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KEY TECHNOLOGIES OF 6G WBAN

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Abstract

6G will not only provide a wider range of air, sky, earth and sea integrated macro-communication services than 5G, but also extend to the micro-communication field of the complex environment inside the human body. The digital twin area network in the future will be a typical 6G new application scene and access unit of "network (twin) with human movement", which integrates micro-communication and basic communication seamlessly, this paper presents a new challenge to the future 6G network in wireless radio, network service architecture, digital twin real-time synchronization and so on. This paper introduces the related protocols and standards of the body area network, and the future development and challenges of the body area network, analyzes some new services of the future body area network, and puts forward some requirements of the micro body area network for the future communication network, it has certain significance of reference for the research of 6G in the direction of micro-network and the establishment of related standards.

Keywords: Micro Body Area Network; Body Area Access Center; Requirement of New Radio; Intelligent Cooperation; Heterogeneous Communication.

Key Technologies of 6G WBAN

（2020）

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1. Introduction

It is possible to provide the abundant personalized-services for individuals due to the revolution of mobile communication service mode and the continuous update of communication technology. The network coverage is getting smaller and smaller which transitioned from large area coverage. Finally, it will be capable to provide the accurate network coverage for every single person.

Meanwhile, some emerging businesses put forward the higher requirements on micro-body area network， such as *in vivo* collaborative health monitoring and targeted surgery through nanorobots, information gathering of multi-modal physical sign, *in vitro* remote consultation of digital organs, the perception migration of digital twin for population portraits, and the precise configuration of network resources for "Internet with business". However, traditional electromagnetic communications and WBAN have problems with the chimney effect of access management, massive multi-dimensional and changeable access requirements, dynamic management of power consumption and calculation balance, electromagnetic wave radiation and information security, data requirements and privacy management in big data modeling, etc.

With the growth of human's multi-dimensional demand for information, the development of Moore's Law and the refinement of network atomization, the WBAN under next-generation network, as the atomizing unit, which has become an important part of the future communication network system and will play an increasingly important role.

2. Status of WBAN

2.1 Overview

As the smallest component of the network coverage, the body area network undertakes the important task of interaction between personal data and the core network, which is a key part of the network connection. The body area network is a human-centered communication network composed of various network devices related to the human body.[1]

It combines wireless sensor network， short-range wireless communication technology and distributed information processing technology, and is also a way to achieve

personalized network services basis in 2030.

Wireless body area network (WBAN) includes personal terminals, various sensor devices and transmission processing devices distributed in the body, on the surface of body, on clothing, and around the body, which are called implanted nodes, body surface nodes, and external nodes, respectively. They constitute a communication network through wireless electromagnetic waves or biological molecular communication. These devices can interact with any terminal device, including computers and mobile phones. The realizing field of communication can also be divided into body surface to outside world, body surface to body, body to body, etc. The human body will participate in the entire communication transmission process , implement the ubiquity of the network truly.

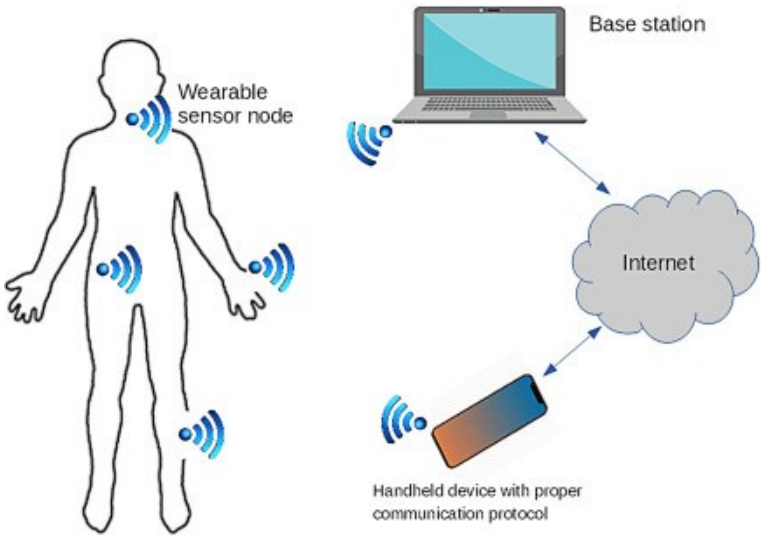

Figure 1. Schematic demonstration of WBAN[2]

Currently, BAN composed by wearable devices have been widely used in medical and non-medical fields. The body area network support includes 4G telemedicine and health monitoring, remote surgery in the 5G era, mobile medical care and AI treatment. BAN The provides more refined guarantees for achieving permanent detection and recording of human physiological movements, capturing and reconstructing group behavior characteristics, tracking and predicting group user behavior, and configuring network construction and network resources.

Figure 2. Applications of WBAN

2.2 Standards and protocols of WBAN

There are three important protocols related to WBAN which are IEEE 802.15.4, IEEE 802.15.6 and low power Bluetooth protocol, respectively. [3]

2.2.1 IEEE 802.15.4

IEEE 802.15.4 has three working frequency bands: 2.4 GHz, 868 MHz, and 915 MHz. Their transmission rates are 250 kbit/s, 20 kbit/s and 40 kbit/s, respectively. They have following characteristics:

(1) Low power consumption. Sleep wake-up time is short, only 15 ms. Sleep mode can be used when the device is not working, meanwhile the transmit power is only 1 mW when receiving and sending data at the same time, therefore the device consumes low power. The node adopts Zigbee short-range wireless communication mode, and also can be maintained for a long time without changing the battery equipment.

(2) Safe and reliable communication . In the process of sending data, the integrity of the data will be checked and the sent data will be encrypted by AES-128. A dedicated gap is reserved for data during the sending process to avoid data conflicts. In the media control layer, a message feedback mechanism is adopted. When a message is received, it is necessary to send a confirmation to receive the message to ensure the reliability of information exchange. If there is a problem in the information exchange process, user could resend it.

(3) Large network capacity. Each network system can contain 255 nodes, and hundreds of

networks can be arranged on different channels, more than 60,000 sensor node devices can be accommodated.

2.2.2 IEEE 802.15.6

The latest standard IEEE 802.15.6 provides a low-power and short-distance wireless communication. [4] It supports data transmission rates ranging from 75.9 Kbps narrowband to 15.6 Mbps ultra-wide band in a small area around human body. IEEE 802.15.6 defines a connection technology with a transmission rate up to 10 Mbps and a longest distance about 3 m. Different from other short-distance and low-power wireless technologies, the new standard specifically considers the application on body surface or in vivo which provides a foundation and standard for the development of WBAN under 6G.

The main technical standards include:

(1) Each WBAN must be able to support 256 nodes, which should be deleted or added to the network in a short time (less than 3 s). All devices can transmit with 0.1 mW (-10 dBm) power, and the maximum transmit power should be less than 1 mW (0 dBm).

(2) The WBAN should support a certain range of jitter, delay and reliability. The latency should be less than 125 ms in medical applications, and which is less than 250 ms in non-medical applications. Additionally, the jitter should be less than 50 ms.

(3) WBAN should be able to operate in a heterogeneous environment. Networks with different standards could cooperate with each other to receive information. The link should support bit rates in the range from 10 Kbps to 10 Mbps.

(4) Reliable communication should also be possible while moving. Data should not be lost due to unstable channel conditions although reducing network capacity is acceptable. The applications considered include body movements relative to sitting, walking, twisting, turning, running, waving arms and dancing poses, which can cause shadow effects and channel fading. The nodes in WBAN may move independently relative to each other, but the WBAN itself may move positions, causing interference.

2.2.3 Summary

In WBAN, the IEEE 802.15.6 protocol can meet the requirements of different applications. The

MAC layer protocol that controls wireless channel and energy consumption has better efficiency in ensuring high service quality, low power consumption and high data transmission rate. In summary, the communication rules in IEEE802.15.6 with different scenarios, devices and security levels in the communication process will be refined. The reliability of high-priority business traffic transmission will be guaranteed through priority differentiation to meet different requirements. According to IEEE802.15.6 standard and diverse sensing and transmission technologies under 6G communication, future communications and applications need diversified radio requirements. Therefore, the refinement of research framework for digital twin of WBAN under 6G and the key technical links of WBAN convergence center are conducive to the further exploration and development of 6G WBAN.

In IEEE802.15.6[4], the following aspects have been greatly changed from the previous standard:

Definition	New in IEEE802.15.6
Physical layer	Three types of physical layers are defined: narrowband, ultra-wideband and human body communication physical layers
MAC layer	According to different business scenarios, differentiate priority users
Access mode	According to different business needs, distinguish different priority access modes
Security Level	Defines the security levels of 0, 1, and 2 three different standards
Frequency band	Including medical, wireless medical, industrial, scientific and medical frequency bands
Error rate	For a payload of 256 octets, the packet error rate (PER) should be less than 10%.
Nodes Number	Each WBAN must be able to support 256 nodes
Delay and jitter	WBAN applications that require jitter, delay and reliability should be supported. In medical applications, the delay should be less than 125 ms, in non-medical applications, the delay should be less than 250 ms, and jitter should be less than 50 ms.
Low power	Incorporating power-saving mechanisms to enable WBAN to operate in a power-constrained environment

With the breakthrough of 6G technology in the future, according to the requirements of IEEE 802.15.6, the digital twin world will provide a broader field for various applications. One of the roles of the future 6G network is to give AI capabilities to applications in various fields based on ubiquitous big data for creating a "smart ubiquitous" world.

3. Deficiencies and tendency of current WBAN

3.1 New business for future WBAN

3.1.1 Brain-computer Interface

Brain-computer Interface (BCI) is a method and system that provides a direct channel for communication between the brain and external devices through bidirectional information stream.[5]

BCI technology has been described as the "information highway" for the communication between human brain and external world. It is recognized as a new generation of human-computer interaction and the core technology of man-machine hybrid intelligence, which relates to information science, cognitive science, materials science, life science, etc. It has an increasingly important impact on intelligence fusion, bioengineering and neuroscience. BCI technology is promising to restore sensory and motor functions as well as cure neurological diseases, while also giving humans the "superhuman ability" to control intelligent terminals with their thoughts.

3.1.2 Synesthesia Internet

The synesthesia internet can get all the senses of bodies. [6] The 6G network will extend the transmission content from traditional pictures, text, voice and video to color, sound, smell, taste, touch and even emotion that can be sensed by human body. In the era of 6G network, it can notify the terminal to smell the delicious dishes so as to have a real share when the others are posting them online. We will get the same feeling when interact with real or virtual people and objects according to synesthesia internet. In practical application and daily life, synesthesia internet will further upgrade shopping and game experience, and even get remote trial experience without actual consumption. The network experience store will become a reality.

3.1.3 Nanorobots

The nanorobots can be used as drug carriers to deliver drugs in diseased areas through automatic or manual control. [7] Some nanorobots can even perform in vivo surgery. In addition, they can perform some cell functions, such as carrying oxygen and sugar instead of red blood cells. The medical service of nanorobots will be a key application scenario of future WBAN. Whereas, to further expand the functions of nanorobots, the network needs to support the precise positioning of them and implement the synchronous-cooperative communication between them. In the future, the WBAN under 6G will be used to further solve the communication rate, communication reliability and network unified control of a large number of nanobots.

3.1.4 Digital organs

Currently, the digital organ is composed of the sectional information of thousands of organs, which is obtained through anatomy in advance. [8]Then, a digital organ is reconstructed through computer image processing. Finally, the precise simulation of the organ information is obtained by the accurate description of each function of the tissue with a three-dimensional model. However, it lacks of personalization, accuracy and instantaneity. Digital virtual human organs have become an important research field in medicine and anatomy. The future digital organ will provide a completely real-time and dynamic digital model, reflecting the organ changes in real time and accurately describing each person's organ by combining with WBAN under 6G. It puts forward higher requirements for the number and accuracy of sensors, and instantaneity and reliability of the network. With the greater computing power and micronetworks of future communication and data processing center, the granularity of digital organs may be further refined. For instance, the further refinement of the thickness of heart slices is helpful to achieve more precise reconstruction.

In the future, 6G will implement the intelligent connection of all things through ubiquitous intelligence. Intelligent collaborative work can be performed between machines. Intelligent monitoring and collaboration can be conducted between devices in WBAN. Deep thought interaction can be proceeded between humans and virtual assistants. Even intellectual exchange can be carried out between humans, so as to comprehensively improve learning skills and efficiency of human.

3.2 Challenges of future development of WBAN

3.2.1 Deficiencies of current WBAN

As an increasingly important access unit, the current WBAN has deficiencies of limited access, poor switching stability, redundant functions of multi-terminal, non-uniform consideration of power consumption management, unscientific access management with different network, and unscientific management of load and computing . It is necessary to provide solutions through the design of integrated new terminal for meeting the requirements of 6G. It is necessary to redesign and update the current WBAN according to new requirements, which will bring impetus to the development of WBAN.

3.2.2 High density and multi-dimensional new business communication requirements in the future

With the extension and improvement of requirements in fields such as digital medical treatment and sports monitoring, and the emergence of new applications such as human-computer intelligent interaction and synaesthetic internet, the current performance of WBAN can no longer meet the high-performance requirements of these services. The emergence of the new transmission and access methods makes higher requirements for communication. The following indicators should be achieved in future WBAN:

	Basic static data volume	Synchronous communication data volume	Synchronous cycle
Digital portrait	100 Mbits	Mbps	s
Digital healthcare	GB	Gbps	s
Holographic portrait	10 GB	1000 Gbps	30 ms
Brain storage	10^9 TB	10^5 Tbps	Day
Digital twin in nanoscale	10^9 TB	10^5 Tbps	Day

Figure 3. Network parameters for different holographic services

Based on new application requirements, BAN should be able to provide massive, multi-dimensional access solutions to ensure that multiple access methods are not dropped, lower power efficiency and higher security (including user privacy and human radiation). Therefore, it is

necessary to solve the current problems of WBAN and complete an integrated new terminal optimization solution for 6G requirements.

3.2.3 Lower power consumption

The factors restricting the further development of WBAN include components, energy consumption, communication capabilities and security. The biggest obstacle is components and the most important factor that affects the long-term stable and efficient operation of components is energy consumption. The safety of human body should be considered for implanted equipment. Biological power generation should be used to instead of battery power generation, which places high requirements to the device.

3.2.4 More safe

It is an unsolved problem whether the WBAN rate can meet the requirement by using molecular communication and the effects of electromagnetic waves used by WBAN on human bodies are still unknown. The security of personal data requires comprehensive consideration. Otherwise, it will cause serious consequences if it is tampered by criminals.

3.2.5 More reliable

The access and switch of different devices under multiple scenarios is also a common scenario in future WBAN. Multi-scenario switching includes reliable switching of multiple devices and simultaneous reliable switching of multi-network cooperation. By realizing smooth switching between devices and multiple networks, the flexibility of the network can be increased and a continuous high-quality service experience can be formed.

3.2.6 Contradiction between privacy and data modeling requirements

Big data modeling cannot be separated from personal data, including physical signs, behaviors, network demand rules, etc. It is necessary to combine multi-party security computing, block chain and other means to give consideration and balance.

3.2.7 Flexible networking optimization requirements of future atomized network

In the future WBAN scenario, the number of nodes will be largely increased. The number of

individual human body acquisition nodes may be up to thousands. In addition to the increment of small nodes in the same scenario, micro-communication can be implemented to provide abundant personal data by WBAN.

4. A new terminal for future WBAN—Access center of body area

4.1 Overview for access center in body area

The future 6G network will not only develop towards the more macro space-air-ground-sea integrated network, but also extend to the field of micro-communication in living bodies. The wireless body area network (WBAN) is more sophisticated than current network which is a communication network built around human bodies and consists of various related network devices. It integrates various technologies including wireless sensor network, short-range wireless communication and distributed information processing, which is essential to the interaction between personal data and core network. In addition, WBAN is the key component of network connection which lays the foundation for implementing the personalized services of future network.

The new terminal for WBAN is an extension of traditional base stations which may be a module embedded in a smart belt or portable device. Mass data from body area can be converged to the data center of WBAN through multi-dimensional and heterogeneous network, containing 4 communication-related technical procedures which are acquisition, transmission and convergence, computing and display. In detail, it consists of 4 steps: 1) data acquisition and access from mass sensors in body area. Sensors, cameras and other devices are used to collect data on human physiological information; 2) transmission and convergence of multi-dimensional and heterogeneous data to the new terminal. The collected data is aggregated in the data center by molecular communication or traditional electromagnetic communication; 3) collaborative computing and digital twin. Collaborative computing, digital twin, holographic display and other technologies are used to calculate and analyze the aggregated data; 4) communication and interaction with base stations and core network. The data can be transmitted to the network for

storage or further screening and analysis.

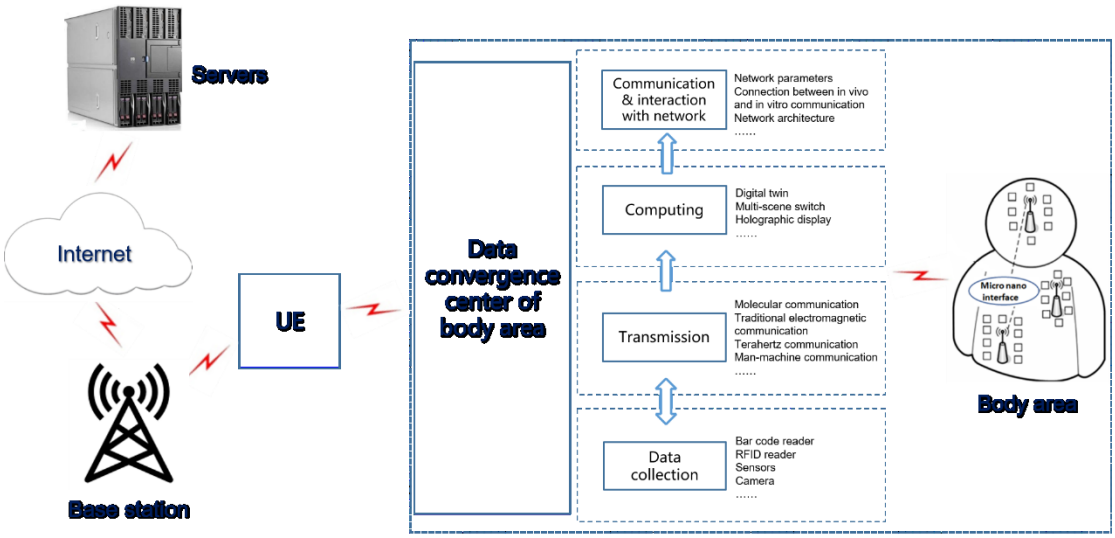

Figure 4. Overview of data center technology for WBAN

4.2 Step 1: Acquisition: sensing, acquisition and radio requirements

Data acquisition of WBAN can usually be classified to two modes: in vitro and in vivo. The sensor technology and the robotics technology corresponding to the two kinds of acquisition have become mature. In vitro acquisition devices usually refer to wearable devices that can measure body temperature, blood pressure, etc. And then, it transforms physical signals such as photoelectric, vibration, pressure and temperature into electrical signals for transmission. In vitro acquisition is low difficulty and high safety. However, some in vivo acquisition scene still cannot be implemented. In vivo acquisition is mainly achieved through internal sensors or robots. The required data collection can be achieved by moving or implanting equipment in living bodies. In vivo collection is more intelligent and does not need to carry equipment. But it is very difficult to collect and the safety still cannot be completely guaranteed.

4.2.1 Key technologies for acquisition and sensing

4.2.1.1 In vivo acquisition

Recently, robotic technology has made great progress. The new robot technology represented by nanorobots and capsule robots provides a new method for data acquisition in vivo. The research and development of nanorobots has become the forefront of science and technology hotspot which

has a wide range of potential applications and attracts worldwide attentions. Nanorobots can control the nanoscale structure of biomolecules and break through the limitation of traditional machine structure. Benefited from the advantages of simple surface modification, autonomous movement performance, efficient capture and target separation, nanorobots with various biological receptors can be used as biological sensors which can detect and separate target molecules in body fluids (such as protein, nucleic acid, cancer cell, etc.), and improve the sensitivity and effectiveness of bioassay. In WBAN system, the nanobots have the effect of precise acquisition of human physiological characteristic information.

The capsule robot itself carries a camera and a wireless transmitter. [9] Its size is generally within the range of 1~4cm and can move freely in the digestive tract system of human body. It can take photos to collect image information in places like gastrointestinal tract, and send the collected data in vivo by traditional electromagnetic communication in real time. The data acquisition method similar to capsule robot provides a new idea for data acquisition of WBAN.

4.2.1.2 Acquisition on body surface

WBAN is a short distance wireless network composed of several portable mobile devices and sensor nodes with different functions. These devices or sensors are placed in different parts of human body, being used to monitor human body conditions or provide various wireless applications. Therefore, the importance of human body sensor technology to WBAN is self-evident.

Structurally, the network system of WBAN is composed of medical sensor nodes or portable mobile devices placed on body surface, convergence nodes and remote control nodes. Various medical sensors or portable mobile devices on body form a network in a distributed manner. Sensor nodes can collect all kinds of physiological data including electroencephalogram (EEG), electrocardiograph (ECG), muscle activity, respiration, body temperature, pulse, blood oxygen and blood pressure. Subsequently, the collected information is transmitted from the convergence node to the remote control node through internet or other ways. The remote control node controls and manages the sensor network, publishes detection tasks and collects monitoring data. As the core of WBAN, convergence node plays a role in connecting WBAN with internet and other external networks, realizing communication conversion between the two protocols and publishing monitoring tasks to remote control node.

Currently, the latest developments and technological advances in wireless communication, microelectromechanical systems (MEMS) technology and integrated circuits make it possible to strategically place low-power, intelligent, miniaturized, invasive/non-invasive micro-/nanosensor nodes on or around human bodies.

4.2.1.3 Acquisition in body area

Human-computer fusion intelligence is a new generation of intelligent science system with physical and biological characteristics which is different from human intelligence and artificial intelligence. [10]It is a new form of intelligence generated by the interaction of human, computer and environmental system. For man-machine integrated intelligence, computer and environment are important parts of human-computer fusion system. Traditional WBAN can only unidirectionally collect data by machine, while ignoring the human demand and feedback for environmental awareness. Under the background of intelligent human-computer fusion intelligence, WBAN will merge human, machine and environment. The human perception will be bidirectionally connected with the machine. The differences of people, machine, environment will feedback to each other, building a set of complete closed loop WBAN system. Under the new situation that 6G network technology is becoming more and more mature, 6G technology, as the media, can promote the new development of human-computer fusion intelligence technology under WBAN.

4.2.1.4 Synaesthesia acquisition

Brain-computer interface (BCI) technology is divided into four layers. The first layer is “repair” which is to replace or repair some body functions of human beings by manipulating computers with thoughts. The second layer is "improvement", which improves the operation of the brain through brain-computer connection technology, so that people can do things with higher spirit and focus. The third layer is "enhancement", which enables human beings to possess a large amount of knowledge and functions in a short time, acquiring and realizing more superpowers through brain-computer interface connections. The fourth layer is "infinite communication". According to the brain-computer connection technology, the infinite communication between each other can be realized by directly relying on the electrical signals in the brain. The current brain-computer connection technology is in the first layer of "repair" capability, it will have a wider scope in the future.

Brain-computer interfaces can be classified into four categories from the perspective of information transmission direction: from brain to computer, from computer to brain, from brain to brain, and brain- computer fusion. Brain-computer fusion is the inevitable trend of brain-computer interface technology. Presently, the interaction technology between human and computer network is still at a very primitive stage. The traditional brain-computer interface system is mostly the operation mode of connecting one brain with one computer, that is, one brain is only connected with one computer. In the future, the main body of social communication is no longer only human which also contain intelligence agents including human, virtual digital human, humanoid, robot, etc. Communication between intelligence agents in the future will not only involve the transfer of data and information, but also intelligent interaction.

4.2.2 Radio requirements

The data of multi-sensor WBAN mainly includes the data generated by various organs and the steady-state system of the human body (including heart rate, temperature, pulse, blood pressure, oxygen and exercise data, etc.). Generally, users collect and analyze these data separately. They can effectively predict the level of physical health through the characteristics of the data.

However, multi-sensor wireless network is used for data acquisition in WBAN environment. Due to a large number of sensor types, the collected data is susceptible to external noise. The performance of the equipment is limited. The collected data is generally characterized by large data dimension and data redundancy.

WBAN technologies require IEEE standards that support quality of service (QoS), ultra-low power consumption, highly reliable wireless communications (low latency and data loss), and data rates up to 10Mbps when implementing body area network communications through brain-computer communications, molecular communications, nanobots, and other access methods. The WBAN sensors can communicate with gateway devices to connect with Internet. A typical medical WBAN claims to have six nodes and can be extended to 256 nodes. Requirements for different data types are shown as follows:

Application	Data Rate	Delay
ECG (12 leads)	288 kbps	250 ms
ECG (6 leads)	71 kbps	250 ms
EMG	320 kbps	250 ms
EEG (12 leads)	43.2 kbps	250 ms
Blood saturation	16 bps	250 ms
Temperature	120 bps	250 ms
Glucose monitoring	1600 bps	250 ms
Cochlear implant	100 kbps	250 ms
Artificial retina	50-700 kbps	250 ms

4.3 Step 2: Transmission, convergence and delivery

Facing the massive micro-nano access devices of body area in the future, a unified data aggregation, computing, distribution and communication processing center is required. The center can be a node in vitro, such as smart belt, smart watch, or an electronic device implanted in the body, such as a pacemaker. The different mediums in different parts, organs and tissues decide the diversity of the conductivity and signal transduction capability in human bodies and the different scenarios also need various transmission distances and speeds, which determine that different transmission schemes should be adopted.

Therefore, it's necessary to study the interface technology between molecular communication and terahertz communication or other frequency bands, involving the information extraction from molecular communication and the expression to terahertz or other frequency bands, as well as the reverse expression.

4.3.1 Electromagnetic communication - Terahertz communication

At present, there is a growing demand for indoor broadband high-speed wireless communication systems, such as ground point-to-point high-speed Bluetooth transmission, ground ultra-high-speed networking (wireless access, wireless download, wireless interconnection, etc.), with a high communication rate from 1GB/s to hundreds of GB/S. Terahertz wave has a communication rate of more than 10GB/s and can be used for wireless secure access with high transmission rate. It is likely to replace the current Bluetooth and wireless LAN in the future. [11]

Taking Terahertz communication as an example, it can support data transmission rate of more than

10 Gbps. In addition, it has a better confidentiality and anti-jamming capability. Its transmission distance is relatively short, which is suitable for short-range wireless communication in body area.

4.3.2 Nonelectromagnetic communication - Molecular communication

Among many solutions of data aggregation in body area, one of them is that the data collected by the sensor are aggregated to the data convergence center on the body surface or in vivo through molecular communication. Molecular communication is a short distance communication technique in which molecules are used as information carriers to communicate between transmitters and receivers. [12] As a new communication technology, there are some differences between molecular communication and traditional electromagnetic communication, which are shown in following Table 1.

Table 1 Comparison between traditional communication and molecular communication

Main features	Traditional communication	Molecular communication
Information carrier	Electromagnetic waves	Molecules
Information type	Electromagnetic or photonic signal	Biochemical signal
Transmission speed	Speed of light (3×10^5 km/s)	Slow (μm/s)
Transmission distance	Long (meter ~ kilometer)	Short (nanometer ~ meter)
Transmission environment	Space or cable	Liquid or gas
Coded message	Voice, text or video	Phenomenon or chemical state
Behavior of receiver	Digital information decoding	Biochemical reactions
Energy consumption	High	Extremely low

Molecular communication architecture mainly contain transmitter, molecular communication interface, molecular propagation system and receiver. The transmitter generates molecules and encodes the information into molecules, and then emit the information molecules to propagation environment. The molecular communication interface is used to encapsulate the emitted information molecules which acts as a molecules container to hide the biochemical and physical properties of the information molecules in transmission process. Molecular propagation systems passively or actively transmit information molecules (or vesicles that encapsulate information molecules) from transmitter to appropriate receiver through communication environment. The receiver selectively receives the unsealed information molecule and reacts with the received information molecule. This biochemical reaction represents the decoding of information.

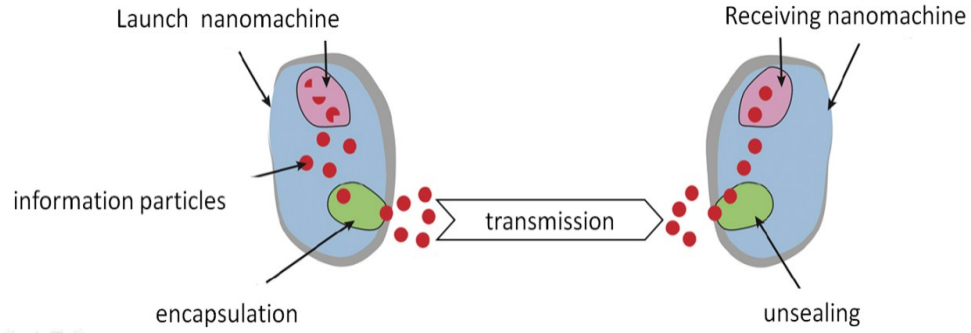

Figure 5. General molecular communication architecture

4.3.3 Multi-dimensional and heterogeneous communication

The body area nanomedicine network can realize complex nanomedicine applications with high reliability and controllability through cooperative molecular communication between therapeutic nanorobots in human body. The human body itself is a very large scale heterogeneous communication nanonetwork which is composed of hundreds of millions of cells. The information exchange between different biological systems (such as nervous system, cardiovascular system and endocrine system) is conducted through molecular communication. The body area nanonetwork is based on the biological system of human body to implement the application of complex nanomedicine. We can explore the human body system by using information or communication theory and other tools, such as the human neural network, cardiovascular network and endocrine network as well as communication channel modeling and analysis. It can promote the implementation of body area nanonetwork engineering and contribute to the application and development of information and communication technology in WBAN.

Similar to OSI model and TCP/IP Internet architecture in traditional communication network, a hierarchical architecture is proposed to decompose a large-scale system into a group of smaller units with independent functions among each layer and information interaction through a specific way. It will enable researchers to better understand the working principles of molecular communication systems for system design and application development.

1) Physical layer: the main function is to deal with physical materials. It consists of two sub-layers: the biological nanorobot sub-layer abstracts the physical details of the biological nanomachines and defines the functions of the biological nanomachines; The signaling sub-layer

provides signaling functions through molecular modulation/demodulation;

2) Molecular link layer: for direct communication range;

3) Molecular network layer: used for communication range larger than link layer distance;

4) Molecular transport layer: for end-to-end communication range;

5) Application layer: provides a variety of functions based on molecular communication applications

4.4 Step 3: Collaborative computing and digital twin

4.4.1 Collaboration: collaboration and equilibrium between network elements

It is used to perform the interface protocol transformation for massive data reception in vivo, cooperate with the calculation of the edge side of base stations and cloud computing side, and the real-time communication with the base stations. In detail, the digital man of personalized twin body area network in virtual world is constructed by deploying dense sensors both in vivo and in vitro for real-time data collection and analysis, distributed modeling of twin models, and the interaction with entity modeling and updating.

4.4.2 Twin: management of digital twin model

Digital twin makes full use of physical model, sensor update, operation history and other data, and integrates multi-disciplinary, multi-physical quantity, multi-scale and multi-probability simulation process to complete mapping in virtual space, so as to reflect the full life cycle process of corresponding entity equipment. The main functions of digital twin are digital model design, simulation, remote monitoring and predictive maintenance, optimization of customer production indicators, product use feedback, etc.

The idea of digital twin is to apply digital twin technology to the human body. Herein, everyone can have their own "digital twin". With a variety of new medical monitors and wearable devices, people can track the movements and changes of every part of this digital body for better health management.

The implementation of digital twin technology depends on the development and application of many advanced technologies. From the basic data acquisition layer to the top-level application layer,

the technology system can be divided into four layers: data guarantee layer, modeling and computing layer, digital twin function layer and immersive experience layer. The realization of each layer is based on the previous layer, which is a further enrichment and expansion of the functions of the previous layer.

4.4.3 Display: syncretic and interactive display of body area

Body area data can be manifested using holographic technology. At present, holographic display technology is reflected in the optical processing of images display which is unable to realize interaction data processing. Through the action collection in the condition of blocking in the process of transmission and capturing of target image such as participants as well as analysis of image analysis system, holographic interactive projection system, as a new type of projection system can produce the motion data of the object and combine real-time video interactive system to enable participants to interact with the screen. When participants interact with the reconstructed image, different positions on the reconstructed image will bring about changes in intensity due to the occlusion of light. Sensors detect this change will judge it and direct the hologram to respond accordingly.

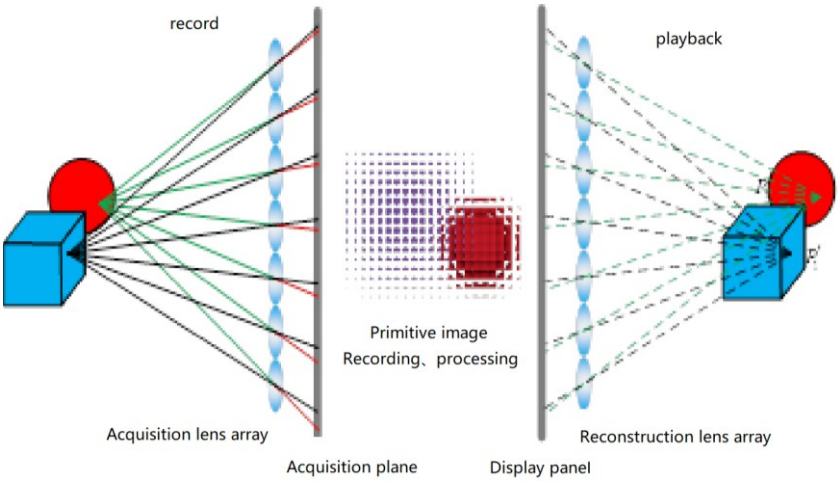

Figure 6. Schematic diagram of holographic display

Holographic display technology not only can realize 360° 3D projection display, but also can realize the interaction between projected content and users. In the previous holographic display principle, we introduce that holographic display includes two processes: recording and reproducing. In the recording process, rays from the same object point in the scene in different directions are

incident into different primitive images through different lens units of lens array, and rays from different object points in space incident into the same lens unit are recorded in the same primitive image. The primitives corresponding to different lens array units record the perspective images of scene at different observation positions in space. The reconstruction of integrated imaging is the inverse process of recording. The recorded primitive image array is loaded onto the display panel, and the reconstruction of the real scene with horizontal and vertical parallax is realized through the projection of the reconstructed lens array.

4.5 Step 4: communication and interaction with backbone network

As a smaller network element, the WBAN is a further refinement and natural extension of future base stations. To meet the diversified requirements of industry network with more flexible and open architectures in future, the WBAN plays an important role in the connection with base stations or other network elements, including the technical requirements for the radio of massive access devices of body area and the schemes for network resource coordination and energy saving.

4.5.1 Cross-layer optimization

Cross layer optimization technology plays an important role in DTWBAN. It is the new WBAN terminal which is the extension of the wireless base stations in 6G era. It can accurately grasp the network element of user requirements and provide information and model for each layer to accurately match user requirements. Furthermore, it provides basis and feedback mechanism for computing, storage, channel and other resources to accurately match between terminal, base station, core network and other network elements.

4.5.2 Multi-network collaboration

Multi-scene switching includes reliable switching between multiple devices and simultaneously reliable switching between multiple networks. By realizing smooth switching between devices and multiple networks, the flexibility of the network can be increased and a continuous high-quality service experience can be formed.

1) In the multi-network scenario, there are the following situations, as shown in Figure 7:

-UE 1, UE 2, using PC5 link +WLAN or other non-3GPP RAT aggregation;

-UE to NW case, remote UE1 relay UE, PC5 link +WLAN or other non-3GPP RAT aggregation;

-UE to UE case, remote UE1/2 relay between UE, PC5 link +WLAN or other non-3GPP RAT aggregation; Remote UE 1 is transmitting UE and remote UE 2 is receiving UE.

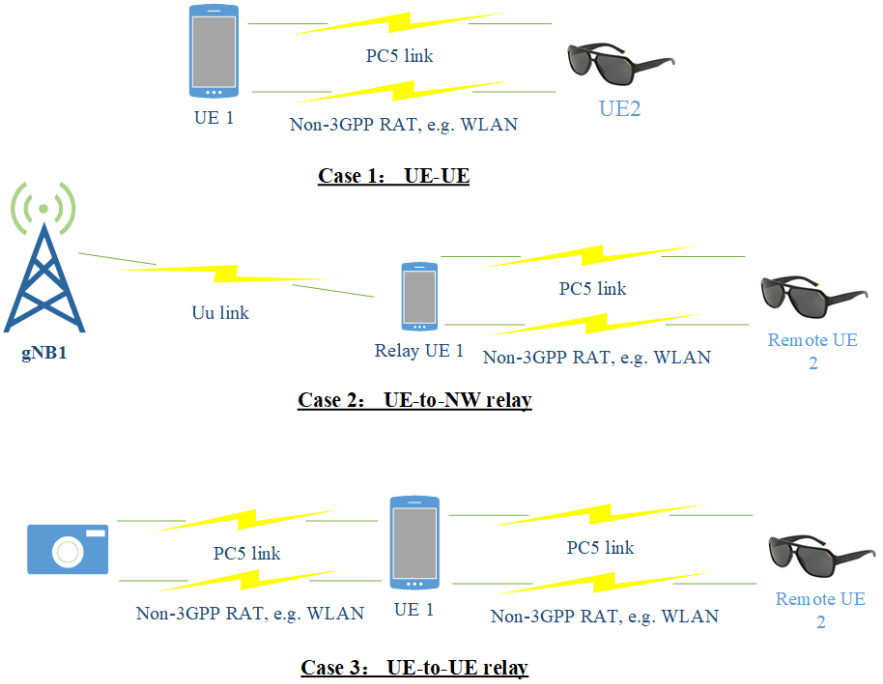

Figure 7. Reliable switching of multiple devices

（2）In the case of multiple devices, it is possible to actively select the appropriate device in different scenes, and at the same time, when the scene changes, find the new device and switch to the appropriate new device through the data center or base station.

Such as:

1. Both the watch and the cell phone have a SIM card. When you run, you don't have your cell phone with you, so the call goes to your watch. As it is RedCap UE, NW does not dispatch large data volume business for watches and does not allow video calls.

2.On the way home, the phone kept ringing; When I got home, my watch found the mobile phone (e.g. based on SL); Then, it forms an inverted DC structure with the mobile phone (a base station connects two related terminals - the mobile phone and the watch). The control surface is maintained on the watch, and the user surface is switched to the phone;

3. At this point, you can make a video call from your phone;

4. In the process, business continuity is guaranteed.

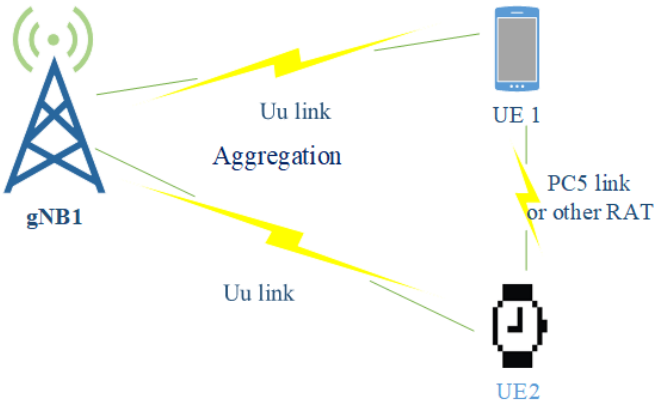

Figure 8. Reliable handoff of multi-network cooperation

5. Requirements for future WBAN

5.1 Network parameters

5.1.1 Frequency

WBAN needs to consider the influence of electromagnetic waves on human body. The higher the frequency, the greater the influence of electromagnetic waves on human body. There are two possible solutions to the spectrum used in future WBAN: one is to use the same higher frequencies as next-generation wireless communications, like terahertz, which requires a reassessment of the effects of higher frequencies on the human body. The second is to still consider using the microwave frequency band within GB8702-88. The influence on human body can be controlled by regulating the power density to 10 μW/cm^2 in the frequency band. However, the frequency band should be wide because of the requirement of higher transmission rates.

5.1.2 Power

In digital twin of WBAN (DTWBAN), due to the rise of frequency band and the intensive deployment of sensor nodes, the overall electromagnetic radiation and energy cost of the system will increase significantly, and the total emission power of the twin-domain network must be very low to ensure energy consumption and human health. Therefore, in order to provide sufficient data rate support, the maximum transmitting power of the future volume domain network needs to be

compromised in combination with the constraints of hardware devices. The volume network equipment is mainly concentrated near the human body, and its equipment density will be much higher than 100 /m^3. Assuming that the total transmitting power remains unchanged at 1mW and the number of equipment is expanded by 100 times, the transmitting power in a single period can be reduced to -20dbm. From the perspective of digital organs and nanobots, the equipment intensity will increase thousands of times.

5.1.3 Rate

The DTWBAN extends many applications beyond 5G standard, such as holographic communication, which requires a Tbps level of transmission rate. According to market analysis, the market of digital twin is expected to reach $26 billion by 2025. To meet the requirements of DTWBAN, the transmission rate should be 0.8 Tbps considering 100T pixels/m^2 of the information, acquisition rate of once every 100 ms and compression rate of 1/300.

5.1.4 Latency

To support real-time monitoring and real-time digital simulation of digital twin, the DTWBAN has certain requirements on latency. In terms of real-time monitoring and enhanced wearable device support, the latency should be set in 10ms. For digital twin service, as it is the simulation prediction under virtual scene, it is necessary to quickly simulate and predict the following situation after some changes occur in the system, which poses a challenge to the latency. Therefore, the DTWBAN latency can be set around 0.1ms.

5.1.5 Reliability

The reliability of 5G network is 99.999%, which can support most medical services. The reliability of DTWBAN is the same. Nonetheless, in some special scenarios in the future, such as digital organs and telemedicine, the reliability requirement of WBAN will be increased to 99.99999% considering the life safety of patients. [13]

5.1.6 Security

Compared with the traditional communication technology, the WBAN should consider more security issues and higher security requirements. Closer to the human body, the WBAN needs to

consider the effects of ionizing radiation on human health. At the same time, the thermal effect of equipment is also one of the factors to be considered in WBAN. In the international standard, the power density of communication frequency should be lower than 40mW/cm^2 , while the domestic and American standards are 8 mW/cm^2 and 600 mW/cm^2, respectively.

	Dense buildings	Medical scenario	High-speed mobile
Transmission rate	1 Gbps	1 Gbps	1 Gbps
Latency	1-10 ms	≤1 ms	1-10 ms
Reliability	99.999%	99.99999%	99.999%

Figure 9 . Requirements of WBAN in different scenarios

5.2 Architecture features of WBAN

1. Small and flexible

In the 5G era, enterprises or parks are the smallest units for edge computing and network slicing, and the influence of the 6G era on individuals will be further reduced.

2. Fog computing and intelligent collaboration

The intelligent selection and collaboration of multiple networks promote the autonomy of network management.

3. Open artificial intelligence crowd sourcing mode

On the basis of SDN before 5G era, digital twins are developed, the uplink data proportion is greatly increased, and more fine-grained open ARTIFICIAL intelligence can realize the data value of enterprises and individuals.

4. Privacy and security

Secure multi-party computing, block chain, private data does not go out of the body network, only the model leaves the body network, which not only ensures security and privacy, but also highlights the value of data and the remaining computing, storage, bandwidth resources.

5. Green and energy

Smart running shoes power generation and other self-powered equipment and computing task

flexible scheduling energy-saving mode, solve the capsule robot and other wearable smart body in the last kilometer of human development. [14]

Figure 10 Micro mobile communication in body, body surface and body domain is seamlessly connected with traditional mobile communication[14]

5.3 Application scenarios

The twin domain network can simulate the virtual human body through 6G and information and communication technology. It can track all the time and predict the lesions in advance. It can also simulate the operation and medication of the virtual human body and predict the effect, so as to improve the quality of human life.

Take the control of novel coronavirus epidemic situation as an example:

1. Digital dual network that transmits health information in real time to the personal network segment of edge calculation;

2. Through the deindividuation model of secure multi-party computing, and through the deployment of comparative fog computing, find the exception;

3. The channel resources of Tiandi Internet are allocated to the remote cloud computing center through independent gateways;

4. The doctor traces the source of crowd behavior and found the source of infection through

non-contact testing of digital twins;

5. Speed up data processing through digital twin's first simulated operation and drug clinical verification;

6. In the process of isolation and emotional interaction, patients communicate with their families through the synesthesia network. [14]

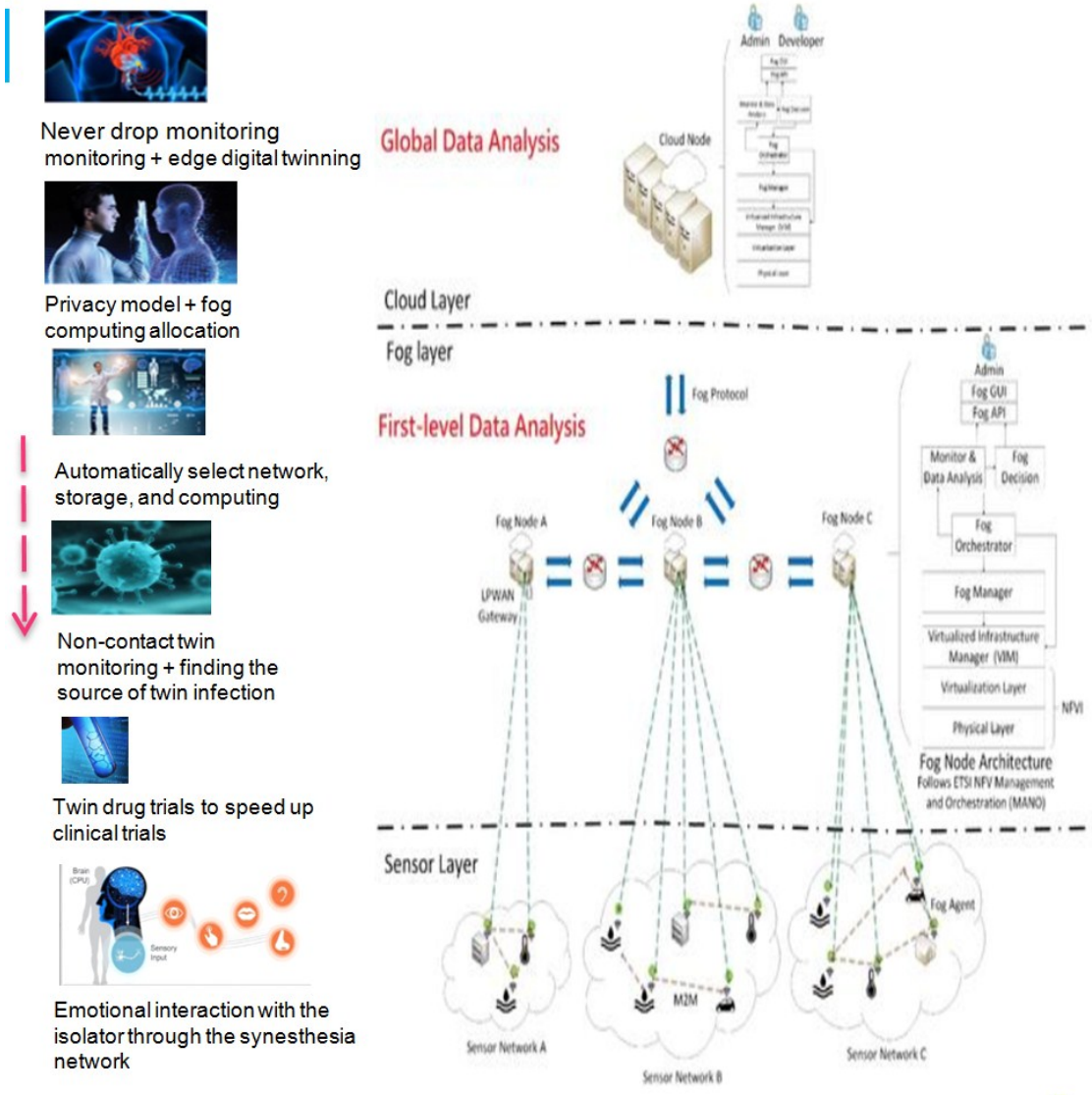

Figure 11 Schematic of the Digital twin body area network to help manage the epidemic [14]

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Abbreviation

WBAN: wireless body area network

DTWBAN: digital twin of wireless body area network

6G: 6th generation mobile networks

EEG: electroencephalogram

ECG: electrocardiograph

EMG: electromyography

MEMS: microelectromechanical systems

BCI: brain-computer interface

QoS: quality of service

LAN: local area network

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