms[45], mesh generation algorithms[46], artificial potential field algorithms[47], and probabilistic model checking algorithms[48]. Aiming at ordinary sensor nodes; is the GEP-MSN algorithm[49], and the enlightenment algorithm[50], etc. aims at heterogeneous nodes.

Recently, LTE-U (LTE Unlicensed)[51] is concerned with researchers, operators and manufacturers of equipment as a kind of resolution program of the short distance networking. LTE-U adopts the wireless communication technology of 4G LTE in the 5 GHz frequency band (the working frequency band of WiFi) to implement small ranges of covering. It keeps a control channel, so it is different from a self-organized network. LTE-U may supply more reliable industrial-class transmission service due to the existence of the control channel, which provides new ideas for short-distance technology in the environment of the IoT.

In the environment of the IoT, the final target for peripheral sensor networks to collect and transmit information is to improve group users' effective experience; that is, "capacity of effectiveness"[4]. Future research on peripheral networks should make full use of characteristics such as cheap sensors and flexible deployment; setting optimizing the effectiveness capacity as the target to be aimed at restrains all kinds of sensors in the network in different aspects such as performance and energy. To realize these targets, it is necessary to deeply converge information processing and information transmission and research how to transmit function and flow effectively in networks so as to realize the transmission of mass information.

2.2.3 Large scale network transmission theory and technology

In the future, wireless networks facing seamless information service need to improve the utilization of wireless resources, improve network coverage performances and obviously decrease energy consumption per bit. An effective resolution method is reusing as many of the existing spectrum resources in space as possible, that is, increasing the network node density on the existing network[52]. This puts forward new challenges for the design of wireless networks: 1) More serious disturbances between nodes will be generated with the deployment of mass nodes and the actual coverage range of network nodes is lessened so that the gains brought by mass nodes is weakened; 2) The design of the best node's position is difficult to implement because the number of nodes connected is huge, which will require new networking theory and 3) Higher deployment cost and operation cost of high-power nodes will also restrain its application seriously so that the number of the nodes deployed is restrained and it cannot improve the handling capacity and coverage rate greatly.

Aiming at the above problems, researchers have put forward mass programs of node coverage with low power consumption and its basic principle is adopting the maximum reuse of space and new types of networking technology to improve the density of network nodes with low power consumption to a brand new layer and the core is using two basic effectiveness[52,53]: First, shortening the distance between wireless nodes and users can enhance the ratio of receiving noise and bring higher transmission rates at the same transmitted power; Second, the capacity of the network and the density of the nodes is in direct ratio to the handling capacity of the network and is increased remarkably through increasing reuse of space (that is deploying more nodes). In addition, deploying mass nodes can improve the coverage performance of networks effectively[54] and supply reliable, seamless information service.

In recent years, research aiming at mass, large-scale networks with low power consumption has been developed. Ref.[55] researches the connection between transmission rate and the number of nodes deployed based on random geometric theory and analyzes the outage probability of the system; Ref.[56] researches the disturbance management methods of super-dense networks, such as strengthening power control, improving disturbance measurement methods, combining optimization processing in time-frequency-space, and power domain and coordination transmission based on disturbance alignment, etc. Ref.[57] puts forward an optimization frame that can be combined with users and jointed with nodes flexibly in super dense wireless networks and this framework adopts density and signaling overhead control of network, combines encoding technology of space and designs a resource management plan. Aiming at the problem of low power consumption of wireless nodes, Refs.[58-60] researche the energy collection and information transmission problem of nodes, puts forward highly efficient energy-information collaborative transmission system frames and suggests corresponding design of transceiver equipment.

From the existing results, research aiming at large-scale networks mainly focus on directions such as interference suppression between nodes, dynamic dispatching of node resources, and energy collection. Its core target is enhancing the transmission rate of the network. However, wireless network-facing information service doesn't only require high rates, high efficacy, and low time delay; high reliability is also an important technical index that needs to be emphasized. In addition, with the mass deployment of nodes, the requirements to system computing and processing capacity are all enhanced. Large-scale wireless networks face many problems that need to be solved and key research theories include: 1) the theory of wireless networking and deployment of mass nodes; 2) the design and realization of network nodes with low power consumption; and 3) transmission technology with low time delay and high reliability for large-scale wireless networks.

2.2.4 Network virtualization and intelligent computing technology

A distinguishing feature of future information services is concentrating on users; that is, supplying resources deployment and service facing users' requirements, which will overturn the traditional service mode of "allotment systems" concentrating on resources and realizing more humanity "customizing type" service. It is obvious that it is a core problem to be solved to realize virtualization characterization of networks and terminals under the condition of coexistence of the current heterogeneous networks and heterogeneous terminals. On one hand, virtualizing the hardware of the physical layer comprehensively and building structured mass data resource management and distribution document systems is convenient for storing and visiting mass data. On the other, it can realize functions of dynamic supply by requirement, configuration of resources, task scheduling, and load balancing. Implement security management and monitoring in order to detect working conditions of resources in real-time and guarantee the security of data[6,60].

Cloud computing is an important support technology for realizing network virtualization and also the key technology for solving the collaboration and convergence of heterogeneous networks, mass sensor information processing and knowledge abstraction of peripherals and large scale network disturbance collaboration with low power consumption. It can build a resource pool of network infrastructure, a terminal resources pool, a frequency spectrum resources pool, or business resources pool. Based on the virtualization technology of cloud computing, and can implement organization and application of network resources with the concept of computing communication. Because of the introduction of cloud computing technology, differences in aspects such as hardware, software, and agreement, etc. are shielded and terminal users only need to be concerned with what kind of resources they need through communication networks and how to get corresponding service through networks, while the communication network itself is much easier to realize with dynamic and elastic extension.

In recent years, network virtualization and cloud computing communication technology have become new research hot topics and research contents mainly focus on three fields: cloud computing applications, realization of platforms, and software definition networks (SDN)[61]. Among these, Ref.[62] researches the service deployment mechanism of cloud computing and virtualization networks and puts forward a service-oriented virtual network layer structure (SOA). Ref.[63] gives a layered structure for internet virtualization and suggests the design target of virtualization networks. Research aiming at platform implementation of virtualization networks mainly comes from industrial fields and representative programs are NVP[64] from Nicira, OnePK[65] from Cisco, and Junosphere[66] from Juniper, of which NVP is constructed according to the idea of SDN.

Most of the above literature develops research aiming at virtualization of network element entities and should further research the virtualization problem of network function so the research objective shall be transferred from core networks to access network, which is the inner requirement of solving heterogeneous multi-network integration problems and realizing the software service definition.

2.2.5 The collaborative network system and service model geared to the application of the IoT

The physical form of ubiquitous information service based on computer communication convergence is the IoT. IoT raised wide concerns from academic and industrial fields just a few years after Aston first put forward the concept of the IoT in 1999. The Auto-ID Center of the Massachusetts Institute of Technology described the vision of the IoT in 2001[67,68]. In 2005, the IoT was introduced formally as one of the subjects of the Internet Report of the Seventh International Telecommunication Union[69]. In 2008, the First International Conference of the IoT was held in Zurich; In 2009, the Chinese government put forward the concept of “Sensing China” and Wuxi became the center of research and industrial application of the Chinese IoT. In the same year, the research organization of the European IoT submited a document and described the research map of the IoT after 2020; In 2014, the first collaboration innovation center of the IoT in Jiangsu Province was founded at Nanjing Post and Communication University, which began the information service-oriented industrial learning and research innovation mode of the IoT.

The technical idea of the IoT can be described as realizing “ubiquitous service” using “ubiquitous networks”, that is, meeting the requirement of smart service everywhere with information networks everywhere[1-3]. From the perspective of research content, system frameworks and service models are cores of current research on the IoT. Ref.[1] was the first to put forward the technical system framework of the IoT and includes heterogeneous terminal platforms, ubiquitous network platforms, and convergent information platforms, and implements uniform management and deployment to terminals, network, data, and service separately so as to compose a smart service system and realize effective perception and service supply to the environment of the IoT. Ref.[2,3] further illustrates the application of the idea of smart service systems in different industries. Ref.[69] puts forward a functional layer frame of the framework of the system of the IoT. In view that the framework of the IoT is a very complex system, there is still no framework of the system of the IoT as a global information infrastructure and it is still being researched around the world.

Besides the framework of hardware systems, management systems and software systems that can realize the service of the IoT are urgently need to be researched. Ref.[70] introduces the human cognition process into the IoT, puts forward the working frame of the “cognition IoT” and illustrates the cognitive service concept and its key technology. Ref.[71] puts forward the research program of the management of the cognitive IoT from the perspective of the management of the IoT itself. Ref.[72] puts forward a software system framework for the IoT aimed at addressing the mixed accumulation problem of mass terminals and it can find the equipment to be used and virtualize it out of physical network, letting the physical equipment interact with the virtualized form. Ref.[73] researches the agreement of MAC (Media Access Control) which supports M2M communication and discusses problems such as the fairness, effectiveness, extendibility, etc. of M2M communication channel.

Generally speaking, the research of information service facing application of the IoT is still in the initial stage and it mainly focuses on smart application of specific context, specific field and many key theories and technical problems referred are to be explored and solved: 1) uniform technical system framework and management system framework of the IoT; 2) uniform characterization and identification of heterogeneous sensor terminal; 3) smart service mode and resource allocation mechanism driven by user requirements. The resolutions of these problems rely on the collaboration of the above four technologies, among which the development of computer communication capacity is the key.

3 Analysis of development trends (prospect)

In the next five to ten years, the “Internet +” information service concept will be further penetrated into various industries; the IoT will enter a new stage of development. Accordingly, the amount of information in the wireless network will increase exponentially, network capacity bottleneck effect will be further intensified. Fortunately, the computing power of the mobile node will grow rapidly following Moore’s Law, exchanging for the communications power with the computing power becomes inevitable, seamless information services based on the convergence of computing and communications will face new challenges and opportunities:

From a network architecture point of view, to promote the fusion of heterogeneous networks and construct space-air-ground seamless network coverage to achieve unified and coordinated scheduling of heterogeneous resources and terminal is an inevitable trend. The key technologies involve fusion network architecture layered model, virtualization characterization of heterogeneous network resources, the smart networking of heterogeneous nodes and terminals, large-scale network transmission technology.

For information acquisition and processing, utilizing smart sensor devices for efficient collection and transmission of classified information to build a unified information processing and control platform is an inevitable trend. The key technologies involve heterogeneous terminal smart sensing and unified addressing perceived hier-archical transmission information, the analysis of massive amounts of information and knowledge learning, heterogeneous virtual terminal reconstruction and smart control, transparent access to the wireless network for terminals, etc. .

From the information service mode, “on-demand service” replaces the “quantitative services”, user-oriented demand, software-defined service mode will become an inevitable trend. The key technologies involve service requirements and user experience characterization, service mode and software architecture, adaptive matching mechanism network resources with business needs, interactive technology based on virtual reality, service protocols.

4 Research areas need to focus on and policy recommendations

Promoting in-depth fusion of information services, production and life, and promoting networking widely used in the field of industry, is an important task for the next decade in the field of information and communications development. Related common technologies and key areas to be developed include: 1) Smart sensor technology and information service node Software-defined sensor design, service-aware technology, smart information service terminal, multi-terminal cooperative sensing technology; 2) Ubiquitous network access technology and integration platform Smart addressing and virtual reconstruction for terminals, collaborative sharing and optimal allocation of smart sensor network nodes and network resources; 3) Software-defined services and information service platform Virtual reality technology, service-oriented mechanism for requirements of individual users, and the construction of smart production services platform.

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