

EMC: Emotion-Aware Mobile Cloud Computing in 5G

Min Chen, Yin Zhang, Yong Li, Shiwen Mao, and Victor C. M. Leung

Abstract

With the development of 5G, the wireless world will be interconnected without barriers. This new technology will enable many challenging applications, and more personalized and interactive services are expected to be available with resource-limited mobile terminals. Fortunately, mobile cloud computing (MCC) emerging in the context of 5G has the potential to overcome this bottleneck, which enables many resource-intensive services for mobile users with the support of mobile big data delivery and cloud-assisted computing. In this article we propose a novel framework named EMC in the context of 5G, which offers personalized emotion-aware services by MCC and affective computing. With the proposed framework, the traditional MCC architecture is modified to achieve the required Quality of Experience in emotion-aware applications. Furthermore, we design a partitioning solution corresponding to the fundamental trade-off between the communication and computation in EMC. The framework would be helpful to provide personalized, human-centric, intelligent emotion-aware services in 5G.

Advances in wearable computing, social networking, and the Internet of Things (IoT) are transforming traditional network applications to be more human-centric. Especially with the recent developments in mobile cloud computing (MCC) and mobile communications, the user's experience can be greatly enhanced by the notion of "carrying small while enjoying large" [1].

As the mobile communications industry traveled a long way from 2G to 4G, now 5G aims to change the world by connecting anything to anything. Different from its previous versions, the research of 5G is focusing on new spectrum bands [2], wireless transmissions [3], cellular networking, etc., for an increase in capacity. It will be an intelligent technology to interconnect the wireless world without barriers. Along with MCC technology, 5G networks are paving the way for the computing-intensive applications involving multi-dimensional massive data processing assisted by the cloud [4].

The system characteristics of 5G include high data rate, low

latency, and high capacity to support various challenging applications. Despite the powerful access capabilities offered by 5G mobile networks, the following issues still need to be addressed to satisfy mobile users' requirements of quality of experience (QoE).

Insufficient Emotion-Oriented Care — Although the development of sensors and wearable devices has spawned a plethora of mobile, pervasive, and intelligent applications as well as new service models, users' psychological status is challenging to deal with to meet the increasing demands of emotional care. Most existing emotion-aware applications sense emotion by the relationship between the user's emotion and behavioral patterns of the mobile phone usage [5]. However, the inference accuracy of emotion recognition is either limited by the small scale data collected by smartphones, or dependent on labor-intensive manual labeling processes, which limit the provisioning of sufficient emotion-oriented care. Thus, the major purpose of such applications is for smartphone-based entertainment [6]. By comparison, this article also considers "serious" emotion care for improving people's health status, especially for those suffering from abnormal mental states.

Resource-Limited Feedback — Nowadays, the usage patterns of mobile phones such as call logs and SMS logs, as well as environmental data collection assisted by the smartphone's built-in sensors, have been utilized to develop personalized applications and services based on human emotion [5]. However, the feedback of such emotion-aware applications simply relies on the smartphone itself, which limits the provisioning of a higher quality of QoE.

Manual Intervention — Being influenced by the traditional service model, most mobile applications passively respond to user input, such as text, touch, voice, image, and so on. Yet applications cannot be aware of a user's "voiceless" require-

Min Chen is with Huazhong University of Science and Technology.

Yin Zhang is with Zhongnan University of Economics and Law

Yong Li is with Tsinghua University.

Shiwen Mao is with Auburn University.

Victor C. M. Leung is with The University of British Columbia.

This work was supported by the Canadian Natural Sciences and Engineering Research Council under grants RGPIN-2014-06119 and RGPAS-462031-2014. This work was also supported in part by the China National Natural Science Foundation under Grant 61300224, the International Science and Technology Collaboration Program (2014DFT10070) funded by the China Ministry of Science and Technology (MOST), the Hubei Provincial Key Project under grant 2013CFA051, the Program for New Century Excellent Talents in University (NCET), and the U.S. NSF under Grant CNS-0953513.

ments when they are not available or when it is not convenient for the user to send his/her requests.

Emotion-aware applications have great potential to bring QoE provisioning to a new level and change the lifestyle of many people, which, however, also demands more advanced technologies to yield effective solutions. Fortunately, with MCC technology, computationally intensive tasks can be offloaded to the cloud instead of only by mobile devices [7]. Through the extensive use of cloud computing and cloud-assisted resources, mobile devices can break the shackles of their limited resources, the models of mobile applications can be improved to enhance user experience, and a user-centric paradigm can be developed, which is also the core objective of 5G [8].

An important aspect of QoE provisioning is to offer personalized mobile service based on the user's emotional variations. This article proposes a novel style of applications enabled by emotion-aware mobile cloud computing (EMC) in 5G. EMC is design to provide emotion-aware mobile services by recognizing users' emotional changes through cloud computing and big data analysis. 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 types and larger 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.

Recently, most existing healthcare systems only provide care for the user's physiological status while EMC also takes into account the user's mental status. The existing healthcare systems exhibit the following features:

- Wearable and mobile devices are used to collect the user's physiological information.
- They only collect the user's physical status, but are not aware of the user's stress levels, unhealthy emotion, and even mental illness conditions.
- The existing mode based on wearable devices for collecting physiological information will give a negative psychological implication that the user is in poor health.

In particular, for users in a mood of loneliness and depression, such a "conscious" way to collect and present their physiological information may lead to even more serious mental illness.

In contrast, with emotion care, the above problems can be alleviated. 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

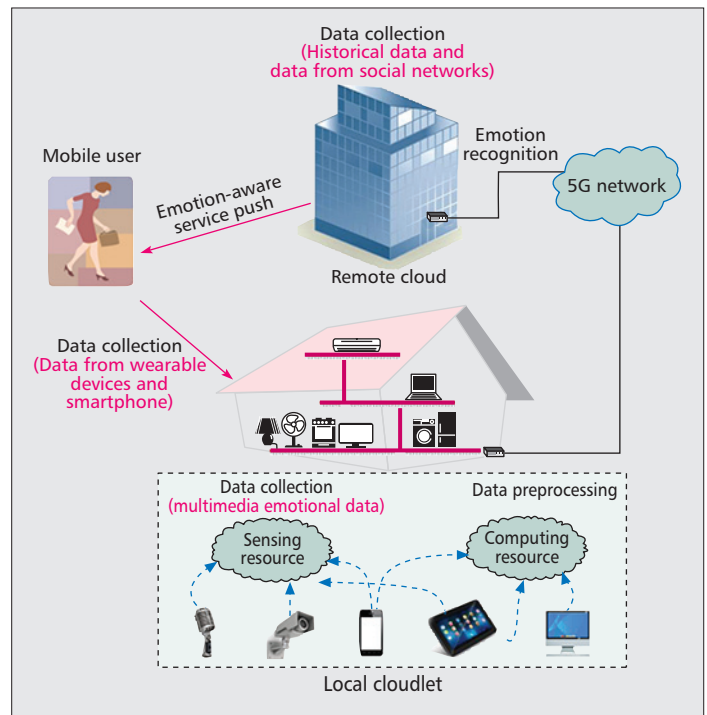


Figure 1. The proposed EMC architecture.

quickly and efficiently, according to their physical and emotional status.

To solve the challenging issues that arise in the EMC architecture, we investigate a comprehensive emotion-aware system with the support of the latest technology advances, such as mobile cloud computing and 5G. The main contributions of this work include:

- Enabling computation-intensive affective computing in mobile applications by MCC and big data analysis.
- Providing users with resource cognition-based emotion-aware feedback by utilizing the abundant cloud resources and the broadband bandwidth supported by 5G.
- Identifying a novel EMC partitioning design trade-off to guarantee users' QoE while achieving optimized resource allocation under dynamic mobile network environments.

The remainder of this article is organized as follows. We first present the EMC architecture and then present a collaborative local cloudlet architecture for data collection and preprocessing, as well as a proposed remote cloud for emotion recognition and service push. Next we introduce elastic emotion-aware computing by joint cloud, communications, and device resource optimization. Then we conclude the article.

Architecture

The proposed EMC architecture is shown in Fig. 1, which includes three main components: a mobile terminal, a local cloudlet, and a remote cloud.

EMC Infrastructure Functional Components

In EMC, infrastructure functional components, which consist of mobile terminals, a local cloudlet, and a remote cloud, provide hardware support for data collection and affective feedback.

Mobile terminal: Affective computing based on physiological signals typically utilizes learning classification algorithms to analyze users' physical status, such as electromyography (EMG), electrocardiogram (ECG), electroencephalogram (EEG), and so on [9]. With integrated sensors and installed plug-ins, mobile terminals collect the physiological emotional

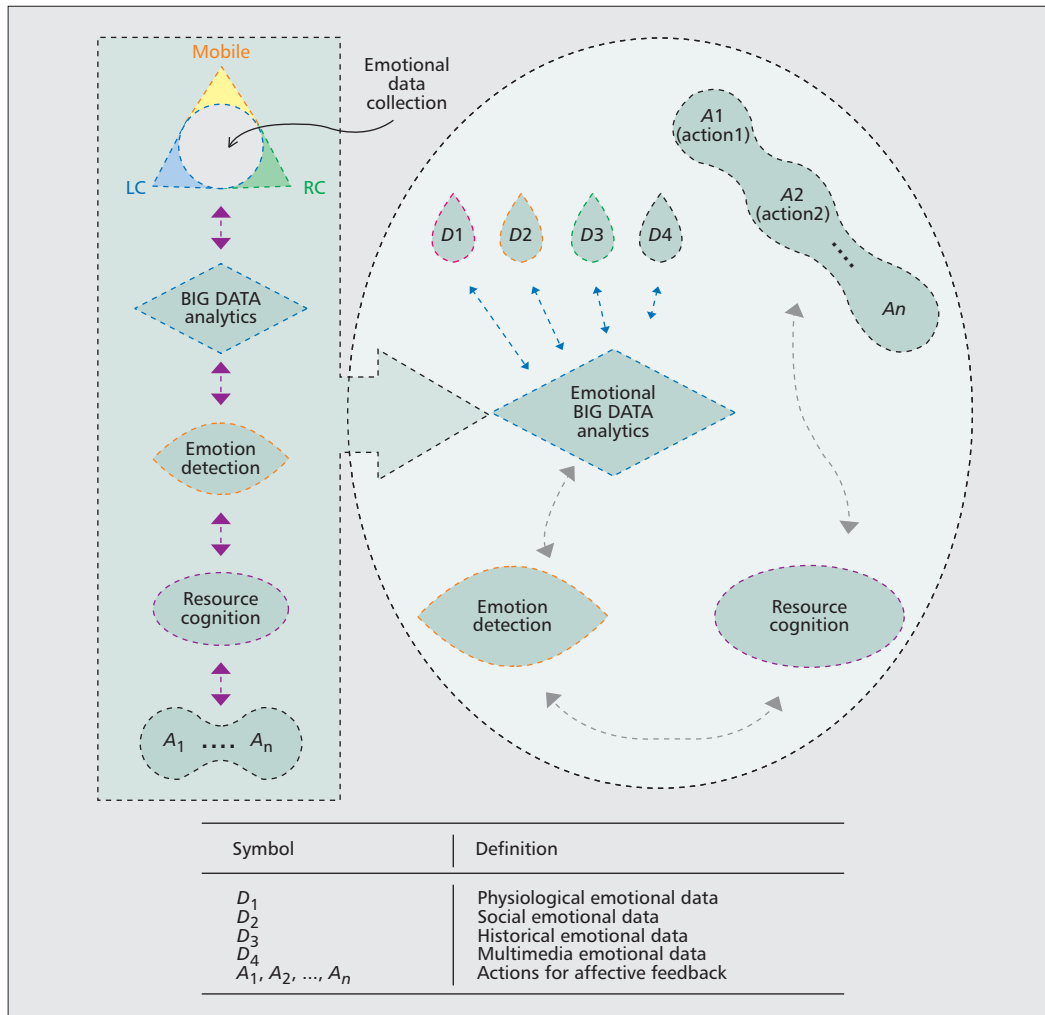


Figure 2. Illustration of the EMC Task components.

data. Furthermore, some basic emotional feedback is supported by the output of the mobile terminal.

Local cloudlet: Through various short range radio communication technologies, nearby static and mobile devices (e.g. PCs, mobile devices, home appliances, and robots) can be interconnected to form a local cloudlet, which has three functions in EMC. First, it provides more emotional data, especially multimedia emotional data. Second, due to the complex mobile environment, the collected data will be noisy and redundant. The local cloudlet can preprocess such data, in order to improve the data quality and reduce data size. Third, the various devices in the local cloudlet can be used for affective feedback.

Remote cloud: Typically, the remote cloud is implemented in a data center. In order to improve QoS/QoE, the analysis of emotional big data is performed in the remote cloud to achieve high accuracy of emotion detection and timely affective interaction. In addition, complex emotion inference is carried out in an inference engine installed in the remote cloud. For each user, a personal classifier can be built up based on historical data associated with the user's emotion labels. Then, the personal classifier will be strengthened by retrieving more updated data from both the mobile terminal and local cloudlet.

EMC Task Components

EMC applies the concept of "divide and conquer" such that an emotion-aware service is divided into multiple task components. As shown in Fig. 2, EMC includes several functional modules that correspond to various categories of task components.

Emotional data collection: Through mobile terminals, various emotional data can be sensed, such as voice, facial expressions, gestures, body movements, etc. Even physiological signals can be sensed via healthcare and other plug-ins. In the local cloudlet, EMC is able to retrieve multimedia emotional data with additional equipment such as a device with facial feature recognition software and a video camera. Based on the rich computational resources in the remote cloud, it is also possible to extract emotional information from social networks and collect historical emotional data. Figure 2 shows the multi-dimensional emotional data collected by the mobile terminal, local cloudlet, and remote cloud.

Emotional data analysis: EMC analyzes emotional data through two approaches:

- 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.

- Based on the big data technology, multidimensional emotional data obtained from social networks can be rapidly analyzed after dimension reduction, and emotional models can be established via feature extraction from a great volume of historical emotional data.

Resource cognition: Once user emotion has been recognized, all hardware resources available for emotional feedback should be cognised. On one hand, resource information is recorded in the remote cloud for quickly locating static resources. On the other hand, since user activities may change at any time, available resources cognised around a user are

organized dynamically and temporarily for emotional feedback.

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 transmitted to the local cloudlet to establish a human-centric emotional feedback system, which provides users with personalized affective-aware services. As shown in Fig. 3, various devices are utilized in the home environment to comfort a user according to the result of emotion detection.

MCC-Based Emotional Data Processing

There are four steps of emotional data processing in the EMC architecture, as shown in Fig. 1: data collection, data preprocessing, emotion recognition, and service push. Typically, emotional data collection and preprocessing are accomplished in the local cloudlet, while emotion recognition and service push are performed in the remote cloud.

Local Cloudlet

Different from the traditional MCC framework, the local cloudlet under the EMC framework includes the mobile devices as well as the local devices. The virtualization technology is also implemented to abstract the computing power of communications equipment for the resource pool, collect and preprocess data locally. The local cloudlet mainly provides collaborative data collection and collaborative data preprocessing.

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, we design a collaborative data sensing mechanism 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, 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 current 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. For example, as shown in Fig. 3, the combination of home appliances used for dynamic data collection changes while the user moves from one room to another room. However, in this way, there will be a large number of redundant and invalid data, which reduces the quality of the data collected.

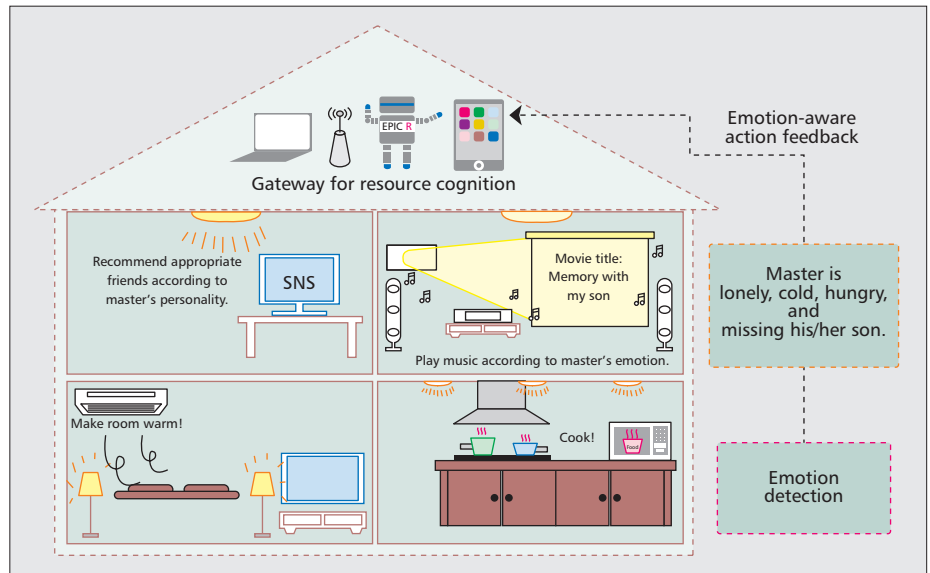


Figure 3. Emotional feedback actions supported by the local cloudlet formed by typical devices in home environment.

In summary, through the comprehensive utilization of dynamic and static collaborative data collection, we can ensure the effectiveness and persistence of data perceived at any time and any place.

Collaborative Data Preprocessing — Depending only on the mobile device, it is difficult to effectively handle massive sensing data. Therefore, we need to use a local static device collaboration. In addition, with the development of mobile network technology, virtualization technology is being recognized as an important component of 5G. Therefore, in order to improve the ability of local data preprocessing, we can abstract computing units of the local network devices (such as switches, routers, base stations) 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, we can identify uncertain, inaccurate, incomplete, or unreasonable 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. We can integrate the emotional data to guarantee data atomicity and reduce the overhead of data transmission. Due to the particularity of mobile data, we propose a data integration method that treats the user as a unit and the space-time labels as the primary key. In Fig. 4, the data structure for data integration is illustrated as an example.

Remote Cloud

The remote cloud can provide a wealth of resources to support affective computing, and more importantly, it provides more data sources. For example, we use the information that

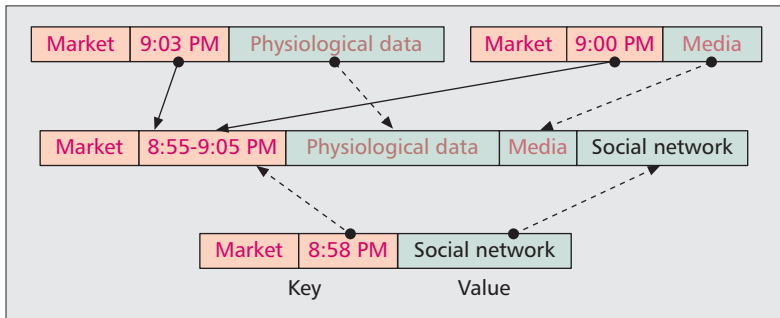


Figure 4. Illustrative example of a data structure for data integration.

the user published in social networks to extract its emotional information, and combine it with the collected mobile environment information for enhanced analysis. This way, we can improve the accuracy of emotion recognition, and also improve the accuracy of the emotion model. As shown in Fig. 5, the remote cloud consists of the following three modules.

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

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.

Results publisher: According to the recognized results of the emotion analyzer, the emotional state will be pushed to mobile application providers to provide a scientific basis for their emotional perception services.

Elastic Emotion-Aware Computing by Joint Cloud, Communications, and Device Resource Optimization

Similar to the traditional MCC, the trade-off between communication and computation is a great challenge in EMC. Figure 6 illustrates the EMC partitioning design to improve

QoE via resources optimization for meeting the demand of task components, that is, emotional data collection, emotional data analysis, resource cognition, and emotion-aware action feedback. Figure 6a is a case where more 5G support and smaller terminal workload are needed, while Fig. 6b is a case with less 5G support and larger terminal workload.

Specifically, as shown in Fig. 6a, with sufficient 5G support, the remote cloud can provide more accurate resource cognition and more rapid action feedback (A_2, \dots, A_n) while mobile devices and the local cloudlet just provide inevitable data collection (D_1, D_4) and action feedback (A_1). As shown in Fig. 6b, 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 all the action feedback tasks will be executed by the local cloudlet and mobile devices, but also resource cognition will be supported by the local cloudlet.

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.

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.

Emotional data analysis: Not only emotion detection based but also affective feedback solution are provided in the remote cloud to support a rapid emotion-aware action.

Resource cognition: 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.

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

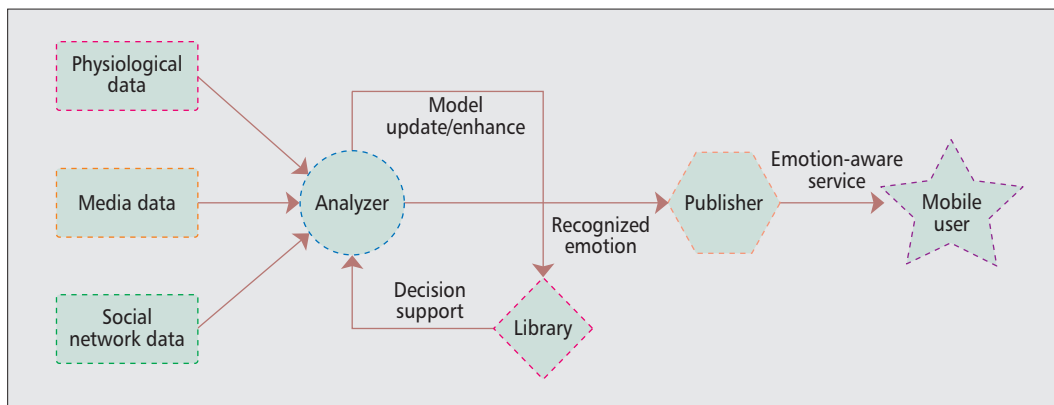


Figure 5. Composition of the remote cloud.

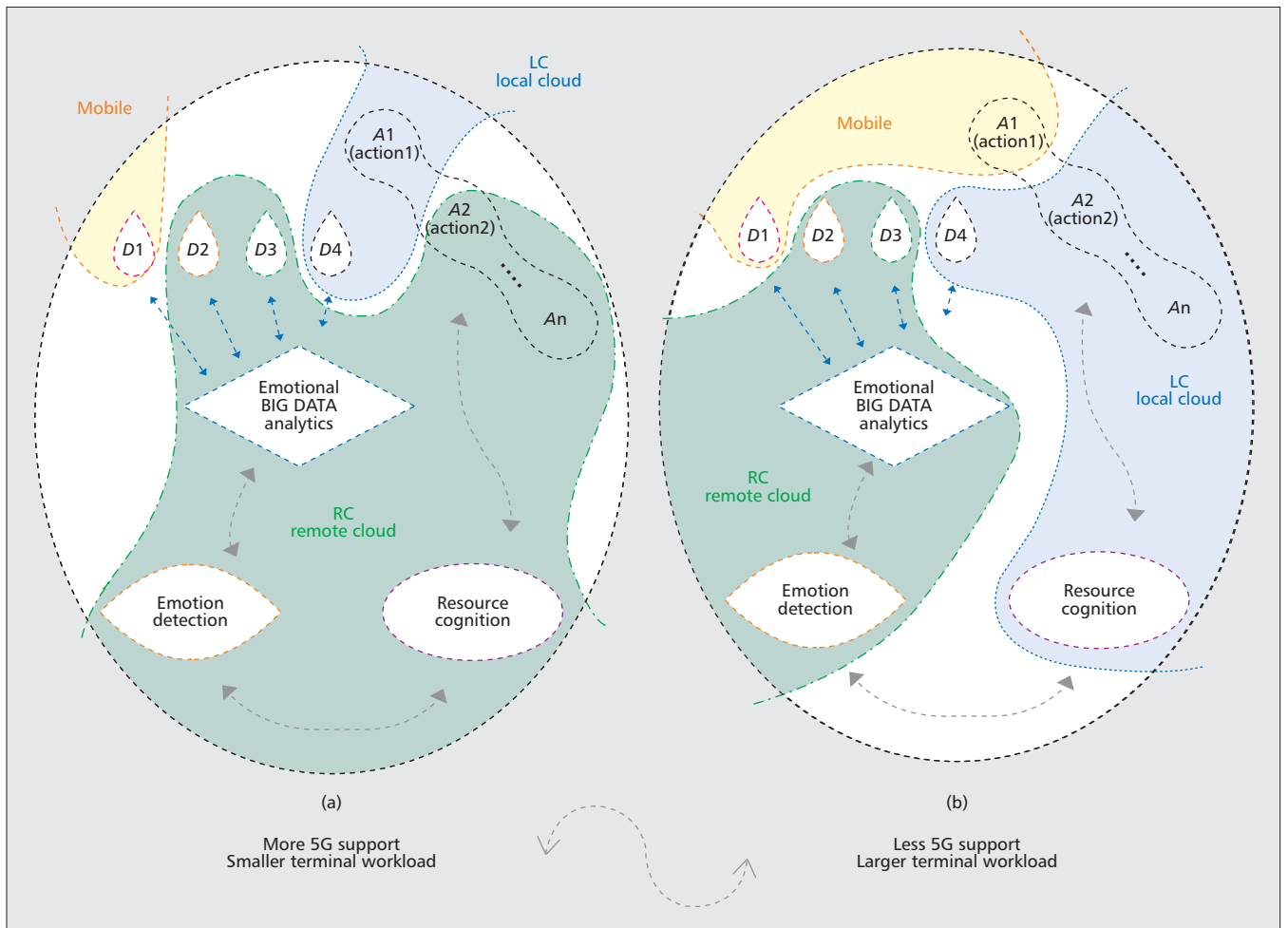


Figure 6. The illustration of the trade-off in the design of EMC partitioning.

system can be implemented for empty nester and other users in-home [10].

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.

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.

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.

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

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.

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. In this article we 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. We identified an interesting research topic of maximizing users' QoE while optimizing resource allocation among the mobile terminal, local cloudlet, and remote cloud, under dynamic network environments. However, the current design does not consider the privacy and security issues of user data in the multi-dimensional emotional data collection process. In addition, it would also be interesting to consider whether the existing mobile application architecture can meet the requirements of EMC service model. These are interesting problems to be investigated in our future work.

References

- [1] Y. Li *et al.*, "Optimal Mobile Content Downloading in Device-to-Device Communication Underlying Cellular Networks," *IEEE Trans. Wireless Commun.*, vol. 13, no. 7, July 2014, pp. 3569–3608.
- [2] T. Yilmaz, E. Fadel, and O.B. Akan, "Employing 60 GHz ISM Band for 5G Wireless Communications," *Proc. 2014 IEEE Int'l Black Sea Conf. Commun. Networking (BlackSeaCom)*, Odessa, Ukraine, May 2014, pp.77–82.
- [3] I. Son *et al.*, "Frame-Based Medium Access Control for 5G Wireless Networks," *Springer Mobile Networks and Applications*, 2015.
- [4] Y. Xu and S. Mao, "A Survey of Mobile Cloud Computing for Rich Media

- Applications," *IEEE Wireless Commun.*, vol. 20, no. 3, June 2013, pp. 46–53.
- [5] R. LiKamWa *et al.*, "Moodscope: Building a Mood Sensor from Smartphone Usage Patterns," *Proc. AMC MobiSys'13*, Taipei, Taiwan, June 2013, pp. 389–402.
- [6] J. Hernandez *et al.*, "Mood Meter: Counting Smiles in the Wild," *Proc. ACM 2012 Int'l Conf. Ubiquitous Computing (UbiComp)*, Pittsburgh, PA, Sept. 2012, pp. 301–10.
- [7] W. Cai, M. Chen, and V. C. M. Leung, "Towards Gaming as a Service," *IEEE Internet Computing*, vol. 18, no. 3, May/June 2014, pp. 12–18.
- [8] A. Osseiran, *et al.*, "Scenarios for 5G Mobile and Wireless Communications: The Vision of the METIS Project," *IEEE Commun. Mag.*, vol. 52, no. 5, May 2014, pp. 26–35.
- [9] E. Jang *et al.*, "Classification of Human Emotions from Physiological Signals Using Machine Learning Algorithms," *Proc. Sixth Int'l Conf. Advances Computer-Human Interactions (ACHI 2013)*, Nice, France, Feb./Mar. 2013, pp. 395–400.
- [10] M. Chen *et al.*, "AIWAC: Affective Interaction through Wearable Computing and Cloud Technology," *IEEE Wireless Commun.*, Feb. 2015.

Biographies

MIN CHEN [M'08, SM'09] (minchen@ieee.org) is a professor at the School of Computer Science and Technology at Huazhong University of Science and Technology (HUST). He is the director of the Embedded and Pervasive Computing (EPIC) lab. He was an assistant professor at the School of Computer Science and Engineering at Seoul National University (SNU) from Sep. 2009 to Feb. 2012. He worked as a post-doctoral fellow in the Department of Electrical and Computer Engineering at the University of British Columbia (UBC) for three years. Before joining UBC he was a post-doctoral fellow at SNU for one and half years. He has more than 180 paper publications. He received the Best Paper Award from IEEE ICC 2012, and the Best Paper Runner-Up Award from QShine 2008.

YIN ZHANG [M'13] (yin.zhang.cn@ieee.org) is a faculty member of the School of Information and Safety Engineering, Zhongnan University of Economics and Law. He was a post-doctoral fellow at the School of Computer Science and Technology at Huazhong University of Science and Technology (HUST). He is a handling guest editor for *New Review of Hypermedia and Multimedia*. He serves as a reviewer for *IEEE Network*, and *Information Sciences*. He is TPC Co-Chair for the 5th International Conference on Cloud Computing (CloudComp 2014). He is the local chair for the 9th International Conference on

Testbeds and Research Infrastructures for the Development of Networks & Communities (TRIDENTCOM 2014), and CloudComp 2013.

YONG LI [M'09] (liyong07@tsinghua.edu.cn) received the B.S. degree in electronics and information engineering from Huazhong University of Science and Technology, Wuhan, China, in 2007, and the Ph.D. degree in electronic engineering from Tsinghua University, Beijing, China, in 2012. From July 2012 to August 2013 he was a visiting research associate with Telekom Innovation Laboratories and The Hong Kong University of Science and Technology, respectively. From December 2013 to March 2014, he was a visiting scientist with the University of Miami. He is currently a faculty member in the Department of Electronic Engineering, Tsinghua University. His research interests are in the areas of networking and communications.

SHIWEN MAO [S'99, M'04, SM'09] (smao@ieee.org) is the McWane Associate Professor in the Department of Electrical and Computer Engineering, Auburn University, Auburn, AL, USA. His research interests include wireless networks and multimedia communications. He is a distinguished lecturer of the IEEE Vehicular Technology Society (VTS) in the Class of 2014, and the Vice Chair—Letters and Member Communications of the IEEE Communications Society Multimedia Communications Technical Committee. He received the 2013 IEEE ComSoc MMTC Outstanding Leadership Award and the NSF CAREER Award in 2010. He is a co-recipient of the IEEE ICC 2013 Best Paper Award and the 2004 IEEE Communications Society Leonard G. Abraham Prize in the Field of Communications Systems.

VICTOR C. M. LEUNG [S'75, M'89, SM'97, F'03] is a professor of electrical and computer engineering and holder of the TELUS Mobility Research Chair at the University of British Columbia (UBC). His research is in the areas of wireless networks and mobile systems. He has co-authored more than 800 technical papers in book chapters, archival journals, and refereed conference proceedings, several of which have won best-paper awards. He is a Fellow of IEEE, the Royal Society of Canada, the Canadian Academy of Engineering, and the Engineering Institute of Canada. He is serving/has served on the editorial boards of *IEEE JSAC*, *Transactions on Computers*, *Transactions on Wireless Communications*, *Transactions on Vehicular Technology*, *Wireless Communications Letters*, and several other journals. He has provided leadership to the technical program committees and organizing committees of numerous international conferences. He was the recipient of the 1977 APEBC Gold Medal, NSERC Postgraduate Scholarships from 1977-1981, a 2012 UBC Killam Research Prize, and an IEEE Vancouver Section Centennial Award.