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A 5G Cognitive System for Healthcare

Min Chen [1], Jun Yang [1], Yixue Hao [1,*], Shiwen Mao [2] and Kai Hwang [3]

[1] School of Computer Science and Technology, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, China; minchen2012@hust.edu.cn (M.C.); junyang_cs@hust.edu.cn (J.Y.)
[2] Department of Electrical and Computer Engineering, Auburn University, Auburn, AL 36849-5201, USA; smao@ieee.org
[3] Electrical Engineering and Computer Science, University of Southern California, Los Angeles, CA 90089, USA; kaihwang@usc.edu
* Correspondence: yixuehao@hust.edu.cn

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Abstract: Developments and new advances in medical technology and the improvement of people's living standards have helped to make many people healthier. However, there are still large design deficiencies due to the imbalanced distribution of medical resources, especially in developing countries. To address this issue, a video conference-based telemedicine system is deployed to break the limitations of medical resources in terms of time and space. By outsourcing medical resources from big hospitals to rural and remote ones, centralized and high quality medical resources can be shared to achieve a higher salvage rate while improving the utilization of medical resources. Though effective, existing telemedicine systems only treat patients' physiological diseases, leaving another challenging problem unsolved: How to remotely detect patients' emotional state to diagnose psychological diseases. In this paper, we propose a novel healthcare system based on a 5G Cognitive System (5G-Csys). The 5G-Csys consists of a resource cognitive engine and a data cognitive engine. Resource cognitive intelligence, based on the learning of network contexts, aims at ultra-low latency and ultra-high reliability for cognitive applications. Data cognitive intelligence, based on the analysis of healthcare big data, is used to handle a patient's health status physiologically and psychologically. In this paper, the architecture of 5G-Csys is first presented, and then the key technologies and application scenarios are discussed. To verify our proposal, we develop a prototype platform of 5G-Csys, incorporating speech emotion recognition. We present our experimental results to demonstrate the effectiveness of the proposed system. We hope this paper will attract further research in the field of healthcare based on 5G cognitive systems.

Keywords: 5G; cognitive system; healthcare; speech emotion recognition

1. Introduction

With the development of medical technology, medical theory, medical equipment, and disease prevention, along with the improvement of people's nutritional level, people's health condition has been improved noticeably [1]. In the 2015 edition of World Health Statistics, the World Health Organization (WHO) reported that the current global average life expectancy of new born babies has increased to 71 years, with a 6-year growth compared to those born in 1990 [2]. However, the scarcity and unbalanced distribution of medical resources still pose great obstacles. A challenging problem is how to break the limitations of medical resources in time and space, to achieve effective distribution of medical resources. Telemedicine is a good choice to solve this problem. Using remote audio, remote video, and other techniques, higher ranked medical institutions can share their resources with lower ranked medical institutions. Eventually, the medical standard of lower ranked medical institutions could be enhanced, and people's medical service could be improved. However, traditional telemedicine applications based on audio and video technology are limited in their ability to meet deeper medical needs, such as remote surgery. In order to solve this problem, a novel technology, named 5G Tactile Internet, is proposed in [3]. As a new architecture, 5G Tactile Internet can cognize haptic movements, and efficiently transfer a human's actions through 5G wireless networks based on tactile perception, modelling, and transmissions.

Applied in the medical field, 5G Tactile Internet exhibits great potential to enable remote surgery, as shown in Figure 2a. In the scenario, remote survey is used for curing a patient's physiological disease. For those patients suffering from psychological diseases, such as depressive patients, autistic children, insomnia patients, etc., a challenging problem is still how to remotely detect the joint psychological and emotional state for an effective psychological treatment [4–7]. In order to overcome this obstacle, this paper, for the first time, presents a novel 5G Cognitive System (5G-Csys). We propose an innovative healthcare system based on 5G-Csys (denoted by 5GCS-Health-Sys). The cognition in 5GCS-Health-Sys is two-fold. On one hand, the cognition of haptic movements in 5GCS-Health-Sys is the key for remote surgery. On the other hand, the cognition of a human's emotion status is used to cure the patient's mental illness. If a 5GCS-Health-Sys mainly focuses on emotion care, it becomes the 5G emotional cognitive system, which can perceive the user's emotion based on the analysis of physiological data, behavioral data and environmental data. Based on perceived user emotion, the interactions between doctor, 5GCS-Health-Sys, and patients are helpful for mental healthcare. However, a challenging problem is how to train 5GCS-Health-Sys to obtain high-level cognitive intelligence for perceiving user emotion and achieve real-time emotion communications.

In 5GCS-Health-Sys, remote sensing of surgical and emotional states requires real-time and reliable delivery. So the design of 5GCS-Health-Sys is facing the following three challenges: (i) ultra-low latency; (ii) ultra-high reliability; (iii) medical cognitive intelligence. In response to these three challenges, in this paper, we first present the system framework of 5G-Csys, including the design of the network architecture and communication modes. Second, we present the key technologies that have been adopted to address these three challenges. Thirdly, we present the application scenario of the proposed system. Finally, a practical platform of the 5G cognitive system for speech emotion recognition is presented, which provides validity of our system. In conclusion, the contributions of this article include:

- We propose a novel 5GCS-Health-Sys. The system can not only enable remote treatment for physiological diseases, but also achieve emotional and psychological cognition for human beings.
- Based on our framework, in order to meet the requirements of ultra-low latency, ultra-high reliability, and intelligence of the system, we incorporate the resource cognitive engine and data cognitive engine. The resource cognitive engine achieves the required ultra-low latency and ultra-high reliability of the system by using a software defined network (SDN) to cognize the resources in the network [8–10]. The data cognitive engine achieves the required intelligence of the system by leveraging machine learning and deep learning algorithms to analyze healthcare big data [11,12].
- We present a platform of the 5G cognitive system for speech emotion recognition. The system can recognize users' speech emotion with the support of 5G cognition, which validates the effectiveness of our proposed system.

The remainder of this article is organized as follows: Section 2 describes previous efforts related to our topic. Section 3 introduces the architecture of 5G-Csys for healthcare. Section 4 introduces the key technologies of 5G-Csys. Section 5 describes the application scenarios of 5G-Csys. Section 6 introduces a testbed of 5G-Csys. Finally, Section 7 concludes this paper.

2. Related Work

Some studies on cognitive computing [11–16] on the basis of cloud computing, big data and machine learning have been done [5,17,18], some of which have also been applied to the domain of healthcare [7,19–28]. Pozna et al. [11] proposed a novel method of cognitive system strategy, zeroing in on the design of a new human knowledge model, considering a new data structure to organize and operate relative information. Bhati et al. [15] made a concise summary of cognitive computing features and designed an open question-answering system with cognitive ability through the application of massive text data and natural language processing. Inspired by the working mechanism of the human brain, Pan et al. [14] attempted to study how to complete a broken picture with the existing knowledge in a cognition system. In [12,13], a general survey was conducted regarding the development of cognitive computing. Zhang et al. [5,17] established cognitive applications by utilizing the big data analysis technique. In [18], concerning the security of confidential user data, the authors discussed the security problems that need to be addressed in the design of a cognitive system.

With regard to healthcare, there are three different domains of exploiting cognitive computing techniques, i.e., physiological healthcare [20,24,25], psychological healthcare [7,19,23,26,28] as well as medicine analysis [21,22]. In order to provide an advanced healthcare service. Zhang et al. [20] proposed a patient-centric system, based on cloud computing and big data analysis technologies. In [24,25], Fortino et al., proposed specific methods for the analysis of blood pressure and heart rate, respectively. In [7], Chen et al., proposed a novel service framework, which offers a personalized emotional awareness service by utilizing mobile cloud computing and affective computing techniques. In [19], the authors proposed an emotional cognitive system based on facial expression recognition, and discussed the inference mechanism of a cognitive system. Hossain et al., discussed the design of an emotional cognitive system based on voice [26,28] and facial expression [26]. Chen et al. [23] utilized a pillow robot, a 5G network as well as a cloud platform to achieve real-time emotional interaction between remote users. The cognitive computing technique is also applied to drug recommendation in [21,22], in order to provide an adequate medical service to both doctors and patients.

3. Architecture of 5G Cognitive System

In this section, we will introduce the framework of 5G-Csys from the network architecture, communication modes, and core components of communication mode perspectives.

3.1. Network Architecture of 5G-Csys

The network architecture of 5G-Csys is shown in Figure 1, which consists of three layers, i.e., the infrastructure layer, the resource cognitive engine layer, and the data cognitive engine layer. The infrastructure layer includes user terminals (e.g., sensors, cognitive devices, smart phones, etc.), radio access network (RAN), core network, edge cloud, and remote cloud. The RAN and core network serve as the communication infrastructure of the system. Edge cloud and remote cloud serve as the storage and computing infrastructure of the system. The variety of terminals, such as smart terminals, humanoid robots, smart clothing and smart cars, etc., utilize various radio access technologies, forming the cognitive sensing layer (or the infrastructure layer) of the system [29–32].

The second layer is the resource cognitive engine. This layer can achieve resource optimization through perception and learning of network contexts (such as network type, data flow, communication quality, and other dynamic environmental parameters) and user information. Utilizing the resource cognitive engine, 5G-Csys can achieve green communications and energy efficiency, which are critical for the healthcare application's infrastructure to fulfil the requirements of healthcare applications. Furthermore, the intelligence generated by cognizing hardware systems and various available resources in terms of computing, communications, and networking, can achieve high reliability, high flexibility, ultra-low latency, and scalability of 5G-Csys. Recent advanced technologies for network softwarization include network function virtualization (NFV), SDN, self-organizing network (SON), and network slicing. Meanwhile, this layer utilizes cloud platforms and intelligent algorithms to construct a cognitive engine for resource optimization and energy saving, so as to improve user experience and satisfy the different communication requirements of various heterogeneous applications [33].

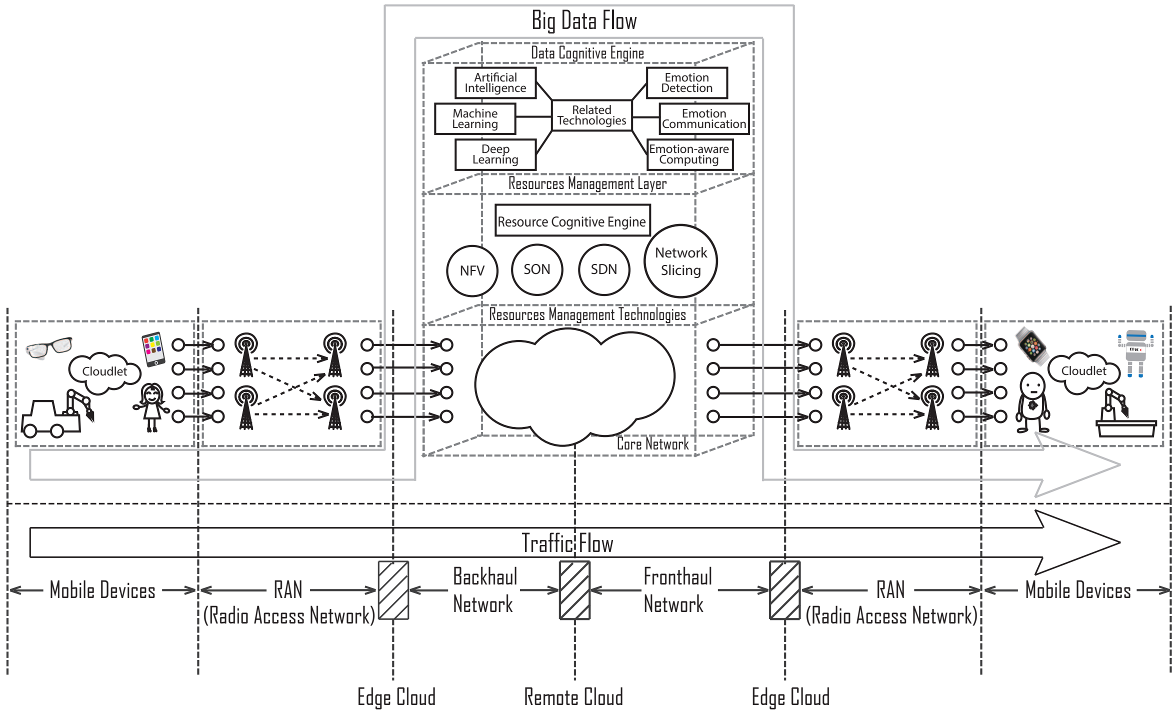


Figure 1. Architecture of a 5G cognitive system (5G-Csys) for healthcare.

The main functionality of the third layer is implemented in the data cognitive engine. In this layer, data supply is critical. For example, cognitive medical application relies on sustainable provisioning of healthcare big data. With the big data, the data cognitive engine can achieve environmental perception and human cognition with specific intelligent algorithms, such as machine learning and deep learning. Perception and cognition are based on the big data flow in the 5G-Csys system, while the data engine analyzes the big data flow to detect various healthcare requests. With the gradual enrichment of data dimension and continuous accumulation of data, the data cognitive engine may be able to simulate a human's cognitive behavior. With this kind of ability, 5G-Csys can better cognize the real world environment and human beings, so as to greatly improve the intelligence of 5G-Csys.

3.2. Communication Modes of 5G-Csys

In consideration of the various communication requirements for geographically distributed users, the communication modes are classified as in Table 1.

Table 1. Classification of Communication Modes.

Name	Abbreviation	Communication Mode
5G Communications in Last Mile Network Access	5C-LM	Short or Medium Range Communication
5G Communications over Multiple Macro-cells	5C-MMC	Long Range Communication without Clouds
5G Communications over Clouds	5C-Cloud	Long Range Communication with Clouds
5G Communications over Co-Located Clouds	5C-Cloudlet&Cloud	Communications with Flexible Coverage

According to communication distance, this paper classifies the communication modes of 5G-Csys into four categories: (i) 5G Communications in Last Mile Network Access (5C-LM); (ii) 5G Communications over Multiple Macro-cells (5C-MMC); (iii) 5G Communications over Clouds (5C-Cloud); (iv) 5G Communications over Co-Located Clouds (5C-Cloudlet&Cloud). 5C-LM means that two users are located in the same cell, where they either communicate with each other via a D2D link or connect through the base station. When two users belong to different cells, a further communication mode (i.e., 5C-MMC) is used to connect the remote devices. Meanwhile, based on the demand of some individual application scenarios, a remote cloud can be deployed for big data storage and computing. Then, two users who are far from each other can be put into contact via the remote cloud. This communication mode is called 5C-Cloud. 5C-Cloudlet&Cloud mode is applicable to either the network edge or core network. Once users at one edge reach a certain quantity, cloudlet can be constructed automatically to enhance communication efficiency among local users, and service offloading can also be implemented by cloudlet. Remote cloud is also critical to provide stable services among multi-users under 5C-Cloudlet&Cloud mode if there are users who are far from others. The relative order of communication ranges of the four communication modes is as follows: 5C-LM < 5C-MMC < 5C-Cloud < 5C-Cloudlet&Cloud. In real application scenarios, with a dynamic update of the user location, the communication mode used for users can be dynamically switched among the four modes.

3.3. Core Components for Communications and Computing in 5G-Csys

In 5G-Csys, the core components include the RAN, core network, cloud and cloudlet. Among them, the RAN and core network form the communication infrastructure, while the storage and computing infrastructure is composed by cloud and cloudlet. As shown in Table 2, the requirement varies for each functional component to enable the four communication modes in 5G-Csys.

Table 2. Components of Communication Modes.

	Radio Access Technology	Core Network	Cloud	Cloudlet
5C-LM	D2D, WiFi, 3G, 4G, 5G, etc.	N/A	N/A	N/A
5C-MMC	D2D, WiFi, 3G, 4G, 5G, etc.	Yes	N/A	N/A
5C-Cloud	D2D, WiFi, 3G, 4G, 5G, etc.	Yes	Yes	N/A
5C-Cloudlet&Cloud	D2D, WiFi, 3G, 4G, 5G, etc.	Yes	Yes	Yes

In addition to the various requirements on the infrastructure resource, different communication modes should provide different guarantees on bounded delay, as shown in Table 3.

Table 3. Comparisons of Delay Bounds in the Four Communication Modes.

	Latency Objective in 5G-Csys			
	Terminal	**Radio Interface**	**Core Network**	**Total**
5C-LM	0–3 ms	2–5 ms	N/A	2–10 ms
5C-MMC	0–3 ms	2–5 ms	10–30 ms	10–40 ms
5C-Cloud	0–3 ms	2–5 ms	10–40 ms	10–50 ms
5C-Cloudlet&Cloud	0–3 ms	5–10 ms	10–40 ms	20–60 ms

4. Key Technologies of 5G Cognitive System

In order to meet the requirements of ultra-low latency, ultra-high reliability, and cognitive intelligence, some key technologies should be deployed in the RAN, the core network, and the cognitive engine.

4.1. Key Technologies Deployed in Radio Access Network

In order to achieve ultra-low latency and ultra-high reliability in the 5G-Csys network, we employ the following three key technologies deployed in RAN, i.e., control and data decoupling, uplink and downlink decoupling, and dynamic access of wireless resources.

- Control and data decoupling: In RAN, the base stations are classified as control base stations and traffic base stations to achieve the decoupling of the control plane and data plane. Meanwhile, control base stations are introduced as an SDN controller to utilize global information of the network to dynamically adjust resources at the traffic base station. Thus, the decoupling could implement functions such as dynamic resource allocation, etc. The main components of the decoupling technology include a decoupling model, decoupling strategy, collaborative controlling mechanism and energy consumption assessment, etc.

- Uplink and downlink decoupling: Uplink and downlink decoupling will assign uplink and downlink tasks to different stations to achieve the optimization of user communications. Uplink selection is based on the principle of minimum transmission distance, i.e., the base station which is nearest to users is selected as the uplink base station. Downlink selection is based on the principle of maximizing the power of the receiving signal, i.e., the base station from which the user terminal receives the most powerful downlink signals is selected as the downlink base station for the user. Uplink and downlink decoupling technology enables the optimization of uplink and downlink access of user communications. The main components of the decoupling technology include environmental awareness, mobile user perception, signaling control and energy efficiency optimization, etc.
- Dynamic access of wireless resources: This technology can dynamically perceive resource consumption, signal interference, energy consumption and workload in the base station, so as to allocate the wireless sources elastically and maximize the capacity and efficiency for the entire network. Furthermore, with the reference of historical data, the technology is able to predict user behavior, user movement, and traffic requirements, and to allocate appropriate wireless resources for users in advance.

4.2. Key Technology Deployed in Core Network

We use the technology of content delivery and network fusion in the core network to guarantee ultra-low latency for 5G-Csys.

- Content delivery: The technology builds an overlay network in the traditional network infrastructure, and achieves effective content delivery with the content delivery network, content caching, and other technologies, aiming to improve the user's quality of experience (QoE).
- Network fusion: In existing networks, wireless domain and IP domain are separated, which leads to low efficiency, stiff control, resource waste, disability of unified control, and other issues. The fusion of the RAN and Core Network is to overcome these obstacles. Furthermore, the fusion can be implemented by utilizing the RAN wireless multicast mechanism, the content delivery mechanism of the core network, and the content cache mechanism of user terminals.

4.3. Key Technology Deployed in Cognitive Engine

In order to achieve ultra-high reliability and intelligence of the system, we employ the resource cognitive engine and data cognitive engine in clouds. The resource cognitive engine can achieve resource cognition, and then achieve ultra-low latency, ultra-high reliability, and energy efficiency of the system. The data cognitive engine can cognize health big data, and then perform intelligent healthcare. The specific description is as follows:

- Resource Cognitive Engine: Based on the cloud platform, the resource cognitive engine is capable of massive storage and powerful computing. Furthermore, various branches of the data cognitive engine can be deployed according to different healthcare requirements. The main issues that need to be solved for the resource cognitive engine include classification of the cognitive engine, functional design of the cognitive engine, modeling of the cognitive algorithm, and interface design of the cognitive engine.
- Data Cognitive Engine: The implementation of the data cognitive engine is relevant to specific healthcare requirements. Taking healthcare requirements into consideration, the cognitive engine can take advantage of machine learning, deep learning, cloud computing, big data analytics, and other technologies to construct the cognitive model and finally achieve the cognitive ability matching with healthcare requirements.

5. Applications of 5G-Csys for Healthcare

In this section, we present six application scenarios of 5G-Csys, including remote surgery, remote emotional pacification, augmented reality game, stunt show, lie detection, and online gaming.

5.1. Archetypal Applications of 5G-Csys

5G-Csys can transmit data among remote clients with ultra-low latency and ultra-high reliability. In our paper, we propose six archetypal applications of 5C-CSys. As shown in Figure 2a, remote surgery is one of the typical application scenarios for 5G-Csys. A 5G emotional communication system is also a typical application scenario for 5G-Csys, as shown in Figure 2b. The remaining potential application scenarios are shown in Figure 2b–f. In the following, we will introduce these archetypal applications of 5G-Csys in detail.

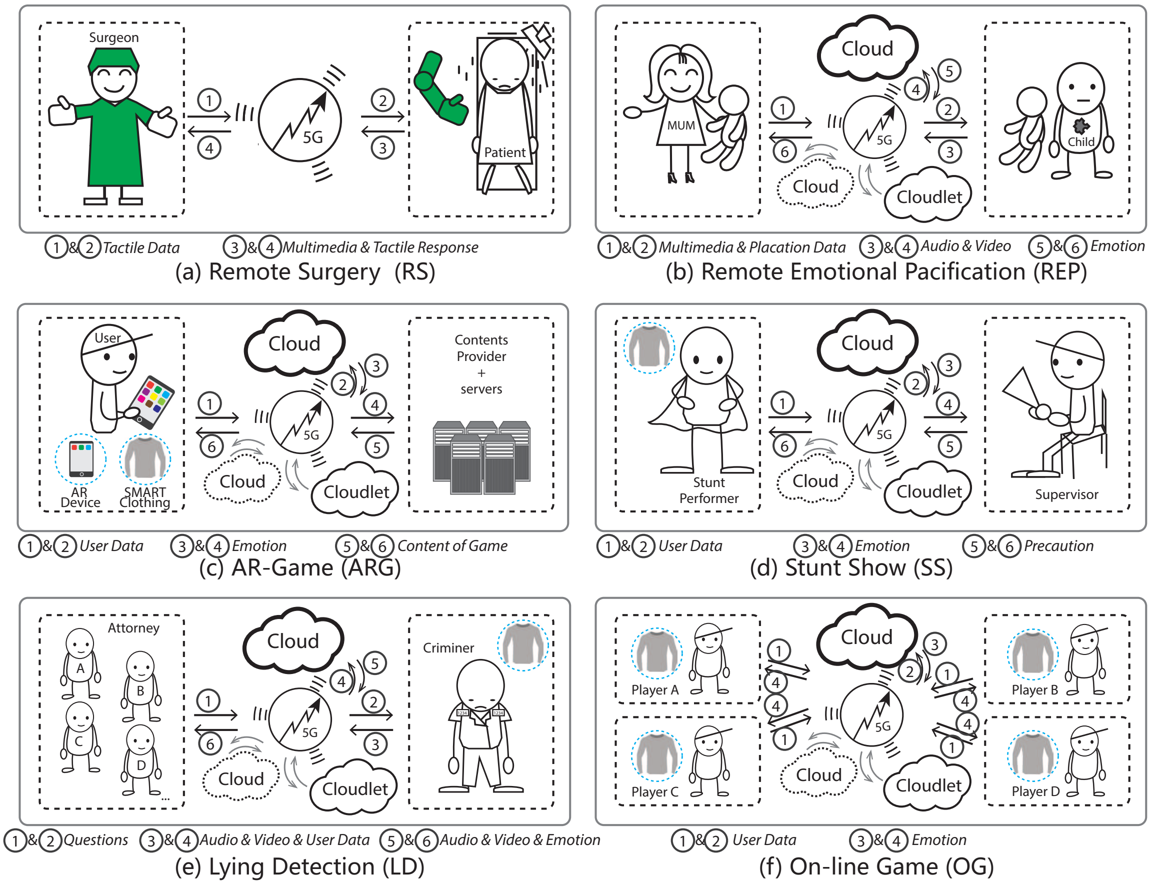


Figure 2. Typical application scenarios of 5G-Csys.

Remote surgery: Due to the lack of medical resources and time, doctors may not reach patients in time to perform operations, which could cause unnecessary risks to patients due to the delay caused by long distance. In order to overcome this obstacle, remote surgery has been proposed. In this remote scenario, patients and doctors are respectively located at remote ends. With the help of display devices and tactile sensing devices, doctors can have real-time information and understanding of the patient's state and perform the corresponding operation according to the patient's current status. During the surgery, the haptic device can capture the posture, position, and movement of the doctor's arm, and the data are swiftly transferred to the operation terminals at the patient's side through 5G networks; then, the mechanical arm of the operation terminals copies the movement of the doctor precisely to perform the operation on the patient. Meanwhile, the sensing device on the patient's side can sense and transfer audio and video information about patient and tactile feedback detected by operation terminals to the doctor. All the information that the doctor receives can be used as the reference for further operation. The information transfer between the doctor and patient forms a communication loop for remote surgery.

Remote emotional pacification: Due to various reasons, mothers cannot accompany their young children all the time. When children's emotions are unstable, utilizing the emotion detection ability provided by the emotional communication system and using the interactive function supported by, e.g., a pillow-robot, mothers can communicate with their children and placate them in real-time. Emotional communication systems can detect and transfer children's emotions swiftly, so the mother can know the child's current emotional state in real-time and perform proper actions to placate the child during the communication period.

Augmented reality game: The content of an augmented reality game is always orchestrated in advance and cannot be changed dynamically along with the change of the gamer's emotion. Integrated with the emotional communication system, a new type of augmented reality game can be offered, which can acquire the gamer's emotion in real-time and transfer it to the remote content provider, which will then dynamically generate the corresponding game strategy and game content in accordance with the gamer's emotion to improve the gaming experience.

Stunt show: Stunts are popular with the public for their excitement and thrill. For stunt performers, stable mentality and exceptional skills are the two key factors for success. Any subtle change in the performer's emotion may greatly affect the performance and performer's safety. In combination with the emotional communication system and smart clothing, the monitoring system can capture the subtle change in the performer's emotion and execute the corresponding precautionary measures in case of danger to the performer.

Lie detection: The polygraph has been a popular tool to interrogate suspects in the past. Now, the emotional communication system can detect the suspect's emotion and it is possible to achieve a joint interrogation of criminals. In international crime cases, the prosecutors appointed by multiple nations can cooperate with each other to interrogate criminals. Procurators can obtain the real-time emotional information of criminals and estimate whether they are lying on the basis of criminals' emotion, i.e., a subtle change in criminals' emotion may help procurators to evaluate the authenticity of criminals' answers.

Online game: Real-time online gaming has become a popular activity with tremendous commercial value. However, existing online games are still lacking with respect to gaming experience. Integrating the emotional communication system and smart clothing system, all players of an online game can sense the real-time emotional state of each other. On the basis of emotion sensing, the team leader can motivate team members more properly and could make better decisions during the period of the game, which will ultimately improve the gaming experience [15,34,35].

5.2. Analysis of Six Applications of 5G-Csys for Healthcare

In summary, the six typical application scenarios of 5G-Csys are Scene-RS (i.e., remote surgery); Scene-REP (i.e., remote emotional pacification); Scene-ARG (i.e., augmented reality game); Scene-SS (i.e., stunt show); Scene-LD (i.e., lie detection); and Scene-OG (i.e., online game). Table 4 lists the feasible network communication modes and the required intelligent equipment for the six application scenarios.

Table 4. Related Requirements of the Scenes.

	Optional Communication Modes	Required Equipment
Scene-RS	5C-MMC, 5C-Cloud, 5C-Cloudlet&Cloud	Robot [36,37], Tactile Device [3], Display Equipment
Scene-REP	5C-MMC	Pillow-Robot [23], Smart Clothing [38]
Scene-ARG	5C-LM, 5C-Cloud, 5C-Cloudlet&Cloud	Augmented Reality Device, Smart Clothing
Scene-SS	5C-LM, 5C-Cloud	Smart Clothing
Scene-LD	5C-MMC, 5C-Cloud, 5C-Cloudlet&Cloud	Display Equipment, Smart Clothing
Scene-OG	5C-Cloud, 5C-Cloudlet&Cloud	Computer, Smart Clothing

6. Testbed of 5G-Csys

In this section, we design and implement a prototype system which incorporates speech emotion recognition as a cognitive approach and EPIC-Robot as the interactive terminal to demonstrate the key factors of the proposed 5G cognitive system.

6.1. Experimental Result of Testbed

The specific procedure of emotional cognition that occurred between the user and EPIC-Robot in the cognitive system is shown in Figure 3. The entire procedure of voice emotional cognition consists of five main steps: A. collection of user voice; B. forward user voice; C. emotion detection in cloud; D. return user emotion; E. behavior feedback from the EPIC-Robot to the user.

Step A: The intelligent terminal collects the user's voice, then transforms the voice data to a file with the audio format of wav.

Step B: Utilizing HTTP REST (Representational State Transfer) API to achieve the file transfer between the intelligent terminal and the cloud, the pattern of REST API is as follows: http://***.***.***.***:1010/Version1.0/epicAudio.

Step C: The cloud will extract the MFCC (Mel-frequency cepstral coefficients) feature from the voice file once it is received. Then, the MFCC feature is input into the trained SVM model to predict the user's emotion. The data sets utilized for SVM model training are collected by EPIC Lab. The size of data sets is 1176, which corresponds to 12 different dialogue scenes. Furthermore, there are 24 people involved in the recording of the data sets; the number of males and females is 13 and 11 respectively, and their ages range between 20 and 30 years old.

Step D: The emotions defined by the SVM model are classified into six categories: happiness, sadness, fear, anger, disgust and surprise. The cloud will encode the emotional results and relay these to the intelligent terminal.

Step E: The intelligent terminal parses the acquired emotional result, packages the corresponding instruction according to the emotional result, and sends it to the EPIC-Robot. Then, the EPIC-Robot performs the corresponding instruction in response to the user's emotion.

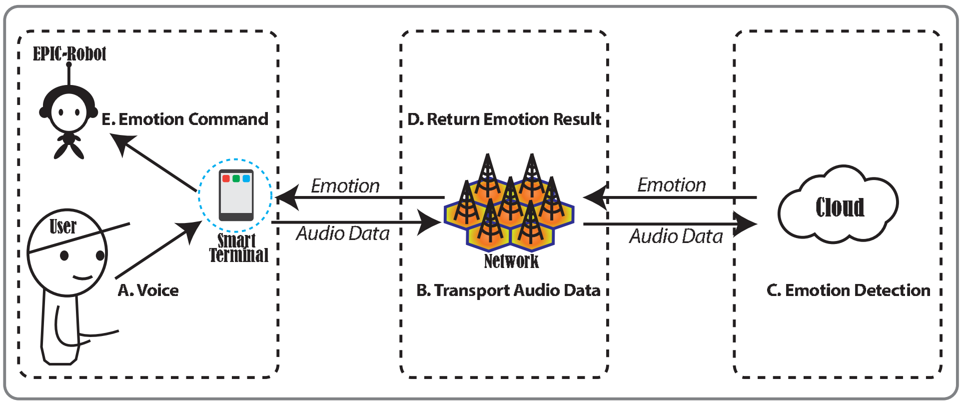


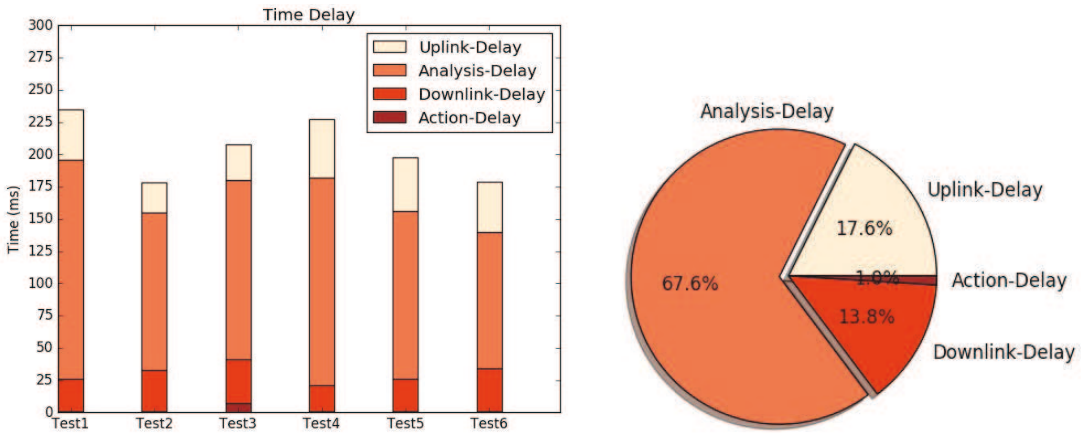
Figure 3. Implementation of the testbed.

We perform the interactive trials several times, and collect statistical data in terms of elapsed time and data size, which can reveal the several key performance aspects of the testbed. The statistical results are presented in Table 5.

Table 5. Statistical Results of the Testbed.

NO. of Test	Voice Duration (A)	Total Elapsed Time (B + C + D)	Elapsed Time in Cloud (C)	Elapsed Time in Network (B + D)	Data Volume Transferred in Network	Elapsed Time of Command Sending (E)
Test1	2749 ms	334 ms	270 ms	64 ms	163 KB	1 ms
Test2	2998 ms	277 ms	222 ms	55 ms	181 KB	1 ms
Test3	2265 ms	301 ms	239 ms	62 ms	133 KB	7 ms
Test4	3021 ms	321 ms	261 ms	60 ms	181 KB	1 ms
Test5	2662 ms	297 ms	230 ms	67 ms	158 KB	1 ms
Test6	2808 ms	378 ms	306 ms	72 ms	168 KB	1 ms

For real-time applications, time delay is critical. Now we utilize the six pieces of experimental data shown in Table 5 to analyze the situation of interaction delay. As shown in Figure 4a, there are four main factors that cause the delay, i.e., delay in backhaul network (Uplink-Delay), data analysis delay (Analysis-Delay), delay in fronthaul network (Downlink-Delay) as well as action feedback delay (Action-Delay) [7]. Figure 4a shows the delay of each part of the six experiments, and it displays that the data analysis delay in the cloud platform occupies the maximum time delay. The statistical results shown in Figure 4b indicate that the data analysis delay in the cloud platform takes up the maximum time delay, i.e., exceeding two-thirds of the total time delay, followed by data forward delay, accounting for 17.6%; then the data backward delay, accounting for 13.8%; and finally the robot feedback delay, only accounting for 1.0%. Obviously, the bottleneck of the time delay is data analysis delay; we can focus on the optimization of this part.



(**a**) (**b**)

Figure 4. Comparisons of Various Delays in the Communication Loop. (**a**) Comparison of Uplink-Delay, Analysis-Delay, Downlink-Delay and Action-Delay; (**b**) Statistics of the Four Kinds of Delays.

6.2. Design of Emotional Feedback of EPIC-Robot

EPIC-Robot is a third-generation bionic robot developed by the EPIC Lab. The profile of the EPIC-Robot is shown in the right part of Figure 5. As shown in Figure 5, the intelligent terminal collects the user's voice and transfers the data to the cloud platform with the help of the LTE (Long Term Evolution) base station and Internet; the cloud platform exploits the machine learning algorithm to perform an analysis of the user's current emotion; then, the cloud platform relays the emotional results to the intelligent terminal by utilizing the infrastructure of the LTE base station and Internet; finally, the intelligent terminal receives the emotional results and guides the behavior of the EPIC-Robot to achieve a real-time emotional interaction between the EPIC-Robot and the user.

The robot mainly consists of the following five parts.

- Head: The head can flexibly turn right, left, upwards, and downwards.
- Torso: The robot's torso carries the central control chip and the entire battery system.
- Upper limbs: The upper limbs are composed of a left arm and right arm, each of which consists of a shoulder, elbow, wrist, and hand, and every joint can perform humanoid movement.
- Lower limbs: The lower limbs include a left leg and right leg. The cooperation between left and right legs can achieve flexible backward, forward, and steering movement.
- Power system: The last part of the robot is the power system. For flexible movement, we design a systematic power system, which can provide elastic power required by all kinds of joints.

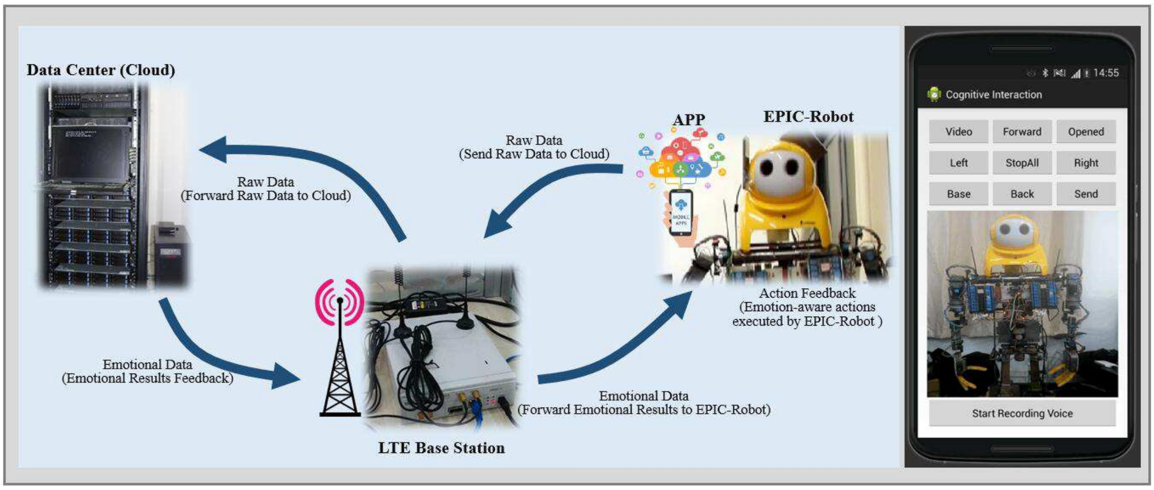


Figure 5. The Emotional Interaction Loop of the EPIC-Robot.

The basic movement units of the EPIC-Robot, shown in Table 6, are classified into four categories (i.e., head, left arm, right arm and lower limbs). In total, 36 basic movements have been implemented [24,25,39–41].

Table 6. Basic Actions of the EPIC-Robot.

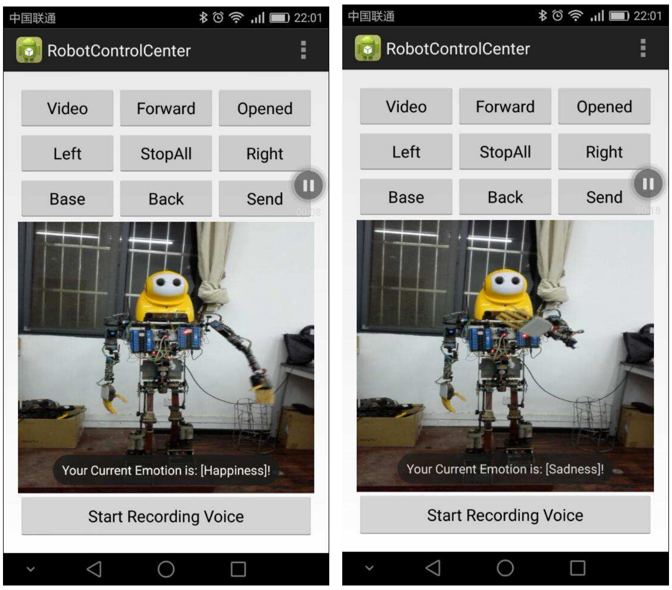
Head	A1 (Lower Head), A2 (Raise Head), A3 (Turn Left), A4 (Turn Right)
Left Arm	B1 (Uplift Shoulder), B2 (Lower Shoulder), B3 (Shift Shoulder Outwards), B4 (Shift Shoulder Inwards), B5 (Move Elbow Outwards), B6 (Move Elbow Inwards), B7 (Turn Elbow Left), B8 (Turn Elbow Right), B9 (Turn Elbow Outwards), B10 (Turn Elbow Inwards), B11 (Turn Wrist Left), B12 (Turn Wrist Right), B13 (Close Left Hand), B14 (Open Left Hand)
Right Arm	C1 (Uplift Shoulder), C2 (Lower Shoulder), C3 (Shift Shoulder Outwards), C4 (Shift Shoulder Inwards), C5 (Move Elbow Outwards), C6 (Move Elbow Inwards), C7 (Turn Elbow Left), C8 (Turn Elbow Right), C9 (Turn Elbow Outwards), C10 (Turn Wrist Inwards), C11 (Turn Wrist Left), C12 (Turn Wrist Right), C13 (Close Right Hand), C14 (Open Right Hand)
Lower Limbs	D1 (Forward), D2 (Backward), D3 (Turn Left), D4 (Turn Right)

In the prototype system, six different emotions have been defined, i.e., happiness, sadness, fear, anger, disgust, and surprise. Once the user's emotion is detected, the system will transfer the corresponding emotional command to the EPIC-Robot. The definition of the robot's actions is provided in Table 7, which correspond to the six emotions. For each emotion, the EPIC-Robot can provide the corresponding actions. Dynamically combining the basic movement units in Table 6, the system allows behaviors to be designed to improve users' emotional state.

Table 7. Emotional Actions of the EPIC-Robot.

Name of Actions	Description of Actions	Orchestration of Actions based on Basic Actions
Action—Happiness	Wave arms from side to side	[B3, B4, C3, C4, B3, B4, C3, C4]
Action—Sadness	Touch	[B1, B7, B8, B7, B8, B7, B8, B7, B8]
Action—Fear	Hug	[B1, C1, B4, C4, B6, C6, B10, C10]
Action—Anger	Put hands down	[B1, C1, B8, C7, B5, C5, B6, C6, B5, C5, B6, C6]
Action—Disgust	Wave left arm	[B1, B8, B5, B6, B5, B6, B5, B6, B5, B6]
Action—Surprise	Move head from side to side	[A3, A4, A3, A4, A3, A4, B1, C1]

Figure 6 shows the Android interface, which supports the actual interactions between users, the cloud, and the EPIC-Robot. Two specific scenes (i.e., happiness scene and sadness scene) are shown in Figure 6a,b, respectively (Demo shown in [42]).



(**a**) (**b**)

Figure 6. Emotional recognition and care on the Android platform. (**a**) Emotion—Happiness; (**b**) Emotion—Sadness.

7. Conclusions

In this paper, we propose the 5G cognitive system (5G-Csys) for healthcare. We first introduce the architecture of 5G-Csys, which includes the infrastructure layer and two different types of cognition engine layer, i.e., a resource cognition engine and a data cognition engine. The resource cognitive engine can realize cognition of resources, while the data cognitive engine can realize cognition of healthcare business. Then, in order to guarantee ultra-low latency, ultra-high reliability and intelligence of 5G-Csys, we discuss the key technologies deployed in the RAN, core network, and cognitive engine. We then present six promising application scenarios based on 5G-Csys. Finally, we describe a platform of the 5G cognitive system for speech emotion recognition, which can recognize users' speech emotion, thus validating the proposed system. However, there are still many difficulties and challenges to overcome before the large-scale deployment of 5G-Csys for healthcare can be realized, e.g., the protection of users' sensitive data and privacy issues. Besides the problem of security, in the future, the system needs improving in two main aspects: on the one hand, we should design a unified development API for the system in order to facilitate the establishment of applications, on the other hand, we should improve the algorithm accuracy with lower time complexity for the intelligent algorithm that our data cognitive engine currently utilizes.

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