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Emotion-Aware Mobile Cloud Computing in 5G

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Abstract: By the introduction of 5G (the fifth-generation wireless broadband), traditional network applications become more human-centric. Computer systems are increasingly capable of reading and responding to human emotions. These systems can be designed to provide response to human emotions promptly in receiving helpful feedback, dealing with negative emotions, and reinforcing positive feelings. These can be made available through mobile services in the form of instant text or video messaging. Cloud computing provides an illusion of infinite computing resources. Mobile cloud computing (MCC) is a new platform combining the mobile devices and cloud computing to create a new infrastructure, whereby cloud performs the heavy lifting of computing-intensive tasks and storing massive amounts of data. It provides many resource-intensive services to mobile users with the help of big mobile data delivery and cloud assisted computing. Both computational capabilities and the mobile broadband connections have improved, thus enabling the devices to constantly monitor the user, understanding his behavior and thus predicting his needs. Emotional mobile computing (EMC) framework is a system that is built on the development of an affordable and reliable system can perform an online analysis of the user's emotions. It is a design to provide emotion-aware mobile services by recognizing the changes in user emotions through cloud computing and big data analysis. The traditional MCC architecture is altered to achieve the required quality of experience in emotion-aware applications. The major tasks are processed in the mobile terminal and local cloudlet, while those tasks which require significant amount of resources, are offloaded to the remote cloud. The framework proposes to combine resource-intensive affective computing with mobile applications, while employing MCC to enhance the capability of mobile devices. Thus it proves its helpfulness in providing personalized human-centric emotion-aware services in 5G.

Keywords: Network applications, Human emotions, Computational capabilities, Mobile devices.

1. INTRODUCTION

Computer systems are undergoing profound changes presently. These systems can be designed to provide timely response to human emotions. They can provide helpful feedback, to support people in dealing with negative emotions, or reinforce positive feelings. Cloud computing is gaining popularity due to virtually unlimited resources, low capital cost, easy adoption, flexible resource provisioning, and high scalability. Considering these benefits, researchers foresee the usage of cloud computing for mobile devices to overcome the ever-increasing computational and energy demands of smartphone applications. Mobile Cloud Computing (MCC) is when cloud computing is integrated into the mobile environment. MCC provides many resource-intensive services to mobile users with the help of mobile big data delivery and cloud assisted computing. Emotional Mobile Computing (EMC) framework is a system whose base is built on the development of an affordable and reliable system that can perform an online analysis of the user's emotions.

2. LITERATURE REVIEW

Significant work has been done in mobile healthcare applications prospect. Researchers proposed platforms and architectures integrate multiple healthcare services on different equipment so as to provide an environment of intelligent routing and monitoring of vital signals. The welfare and health of the patient are the main requirements.

Mobile devices can be helpful in healthcare in terms of applications, patient monitoring and providing location-based services [1]. Doctors and staff can review or update a patient's medical records from any location using a handheld device. Plenty of portable devices are available that can detect medical conditions like pulse rate, blood pressure, breath alcohol level, and so on. Handheld wireless devices can be integrated with such kind of capabilities along with the provision of the user's medical history.

The application of mobile devices for pervasive healthcare information management has already been acknowledged and is well established [2]. The main purpose of this work was to provide consistent communication flow between home health care and primary care providers using devices like Personal Digital Assistants (PDAs) and Tablet PCs. The requirement was that patient information, which could have been configured differently at different locations and spread across different sites, needed to be integrated into a unified set of data available to the user. WLAN hotspots are installed at various nursing homes. The primary medical information on a patient could be stored across different health information systems and in different formats. The virtual health record provides an integrated view of all such data to the user. It gathers information from three separate feeder systems, each accessed through a web service. The web services deliver information as an XML file in a pre-defined format. The information broker maps the XML-files from the feeder systems, and sends it as input to a web service which inserts it in the mediator database. Once information is present at the mediator database, users can access it through their virtual health record applications. This work or applications focus mostly on delivering data to healthcare applications and do not address issues of management of data and issues introduced by integrating data from heterogeneous data sources found in modern healthcare systems. The usage of MCC provides data management and access functionalities.

In MCC, mobile devices do not need powerful configurations such as those of memory capacity, and CPU speed. All the data and complicated computing modules can be processed into the clouds [3].

MCC comes into many applications that analyze human emotions. Sensors in mobile devices are used to monitor the movements of the user and locate him for evacuation during an emergency situation. The data originating from the sensors or applications running on the mobile node is transmitted through Wi-Fi or 3G networks to local clouds for processing, storage, and analysis. Mobility management system for MCC is described as the first MCC system to support cloud and network-aware mobility management while responders are roaming in an emergency area [4]. Experiments were conducted for overall latency of performing activity recognition on the local cloud is significantly lower than on the public cloud. This is because the distance between a mobile node and the cloud contributes to the increase in overall wide area network latency. EMC architecture employs 5G due its significant advantages and improvements over 3G and 4G. One of the benefits of 5G is reduced latency. It should take significantly less time for data transfers to take place. Another benefit is that it will be able to reach areas that current networks cannot. 5G will make communications so fast they become almost real-time.

In the article ‘Communicating While Computing’, the authors describe the capacity improvements of 5G over 3G and 4G [5]. It discusses distributed mobile cloud computing over 5G heterogeneous networks. The major limitations of traditional MCC are the energy consumption concerned with radio access and the latency experienced in reaching the cloud provider through a WAN.Mobile users located at the edge of macrocellular networks are particularly deprived in terms of power consumption and it is difficult to control latency over a WAN.

Jiehan Zhaou, Changrong Yu, Ylianttila M, explain in their article [6] how user emotions are recognized using conversation analysis techniques. PEACE model is described, which is the short name of a model for realizing several different types of emotions and emotion-aware knowledge. The four categories of this model are person-related, event-related, agent-related, and object-related emotions.
An application that senses user’s mood from his smartphone usage patterns is explained in [7]. This could be requirement in gaming or other such entertainment applications. But not every factor that affects mood can be inferred from smartphone usage alone, especially in terms of the requirements of healthcare applications.
It is demonstrated in the article [8] how offloading computation intensive tasks to the cloud can help in saving energy and thus help prolong battery lifetime of mobiles. How wearable and mobile devices can be used to collect the physiological information of user is explained in [9].

From this literature review, it is seen that though most existing emotion-aware applications sense emotion by the relationship between the user’s emotion and behavioral pattern of the mobile phone usage. The data has to be much more accurate and precise. What could be noted as a drawback is that, most healthcare systems existing today only provide care for the users’ physiological status. The mental status of users is overlooked.

3. EMC ARCHITECTURE

Figure 1 is a model of and EMC architecture, which includes three main components: a mobile terminal, a local cloudlet, and a remote cloud.

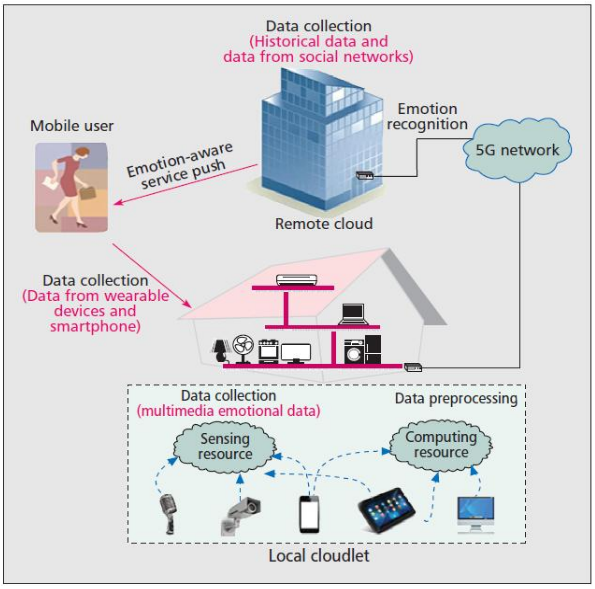

Figure 1 An EMC Architecture model [10]

3.1. EMC infrastructure functional components

3.1.1. Mobile terminal.

Affective computing systems and devices can recognize, interpret, process, and simulate human emotions. In order to analyze a users’ physical status, such as EMG, ECG,

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EEG etc. learning classification algorithms are utilized. Mobile terminals can collect the physiological emotional data with integrated sensors and plug-ins installed. Also, some basic emotional feedback is supported by the output of the mobile terminals.

3.1.2. Local cloudlet

Nearby static and mobile devices (e.g., home appliances, mobile devices, PCs etc.) can be interconnected through various short range radio communication technologies, to form a local cloudlet.

There are three functions in EMC: (i) it provides more emotional data, especially multimedia emotional data, (ii) the local cloudlet can preprocess noisy and redundant data, for improving the quality of data and reducing the data size, and (iii) the different devices within the local cloudlet can be used to collect affective feedback.

3.1.3. Remote cloud

The remote cloud is implemented in a data center where the analysis big emotional data is performed. This is because to achieve high accuracy of emotion detection and timely affective interaction. An inference engine is installed in the remote cloud in which complex emotion inference can be carried out. An example of big data can be petabytes (1,024 terabytes) or even exabytes (1,024 petabytes) of data consists of billions to trillions of records of millions of people, all collected from different sources (e.g., web, social media, mobile data and son on). The data is typically unstructured that is often incomplete and inaccessible. This data, when captured, formatted, manipulated, stored and analyzed can help to gain useful information. Definition of big data can be stated as three Vs of big data: volume, velocity and variety:

- **Volume**. Several factors contribute to the increase in data volume. Transaction-based data stored through the years, unstructured data flowing in from social media and increasing amounts of sensor and machine-to-machine data being collection. In the past, increase in data volume was a storage issued. But to decrease storage cost, new issues emerge, including how to determine relevance within large data volumes and how to analyze and create value from relevant data.

- **Velocity**. Data is pouring in at unmatched speed and must be dealt with in a timely manner. The need to deal with torrents of data in near-real time is driven by RFID tags, sensors and smart metering. Reacting quickly enough to handle this velocity of data is a challenge for most organizations.

- **Variety.** Data today comes in all types of formats such as structured data, numeric data in traditional databases, information created from a line-of-business applications, unstructured text documents, emails, videos, audios, stock ticker data, and financial transactions. Many organizations find it challenging to manage, merge and govern the different varieties of data.

3.2. EMC task components

In the EMC architecture, an emotion-aware service is divided into multiple task components. EMC includes different functional modules that correspond to different categories of task components (Fig. 2).

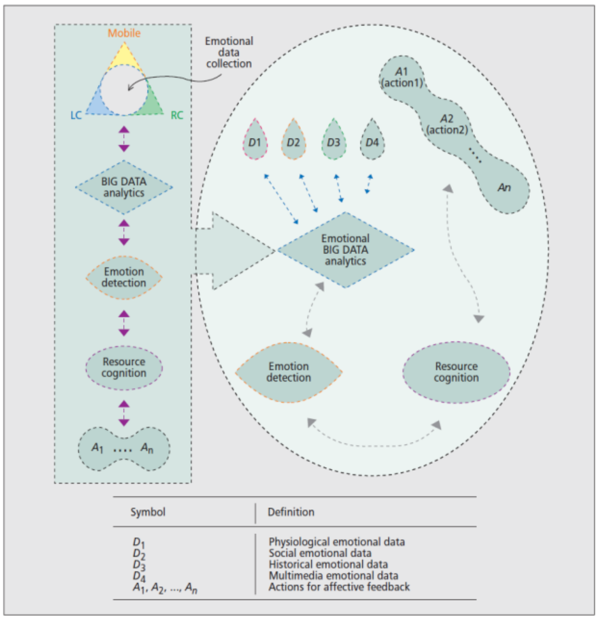

Figure 2 EMC task components [10]

3.2.1. Emotional data collection

Emotions can basically be classified by two types: positive and negative emotions. The rough distinction between these kinds of emotion has been proposed by the cognitive approach. Negative emotions express an attempt or intention to exclude. Negative emotions lead to many problems in wellness, professional work, and social interactions, such as irritation, fear, or despair.

Various emotional data can be sensed, such as voice, facial expressions, gestures, etc. through the mobile terminals. Even physiological signals can be sensed via healthcare and other plug-ins. The local cloudlet can have additional equipment like a device with software that recognizes facial features and a video camera. EMC is thus able to retrieve multimedia emotional data. Emotional information can be extracted from social networks and collect historical emotional data, based on the computational resources in the remote cloud. So the mobile terminal, local cloudlet and remote cloud together collect a set of multi-dimensional emotional data as shown in Fig. 2.

3.2.1. Emotional data analysis

Any data analysis method needs to be evaluated in terms of accuracy. However, it is difficult to verify the results of sentiment analysis since emotion is affected by subjective factors and cannot be quantified. According to the source data types, emotion analysis can be divided into the following categories:

- **Physiology-based.** Physical characteristics, bio-electricity signal characteristics, and behavioral characteristics are three major factors that reflect the affective state of human beings. Currently, a large number of studies investigate various methods of extracting and processing physical characteristics (including voice, posture, pupil, respiration, heart rate, body temperature, body characterization, blood pressure etc.)
- **Video-based.** By integrating the theory of multiple disciplines such as image processing, computer vision, computer graphics, artificial intelligence, machine learning, human brain cognitive science, optic neurophysiology, and psychology, sentiment analysis became a mutli-disciplinary research. Video-based sentiment analysis mainly focuses on fusion of visual features and multi-information, mostly involving the image and video segmentation and cognition.
- **Text-based.** Text sentiment analysis, also known as opinion mining, is to analyze summarize, and reason the subjective text with emotional words. With the advent of a large number of subjective texts on the internet and social network, researchers have managed to gradually transit from analysis of simple words to the complex analysis of emotional sentences and chapters.

EMC analyzes emotional data using two approaches: (i) based on traditional affective computing, user emotion can be recognized from text, image, video, and other emotional data collected by mobile terminals and the local cloudlet, and (ii) based the big data technology, multi-dimensional emotional data obtained from social networks can be rapidly analyzed after dimension reduction. Emotional models can be established by feature extraction from a great volume of historical emotional data.

3.2.2. Resource cognition

All hardware resources available for emotional feedback should be cognized, once the user emotion has been recognized. Resource information is recorded in the remote cloud for quickly locating static resources. Since user activities may change at any time, available resources cognized around a user are organized dynamically and temporarily for emotional feedback.

3.2.3. Emotion-aware action feedback

Based on the comprehensive consideration of user emotion, location, and behavior, a command list for effective feedback is generated in the remote cloud, and transferred to the local cloudlet to establish a human-centric emotional feedback system, which provides users with personalized affective-aware services. Various devices are utilized in the home environment to comfort a user according to the result of emotion detection.

4. MCC-BASED EMOTIONAL DATA PROCESSING

A user's emotional trends are deducted in real-time through emotional data analysis. There are four steps of emotional data processing in the EMC architecture, as shown in Figure 1: data collection, data preprocessing, emotion recognition, and service push.

Data Collection can be defined as a systematic approach for gathering information from a variety of sources. Data have quality if the purpose of the intended use is met. There are many factors compromising data quality which includes accuracy, completeness, consistency, timeliness, believability and the interpretability of data. This is why data needs to be preprocessed. Major tasks included in data preprocessing can be elaborated as: data cleaning routines by filling in missing values, smoothing noisy data, identifying or removing outliers, and resolving inconsistencies. Data cleaning is usually performed as an iterative two-step process consisting of discrepancy detection and data transformation.

By data integration, data from multiple sources are combined to form a coherent data store. Smooth data integration is obtained by the resolution of semantic heterogeneity, metadata, correlation analysis, tuple duplication detection and data conflict resolution.

Typically, emotional data collection and preprocessing are accomplished in the local cloudlet, while emotion recognition and service push are performed in the remote cloud.

4.1. Local cloudlet

As opposed to the traditional MCC framework, the local cloudlet under the EMC framework includes the mobile devices as well as the local devices. To abstract the computing power of communications equipment for the resource pool, and to collect and preprocess data locally, the virtualization technology is also implemented. The local cloudlet mainly provides collaborative data collection and collaborative data preprocessing, which are major steps of data mining process.

4.1.1. Collaborative data collection

Affective computing requires a large collection of sensory data; while the user's mobile device resources are usually limited. In order to meet the data requirements of affective computing, a collaborative data sensing mechanism is designed that utilizes the equipment in the local cloudlet to collect a full range of user data through the following collaboration approaches:

Static collaboration: The approach uses static equipment in the local cloudlet (i.e. computer, camera, microphone, etc.) to collect the user's voice, pictures, video, and other data. Because the static equipment is more resourceful and powerful, a better data quality can be achieved. However,

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since the user may be highly mobile, while the static device cannot change its position as the user does, the performance of static cooperation depends heavily on the present geographic location of the user.

Dynamic collaboration: Around the mobile user, there may be plenty of other devices that can help to collect various data. This collaborative approach effectively compensates for the lack of static collaboration. With this approach, according to the user's location, a user-centric data collection field can be dynamically formed, which effectively ensures the continuity of data collection.

4.1.2. Collaborative data preprocessing

It is difficult to handle massive sensing data, depending only on the mobile device. Therefore, local static device collaboration needs to be used. In addition, with the development of mobile network technology, virtualization technology is being identified as an important component of 5G. Therefore, in order to enhance the ability of local data preprocessing, it can be abstracted computing units of the local network devices (switches, routers, base stations, etc.) to form a resource pool to provide a powerful computing capability. Collaborative data preprocessing in the local cloudlet offers the following functions.

Data cleaning. By cleaning up the collected data, it can be identified uncertainty, inaccuracy, incompleteness, or non-reasonability of data and then modify or delete it to improve the data quality. In the clean-up process, the format, integrity, reasonableness, and limitation of the data should be examined. Data cleaning is essential to maintain the consistency and accuracy of data analysis.

Eliminate redundancy. Data redundancy will increase the unnecessary data transmission overhead and bring the defect to the storage system, leading to waste of storage space, resulting in data inconsistencies, reduction of data reliability, and causing data corruption. Redundancy detection, data filtering, and other means are needed to reduce the redundancy of collected data. In particular, there is a need to use image and video data compression methods to effectively reduce the volume of multimedia data.

Data integration. The accuracy of sentiment analysis and prediction depends on the diversity of the collected data. Due to the particularity of mobile data, a data integration method that treats the user as a unit and the space-time labels as the primary key is proposed. Unstructured data such as text, image, and video in social networks need a large storage space, while not all information contains valid emotional data; On the other hand, a large amount of various data are generated, including heart rate, blood pressure, body temperature, and other physiological data collected by wearable devices. Therefore, different data preprocessing methods are required for different types of data to clean invalid data, reduce redundancy, extract features, and compress size. In Figure. 3, the data structure for data integration is illustrated as an example and in Figure. 4. it is illustrated of how the different data obtained can be integrated.

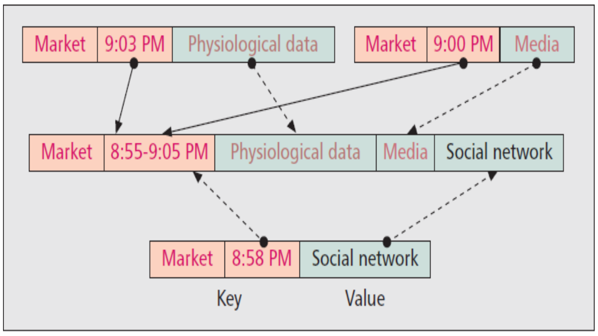

Figure 3. Example of a data structure for data integration [10]

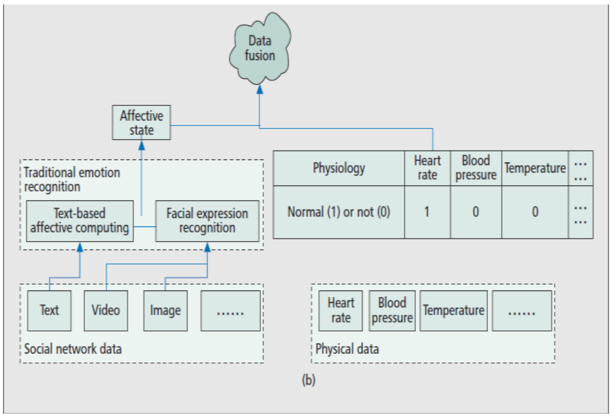

Figure 4. Various emotional data fusion [9]

4.2. Remote cloud

The remote cloud can provide a wealth of resources to support affective computing, and more importantly, it provides more data sources.

4.2.1. Emotion analyzer.

EMC infers emotion based on affective computing, which is a complex process requiring a paradigm shift in user modeling, for example, mode of operation, expression characteristics, attitudes, preferences, cognitive styles, background knowledge, and so on. The performance of affective computing largely depends on the quality of collected data, which could be very large in volume and variety. The more the type and larger the scale of emotional data, the higher the accuracy of emotional analysis results. Hence, in order to provide accurate and timely emotion-aware services, affective computing is resource-intensive based on the analysis of emotional big data in the forms of text, video, social data, facial features, and physiological signals, among others.

Using advanced affective computing algorithms, we can extract emotional features from the collected data, and rely on the emotional decision support model libraries to identify the user's current emotional state. Once the analysis is completed, the results will be sent to the

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emotion pusher. In addition, the current analysis results and extracted emotional characteristics will be transferred to the emotion model library for storage.

4.2.2. Models library

This module provides three main functions: decision support, based on emotional features extracted by the emotion analyzer to match the best result from the model library, and to provide the decision identified as emotion recognition; model update, based on the result of the emotion analyzer to update the existing models in the emotion library; and model enhancement, using other networks' emotional information to verify the emotional state of the analysis in the same environment, and enhancing existing models.

5. ELASTIC EMOTION-AWARE COMPUTING BY JOINT CLOUD, COMMUNICATIONS, AND DEVICE RESOURCE OPTIMIZATION.

The trade-off between communication and computation is a great challenge in EMC. Even if 5G is still undefined, some key features can be identified as:

- Ultra dense cell deployment: The deployment of small-cell networks is already part of 4G evolution, but network "densification" is going to play an important role in 5G systems.
- Millimeter-wave links: The usage of wideband links, with very high capacity and directivity, provides an effective way for the radio access points to forward the users' offloading requests to the cloud with reduced latency. Millimeter-wave frequencies don't pass through solid objects very well, and it's difficult to sustain them over long distances, which is why they haven't been used in previous mobile networks. As a result, any 5G networks that adopt this approach will likely use lots of little base stations rather than relatively few large masts.
- Massive multiple-input, multiple-output (MIMO): MIMO transceivers improve spectral efficiency, thus reducing the time necessary to transfer the program execution from the mobile site to the cloud.
- QoE versus QoS: A design driven by a user's QoE implies a system approach that does not consider radio or networking aspects separated from the application requirement.
- 5G technology may consume low battery power, provide a wide range of coverage, cheap rate of network services and many other advantages.

The frequency range lies between 3 to 300MHz, which is much higher than current network standards. The main advantage of using this frequency range is that it's scarcely used by other broadcast technologies. The result is the potential for greater speeds, as well as the capacity for more data to be drawn through it.

Figure 5 illustrates the EMC partitioning design to enhance QoE via resource optimization for meeting the demand of task components, that is, emotional data collection, emotional data analysis, resource cognition, and emotion-aware action feedback. Figure 5a is a case where more 5G supports and smaller terminal workload are needed, while Figure.5b is a case with less 5G support and larger terminal workload. With sufficient 5G support, as shown in Figure 5a, the remote cloud can provide more accurate resource cognition and more rapid action feedback (A2,…, An). Mobile devices and the local cloudlet just provide inevitable data collection (D1, D4) and action feedback (A1). As shown in Figure. 5b, if 5G support is expensive or limited, the remote cloud will only execute the compute-intensive tasks, that is, emotional big data analysis and emotion detection. Meanwhile, the local cloudlet and mobile devices will be assigned with more tasks. Not only will all the action feedback tasks be executed by the local cloudlet and mobile devices, but also resource cognition will be supported by the local cloudlet.

5.1 More 5G Support and Smaller Terminal Workload

In this scenario, EMC offloads the major tasks to the remote cloud, while only the essential tasks are processed in the mobile terminal and local cloudlet.

5.1.1. Emotional data collection

With bandwidth-intensive delivery supported by 5G, it is more effective to collect and transmit a large variety and volume of emotional data, especially for multimedia data with big volumes.

5.1.2. Emotional data analysis

Not only emotion detection based but also affective feedback solutions are provided in the remote cloud to support a rapid emotion-aware action.

5.1.3. Resource cognition

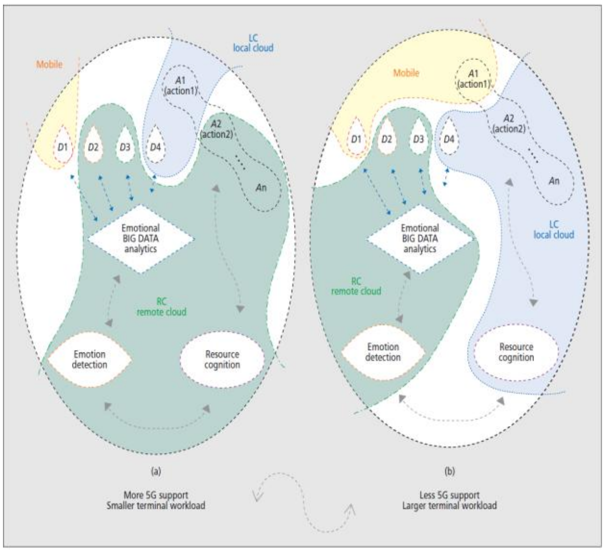

Figure 5 Trade-off in the design of EMC partitioning [10]

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Based on the static resource record with location tag stored in the remote cloud, available devices and media can be quickly identified around a user location to establish an affective feedback solution.

5.1.4. Emotion-aware action feedback

According to the affective feedback solution and resource cognition, the remote cloud controls various resources to provide comprehensive emotion aware actions, while the local cloudlet provides some basic actions.

Obviously, this scenario improves QoE with more effective data collection, more accurate data analysis, more timely resource cognition, and richer feedback. However, requiring more 5G support causes higher communications cost. For example, with more 5G support and smaller terminal workload, a robotic and cloud-assisted healthcare system can be implemented for empty nester and other users in-home.

5.2. Less 5G Support and Larger Terminal Workload

In this scenario, the major tasks are processed in the mobile terminal and local cloudlet, while only the resource-intensive tasks are offloaded to the remote cloud.

5.2.1. Emotional data collection

Only the physiological data are collected by the mobile terminal and transmitted to the remote cloud for emotional analysis. Unless necessary, the emotional multimedia data collection task should not be performed in the local cloudlet.

5.2.2. Emotional data analysis

Because the emotional data has relatively low dimensions, it is easier to analyze. Emotion detection can be quickly sent to the local cloudlet.

5.2.3. Resource cognition

According to the emotion detection received, in the local cloudlet, a temporary user-centric feedback system can be organized after resource cognition.

5.2.4. Emotion-aware action feedback

Resources provided by the mobile terminal and the local cloudlet collaboratively serve the users to support emotion-aware feedback.

Compared with the former scenario, although the provided QoE level may be relatively lower, this scenario is weakly dependent on 5G, thus ensuring that EMC provides the basic functions even in a poor wireless network environment. For example, with less 5G support and larger terminal workload, rich media healthcare applications, such as medical emergency handling, telehealth education, and help-on-demand healthcare video delivery, are available to provide professional and rapid service.

6. APPLICATIONS

As examples, EMC can serve various scenarios as follows.

- For elderly people, EMC can collect their physical conditions, as well as perceive their mental status, which alleviates their loneliness and other negative emotions.
- For those working in a closed environment over a long period, such as deep-sea or space exploration, EMC can be utilized to perceive their emotions and help adjust their physical and mental state to ensure successful completion of their missions.
- For people suffering from social autism, EMC can sense their abnormal mental state and help them escape from the shadows of social phobia.
- For patients leaving the hospital who bear dual physical and psychological pressures, EMC can customize an individual rehabilitation strategy and guide them to recover more quickly and efficiently, according to their physical and emotional status.
- EMC can also be employed in emergency management. Emotion detection capabilities can leverage the capabilities of the existing emergency management systems

7. CONCLUSION

The recent advances in 5G enable higher network capacity and more powerful access capability. More important, 5G provides an enhanced technology to enable a new class of rich user-centric mobile applications and services. It is proposed to integrate resource-intensive affective computing with mobile applications, while leveraging mobile cloud computing to enhance the capability of mobile devices. The goal was to provide personalized, human-centric, intelligent emotion-aware services. Users' QoE can be maximized by optimizing resource allocation among the mobile terminal, local cloudlet, and remote cloud, under dynamic network environments.

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BIOGRAPHY

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