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An Overview of Mobile Cloud Computing for Pervasive Healthcare

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ABSTRACT Mobile devices, along with wearable sensors, allow patients to access healthcare services from anywhere at any time. The longstanding constraints of computational capability and storage space on mobile devices can be alleviated by outsourcing computation- or data-intensive tasks to remote cloud centers. Thus, mobile cloud computing (MCC) has been recognized as a promising approach to provide pervasive healthcare services to people in their daily life. As the development and adoption of MCC techniques in healthcare, new optimization strategies have been explored and studied to help mobile cloud healthcare services to be deployed in a more effective and efficient manner. In this survey, we demonstrate how MCC techniques have been extensively deployed in various healthcare applications and, specifically, describe the general architecture and design considerations one should take into account while designing an MCC for healthcare scenarios. Given a large number of factors that may affect the performance of the MCC and even result in catastrophic consequences in healthcare, this paper presents the state-of-the-art optimization methods on the MCC for meeting the diverse priorities and achieving the optimal tradeoff among multiple objectives. Finally, the security and privacy issues of the MCC in healthcare are also discussed.

INDEX TERMS Mobile cloud computing, pervasive healthcare. optimization, offloading, security and privacy.

NOMENCLATURE

CC	Cloud Computing
EC	Edge Computing
EHR	Electronic Health Record
EMR	Electronic Medical Record
FC	Fog Computing
HIPAA	Health Insurance Portability and Accountability Act
HMM	Hidden Markov Model
IoT	Internet of Things
MCC	Mobile Cloud Computing
MEC	Mobile Edge Computing
MHR	Mobile Health Record
PHR	Personal Health Record
SaaS	Security as a Service
WBAN	Wireless Body Area Network
WSN	Wireless Sensor Network

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I. INTRODUCTION

Mobile cloud computing (MCC) has been widely recognized as a promising approach for next-generation pervasive healthcare solutions [37], [107], [139]. As shown in Figure 1, there are various kinds of applications utilizing MCC to provide healthcare services. Based on MCC infrastructure, physiological signals and vital signs collected from wireless body area networks (WBAN) could be transmitted to either the public cloud or the private cloud through smartphones or personal computers. MCC generates the healthcare data analysis results, depending on the urgency of the patient's condition, which could either trigger the alarm to physicians or be stored in the medical database for future access. Particularly, MCC is an ideal platform that enables users to share, transmit, and process Electronic Health Record (EHR) [86], [88] and personal medical images [126], [159]. In recent years, MCC-based healthcare systems have been widely deployed for telemonitoring and physiological data analysis [1], [44]. In addition, mobile cloud healthcare has been greatly leveraged in multi-agent medical consultations [53], [64].

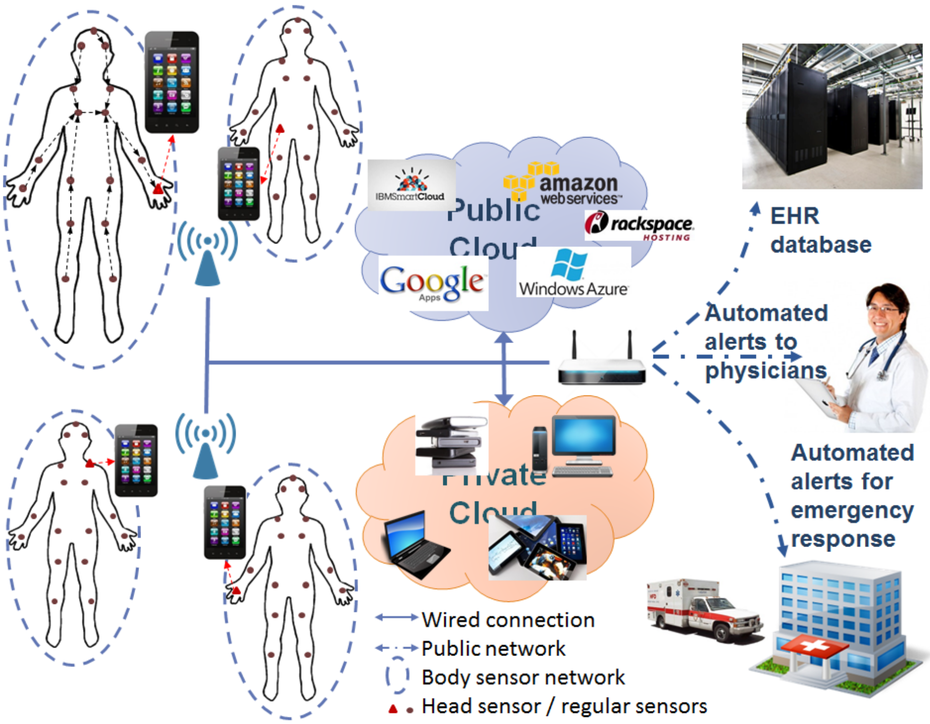

FIGURE 1. Mobile cloud computing for healthcare.

Accordingly, a variety of MCC architectures have been proposed for diverse healthcare demands [9], [17], [54]. Roughly speaking, the mobile cloud services for healthcare could be grouped into two categories, mobile cloud computing [30], [49] and mobile cloud storage for healthcare [39], [87].

On one hand, offloading the execution of computationally intensive tasks from mobile to cloud can alleviate the mobile devices from performing complicated, energy-consuming jobs and thus extend the limited battery life of mobile devices, which has been a major concern in the mobile computing era. On the other hand, the uncertainties in the communication networks not only introduce unpredictable delays, but also make the wireless communication module of mobile devices consume energy much faster than usual. Many researchers have provided comprehensive analysis towards the mobile cloud offloading cost from the energy perspective, especially when the network condition deteriorates significantly. For example, researchers have analyzed the effects of various network situations on the application migration process to the cloud comprehensively [6]. It concluded that the network related information should definitely be incorporated in the decision-making process of the application migration. At the same time, researchers have also discussed the intelligent task scheduling policy establishment for multi-objective optimized mobile cloud offloading [75], [80]. More and more mobile cloud based healthcare applications also strive for their multi-objective optimization solutions accordingly [90], [100]. As mobile cloud based healthcare involves the collection, transmission, analysis, and storage of a large volume of data, the potential risks of privacy leakage and security attacks become severe concerns to both researchers and service providers. A lot of efforts have also been reported to address the privacy and security issues in healthcare services [111], [113], [150].

However, there are still many open questions yet to be solved to enable the pervasive healthcare leveraging the MCC technology. In this survey, we aim to provide a comprehensive view on the advances and state of the arts of pervasive healthcare service technologies. It is expected that this survey will help inspire more creative ideas and bring up more attention to this critical area from policy makers, researchers, service providers, and healthcare practitioners.

The rest of the paper is organized as follows. Section II gives an introduction to the applications utilizing mobile cloud for healthcare. Section III provides a taxonomy that summarizes different mobile cloud architectures used for healthcare. Section IV discusses how mobile cloud computing and storage are leveraged for pervasive healthcare. Section V provides different optimization strategies employed by today's mobile cloud healthcare. Section VI highlights the security and privacy issues and how they can be addressed in mobile cloud healthcare. Section VII concludes this paper.

II. MOBILE CLOUD HEALTHCARE APPLICATIONS

As shown in Figure 2, MCC-based healthcare applications could be categorized into the following groups: Electronic Health Record, Picture Archiving and Communication

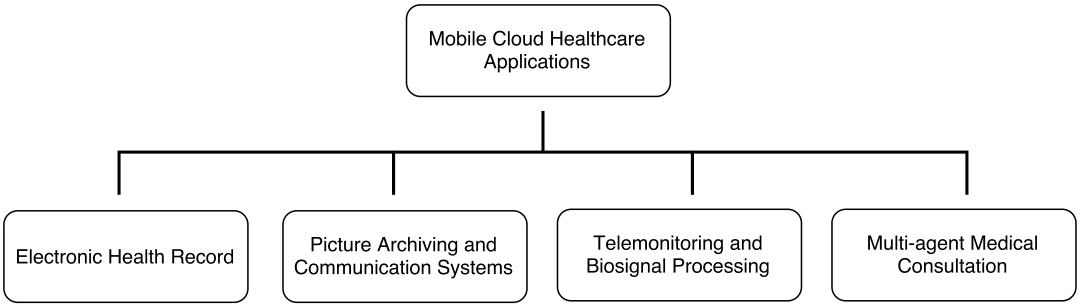

FIGURE 2. Categories of mobile cloud healthcare applications.

Systems, Telemonitoring and Biosignal Processing, and Multi-agent Medical Consultation.

A. ELECTRONIC HEALTH RECORD (EHR)

An Electronic Health Record (EHR) provides an organized approach, which collects the health information of patients and population utilizing an electronic digital format. EHRs establish such a standardized platform, which facilitates the exchange of different sets of information, such as medical history, vital signs, medication and allergies among various clinic settings. MCC has been widely selected as one of the EHR deployment methods. Lomotey *et al.* [88] focused on how to ensure efficient synchronization of the EHR in unreliable mobile environments. Their work took advantage of the ubiquitous nature of MCC and proposed a middleware to facilitate efficient processing of medical data synchronization with minimal latency. A secure and fine-grained access control scheme was proposed on e-healthcare records in the MCC environment [86]. The authors, being concerned about the restricted resources provided by wearable devices in MCC, proposed a fine-grained EHR access control scheme, in which an EHR owner can generate offline ciphertexts before knowing EHR data and access policies. Liu *et al.* [84] expressed their concerns about cloud security issues in Personal Health Record (PHR) access, especially in circumstances when a large quantity of services were provided simultaneously. Accordingly, they proposed a pairing based encryption scheme to enhance the user access protection. Estuar *et al.* [42] studied the implementation of mobile cloud based Electronic Medical Record (EMR), which was capable of integrating different formats of data and providing a uniform interface for users to access.

B. PICTURE ARCHIVING AND COMMUNICATION SYSTEMS

A Picture Archiving and Communication System (PACS) is a medical imaging technique, which enables an efficient and easily maintainable method for storing and sharing medical images across manifold modals of source machines. MCC approach has been broadly adopted for the implementation of PACS. Given the complex and unpredictable communication conditions in the mobile cloud environment, Zhuang *et al.* [159] developed a self-adaptive method to enable high resolution medical images retrieved and transmitted over network in a reliable way. In their study, different partitions of images would be diversely prioritized for transmission, considering performance demand and network bandwidth restrictions. Somasundaram *et al.* [120] proposed a mobile cloud based medical image administration system, which allowed both physicians and patients to easily access medical data. Teng *et al.* [126] developed a mobile cloud infrastructure for medical images stored and transmitted in a secure manner. Another mobile cloud based storage system [39] was also developed for helping manage patient health records and medical images effectively.

C. TELEMONITORING AND BIOSIGNAL PROCESSING

Medical telemonitoring, normally accompanied by processing of the collected biosignals, is a technique which leverages the information analysis and communication methodology to provide healthcare services at distance. Many prior research efforts have been focused on telemonitoring, one of the most effective solutions that can reduce medical costs and improve healthcare efficiency. Based on mobile cloud platform, a depression diagnosis approach was presented in [21]. In a mobile cloud based health drive system, a vehicular social network was established to collect and process diverse sensing data [59], so that safety improvement service was delivered to drivers in a real-time manner. A non-contact Electrocardiogram (ECG) measurement system was established relying on mobile cloud infrastructure [44], through which health issues for elderly people could be reported in an efficient manner. An energy saving mobile cloud based ECG telemonitoring service was provided towards patients with heart disease in [1]. Researchers have also considered a hybrid mobile cloud approach to deploy energy-efficient and accurate ECG telemonitoring towards personalized, pervasive healthcare services [135].

There are many novel applications on biosignal processing that make MCC widely recognized and applauded. For instance, MCC was adopted for child mental disorders monitoring [105]. A speech recognition and natural language processing system was provided relying on mobile cloud infrastructure to help caregivers record notes for patients [31]. A mobile cloud system was established [40] for Electroencephalography (EEG) analysis, based on which, further applications, such as Brain Computer Interface, could be deployed. Recently, a voice pathology detection system utilizing the mobile and IoT - Cloud technology was proposed [93], which was easy to use and can achieve a high level of detection accuracy. Moreover, a mobile cloud system [17] was set up to keep track of the daily calorie consumption, which was proven effective to drive people to do more excises to keep fit.

A mobile cloud based vital sign detection system was developed in [123]. The proposed system stored the user history data and extracted characteristics for each individual user under different conditions, through which an alert would be reported whenever there was an imminent emergency situation. Mobile cloud computing methods have also been broadly utilized for different kinds of heart disease and stroke diagnosis [68], [131].

D. MULTI-AGENT MEDICAL CONSULTATION

In order to deliver high-quality healthcare services, multiple agents, such as doctors, nurses and other medical practitioners, may coordinate with each other to give comprehensive consultation to patients. MCC has been utilized dramatically to provide such multi-agent medical consultation services. The MHealthInt system [104] used mobile application and Google Cloud Messaging to automate the intervention tasks extensively, through which providers could schedule the intervention messages at any time across different intervention and control groups. Similarly, a multi-agent mobile cloud system [64] was designed to enable doctors, nurses and other medical staff to cooperate efficiently with each other in healthcare service provision. The performance of an enhanced multi-agent healthcare system in MCC environment (MCMAS) was compared with a traditional system in Polyclinique Essalema (Sfax, Tunisia) [53], which yielded better results than usual applications. A mobile cloud based clinic support system was set up to enable general practitioners (GPs) to offer diagnosis towards patients in rural area and also specific further request could be sent to medical experts according to the health information collected. [91]. Alshareef and Grigoras [12] developed a mobile cloud system to enable local physicians to provide assistance to people who had imminent health conditions and demanded urgent care immediately.

III. MOBILE CLOUD HEALTHCARE ARCHITECTURES

Various mobile cloud architectures have been developed and deployed for healthcare services, which can be roughly divided into three parts: sensors and mobile devices, cloud computing facilities, and communication networks.

A. SENSORS AND MOBILE DEVICES

Sensors and mobile devices are a significant part in the mobile cloud computing paradigm. The effective coordination between sensors and mobile devices could efficiently improve the performance of mobile cloud systems. Because of the limited battery life and restricted processing capability in both sensors and mobile devices, a lot of different approaches have been explored towards energy saving and efficient data processing.

Zhu *et al.* [156] proposed a mobile cloud system, which coordinated with Wireless Sensor Networks to provide diversified services to users based on their locations. Wireless Sensor Networks were wakening in an optimized way so that they could respond to requests from mobile devices in a reliable and energy-saving manner. Another exemplary system which integrated the Wireless Sensor Networks with MCC was provided in [157], where timing latency and precedence level of the task has been considered to manipulate sensors into different status. In such a way, critical data would be transmitted to mobile cloud infrastructure dependably. A paradigm of mobile cloud system cooperating with the Wireless Sensor Network (WSN) [158] was presented to offer forecast towards the succeeding sensory information, based on which, gathered data would be processed, transmitted and stored in an efficient and sustainable manner. Zhou *et al.* [154] developed a dynamic adaptive scheme to selectively offload computing tasks from the mobile device to different cloud computing resources. Different deployment circumstances of mobile cloud computing were extensively investigated in [43]. Various metrics, such as computation resource cost and energy consumption, were recorded to evaluate the pros and cons of different methods.

The collaborative working of sensors and mobile devices also plays an important role in mobile cloud based healthcare. Hiremath *et al.* [56] proposed the Wearable IoT (WIoT) in their study and performed a comprehensive discussion towards the methodology of designing such WIoT systems and the applicability in clinic healthcare. Fong and Chung [44] proposed a non-contact ECG monitoring solution through combining the sensor, mobile and cloud. Doukas and Maglogiannis [38] also set up a mobile cloud system, which worked with sensors to provide real-time pervasive healthcare monitoring for the patients. Das *et al.* [34] established a mobile sensor cloud system to undertake healthcare monitoring for patients and provided a dynamic scheme to map mobile sensors to servers as the patients, who wore sensors, moved from one place to another. In this way, the computing resource could be optimally allocated and the utilization ratio of servers was largely increased. Wan *et al.* [133] devised a Wireless Body Area Network (WBAN) based cloud system to provide ubiquitous healthcare services. The system sought for information security and energy saving within its deployment. Chen *et al.* [24] designed a system which employed intelligent clothing as physiological sensors. Such special kind of clothing system could collect users' critical vital sign information and transmit them over to cloud for further analysis. Quwaider and Jararweh [106] in their study proposed a cloudlet system working together with Wireless Body Area Networks (WBANs) to perform intensive information aggregation efficiently. In the mobile cloud system developed in [30], position, temperature, and breath frequency of the monitored

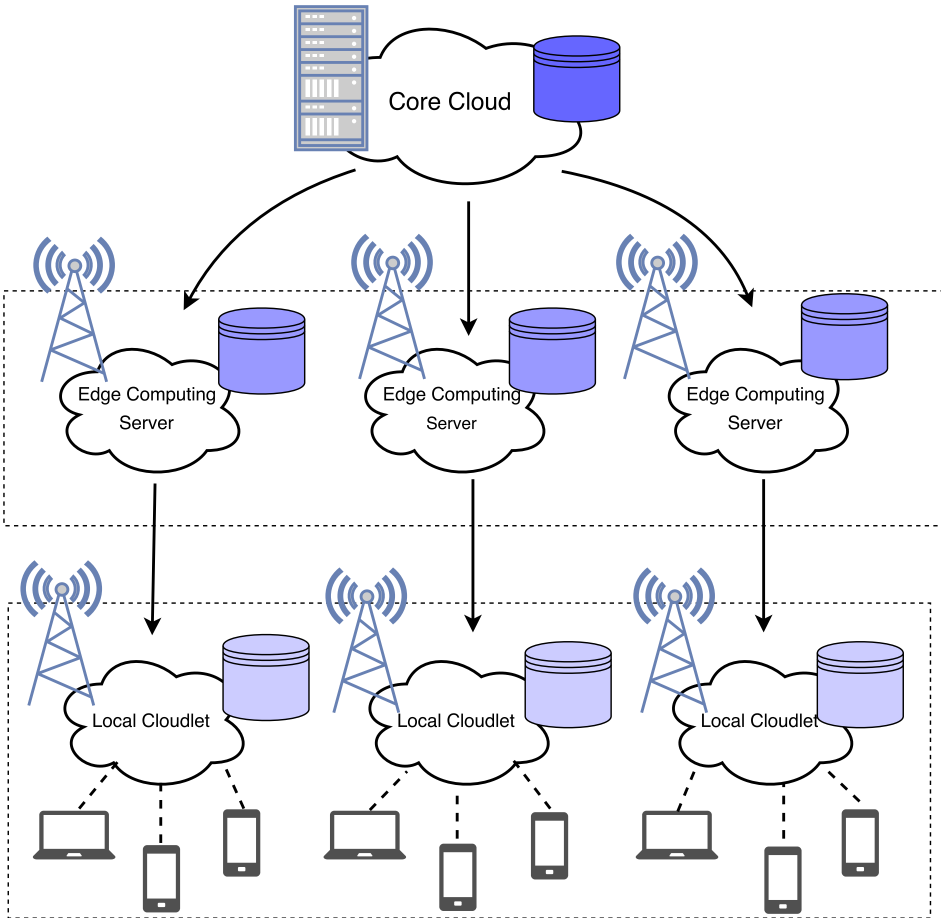

FIGURE 3. Hierarchy of modern cloud computing.

subjects collected by sensors were sent to the cloud for comprehensive evaluation of the subject's health status. Pagán *et al.* [100] presented a study which utilized MCC for migraine monitoring and prediction, based on a low-power, unobtrusive Wireless Body Sensor Network.

B. CLOUD COMPUTING

Cloud computing, due to its superior computational capability, elasticity and scalability, becomes an indispensable part in MCC. Figure 3 presents a hierarchy of MCC, consisting of the Core Cloud, the Edge Computing servers and the local cloudlets. To enhance the computational capabilities of mobile devices, Abolfazli *et al.* [3] designed a multi-level MCC infrastructure based on the granularity of different cloud resources. Their approach was proven to be able to reduce cloud reaction time and increase energy saving. Considering various kinds of communication network situations, Gai *et al.* [46] developed an adaptive energy-saving scheme for MCC, within which cloudlet executed task scheduling for different network conditions. Mobile Edge Computing (MEC) could allow services to be provided close to users by taking advantage of resources nearby. Jararweh *et al.* [63] leveraged MEC to offer high quality services to mobile users with minimized timing delay and energy consumption.

In mobile cloud based healthcare system, there are also plenty of discussions on how cloud resources could be better utilized to provide high quality of healthcare services [51], [134]. He *et al.* [55] proposed a hierarchical MCC infrastructure to provide pervasive healthcare services in response to a large scale of requests efficiently, where different kinds of physiological data and medical information could be easily retrieved in the cloud. Abbas *et al.* [2] deployed an MCC infrastructure for user health condition evaluation. Big data obtained from social media were analyzed in order to provide professional healthcare services to mobile users. Jin *et al.* [66] proposed a multi-parameter cloud fusion method to facilitate mobile cloud systems for medical decision making and clinic support. Zhang *et al.* [152] also promoted big data and cloud computing techniques to provide healthcare services towards users. Specifically, they designed a multi-layer cyber-physical system to process and store data concurrently.

Offloading task execution from mobile to cloud has been proved to be a promising approach to extend the functionality of mobile devices. However, when request for resources scale up instantaneously, more advanced resource administration techniques need to be employed on the cloud side. Ahn *et al.* [9] established a cloud resource management scheme, relying on which, the surging large volume of client requests could be handled in a real-time manner. Rahmani *et al.* [110] explored the extensive functionalities of gateways, based on which, they proposed the IoT-based Fog Computing (FC) platform to provide pervasive healthcare services. Through filling the distance gap between the sensors and the cloud, such FC infrastructure was able to boost system performance in terms of both reliability and energy consumption. Lo'ai *et al.* [87] set up a cloudlet based MCC infrastructure, within which inter-cloudlet connection has been managed wisely to increase the energy-saving and throughput of the whole system. García *et al.* [47] provided a mobile cloud solution to detect cerebral stroke, with which, cloud played a role of analyzing and storing data of users. Chen *et al.* [25] devised a mobile cloud based big data system to monitor and forecast the influence of air quality over health of people in the city. Especially, mobile crowdsourcing data and personal physiological information were processed in a fusion manner so as to offer guidance for urban residents in need.

C. COMMUNICATION NETWORK

The communication networks connect mobile devices to cloud servers. The speed and quality of network communications have direct impacts on the performance of MCC, which are often neglected in most prior studies. Han *et al.* [52] discussed the emergence of 5G network coupled with the analysis of big data would help overcome the limitations of traditional mobile cloud sensing. Big data analysis could augment the ability of processing large scale data compared with traditional servers. 5G network could solve the bandwidth constraint of previous network infrastructures to support the massive data capacity and massive connection request in the new mobile cloud sensing era. Ahmed *et al.* [8] proposed a scheme to prevent MCC system from the influence of communication network discontinuity. Through their efforts, timing performance could be largely improved in circumstances of unstable network connection. Tärneberg *et al.* [125] considered heterogeneous distribution of cost and capacity for network infrastructure in an MCC environment and accordingly proposed a resource management scheme to incorporate the analysis of data center utilization and communication link utilization so as to address the issues of elasticity for mobile cloud network. Wang *et al.* [140] established a resource management method considering both the user experience of mobile devices and cost of service providing at cloud. They managed to allocate the communication network bandwidth efficiently so that the performance requirement from mobile devices could be satisfied at relatively low cost.

Various kinds of new communication network infrastructures have been proposed for healthcare services. Nunna and Ganesan [97] claimed that Mobile Edge Computing (MEC) was capable of meeting the needs of Health 4.0 by providing a scalable low-latency context-aware cloud platform for a variety of service subsystems. They discussed the potential platforms that could be built on top of MEC to facilitate the difficult scenarios of health sector. Hassan *et al.* [54] devised a multiple-layer network architecture capable of transferring a large scale of health media information to cloud in a timely manner while still guaranteeing the quality of service. Gillis *et al.* [50] set up mesh network for a mobile cloud system to provide a reliable and secure communication method for caregivers in mass casualty disaster triage. Their proposed Web Real-Time Communication (WebRTC) based communication approach has proven to be very effective in assisting information sharing among doctors and patients under emergency case of disaster. Choh *et al.* [28] proposed a HTTP 2.0 based network infrastructure for mobile cloud health, which enabled secure and fast transmission of medical information to individual users. De *et al.* and Mukherjee incorporated the femtocell into mobile cloud systems. Femtocell worked as an intermediate hub in the data transmission from mobile to cloud. Through 'filtering' of femtocell, only abnormal health data would be eventually sent from mobile to cloud so that the system can be very cost effective. In a study by Chen *et al.* [26], an emotion aware healthcare system was demonstrated based on mobile cloud infrastructure. Specifically, 5G technique has been incorporated to expand the resources of mobile devices to cloud computing so as to offer personalized and intelligent service to users. Considering the potential influences from network conditions, Muhammed *et al.* [94] leveraged edge computing based IoT platform to establish pervasive healthcare service for users. Within such a system, machine learning together with big data techniques have been utilized to administrate and forecast the communication network traffic so that issues related to network, such as latency, energy efficiency and security could be solved to a large extent.

IV. MOBILE CLOUD COMPUTING AND STORAGE FOR HEALTHCARE

As showed in Figure 4, mobile cloud computing, storage or their hybrid use have been widely adopted for healthcare services.

A. MOBILE CLOUD COMPUTING FOR HEALTHCARE

MCC has significantly evolved and expanded over the past decade. Zhou *et al.* [154] devised an MCC system that involved multiple-level resources as the computation offloading destination. Their proposed context-aware approach was able to choose the optimal communication method and task migration destination on the fly, so that advanced timing performance could be achieved at a low energy cost. Shuja *et al.* [118] discussed both the feasibility and challenges in application migration from mobile devices to cloud centers. Through performance profiling, the overhead of computation offloading from mobile to cloud in terms of virtualization and emulation costs has been analyzed

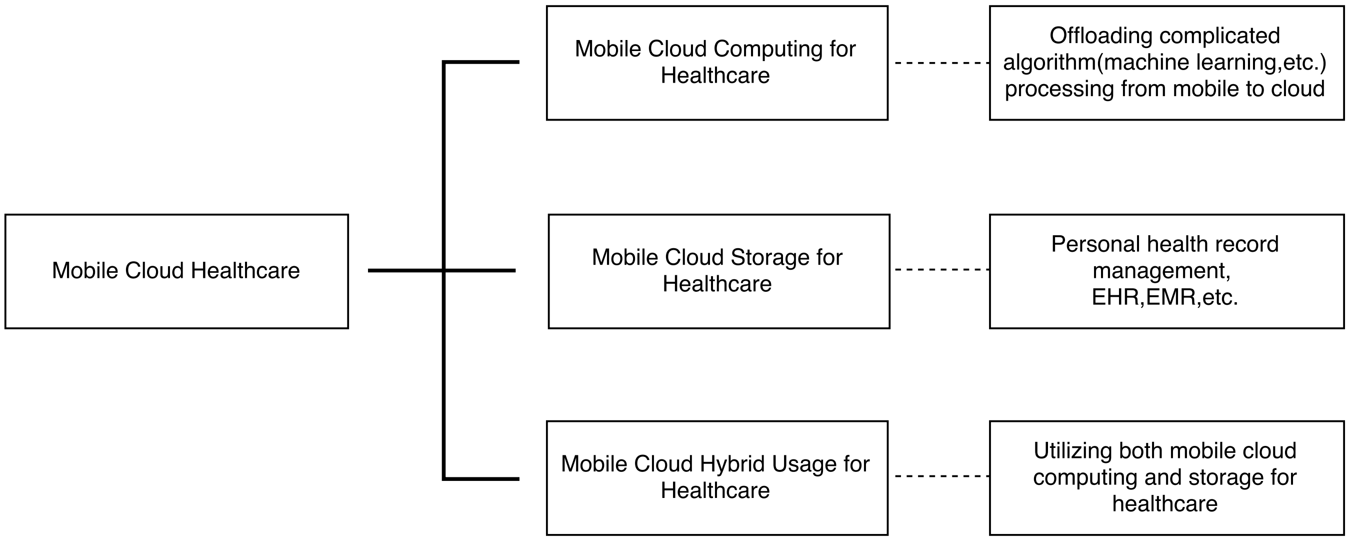

FIGURE 4. **Mobile cloud computing and storage for healthcare.**

considerately. Finally, they presented instruction-level optimization strategies to help improve the efficiency during the procedures of computation offloading from mobile to cloud. Chen [27] analyzed the conditions of multiple users offloading computation tasks from mobile to cloud. The study considered the influences and restrictions mobile users imposed over each other in the offloading procedures and proposed a game theory based approach to optimize the migration performance at large scale. Yang *et al.* [148] implemented a code offloading strategy from mobile to cloud, which selected critical heap region data for transmission. In this way, offloading cost could be reduced in terms of both timing latency and energy consumption. Viswanathan *et al.* [132] incorporated dynamic resource scheduling techniques for cloud based mobile grid computing. Wu *et al.* [142] utilized rich communication network resources among clouds to deploy a multi-cloud offloading scheme for MCC. Niyato *et al.* [95] proposed a mobile user access granting scheme to assist regular operation of the cloud services. A cooperative game approach was presented for multiple cloud service providers to help them achieve the maximal profit. Cardellini *et al.* [20] investigated a multi-tier mobile cloud infrastructure, which included mobile devices, proximate computing cloudlet and traditional remote cloud. They utilized a game theory method to emulate the situation when multiple mobile users requested to offload computational tasks to the cloud, based on which an efficient scheduling approach was proposed to facilitate such multi-user offloading procedures. Zhang *et al.* [153] considered the circumstances, in which multi-mobile users requested cloud resources for offloading, and thus proposed a cluster resource scheduling scheme to enable the transferred applications from mobile to be executed over cloud in an efficient and sustainable manner. Alshareef and Grigoras [13] devised a mobile cloud system which leveraged social media platform for healthcare services. In their study, an MCC framework was presented to inform potential imminent health status and risk at an early time.

Particularly, MCC has been greatly leveraged for many clinical diagnosis and prognosis. Through migrating the computationally intensive training procedures to the cloud, Wang *et al.* [135] proposed a machine learning algorithm based MCC approach for accurate and sustainable ECG telemonitoring. Kumari *et al.* [74] devised a mobile cloud healthcare system, which divided the transmitted data into several categories. Among those categories, the critical groups of data were prioritized for transmission in an expeditious way, with which the entire system timing latency could be dramatically alleviated. An *et al.* [15] presented a mobile cloud system to provide health media services. Within such a system, they adopted adaptive encoding methodologies for different forms of multimedia data, so that the quality of experience for users could be maximized at a relatively low level of resource consumption. Gatuha and Jiang [49] deployed a statistic model over mobile cloud infrastructure for diagnosing breast cancer. Stantchev *et al.* [121] presented a multi-level MCC infrastructure to facilitate healthcare services for the elderly. Within such a system, cloud computing collaborating with sensors, provided high quality and personalized services to users. Mathew and Obradovic [90] developed a data restructuring scheme in mobile device to strive for performance improvement as well as energy saving in the MCC environment. Hoang and Chen [57] proposed an MCC infrastructure to provide context-aware assistive healthcare services to users in an energy-efficient manner. Within such a system, quality of service issues, such as security and reliability, have also been addressed. Cimler *et al.* [30] developed a mobile cloud healthcare system, which first collected position, temperature, breath frequency of the monitored subject from sensors and then sent those sensory information to the cloud for further detailed analysis of the subject's health status. Venkatesan *et al.* [131] established an MCC-based method to evaluate the probability of an individual exposing to heart disease hazard.

B. MOBILE CLOUD STORAGE FOR HEALTHCARE

Mobile cloud utilized to provide storage services has appeared in different application scenarios. Aminzadeh *et al.* [14] introduced different approaches which leveraged cloud resources to augment mobile storage. Various issues regarding mobile cloud storage, such as power consumption, security and privacy, data interoperability, have been investigated in their study. Vandenbroucke *et al.* [130] analyzed the influence of different context factors, such as time, network situation, emotion status, social environment, over user experience when mobile cloud storage was deployed. Cui *et al.* [33] provided an insightful analysis towards the architecture of modern mobile cloud storage services. Specifically, they looked into the synchronization mechanisms and optimization strategies which were normally used to increase the data transmission speed between mobile and cloud. They also presented a performance study for several representative mobile cloud storage applications and concluded that many sophisticated design skills, such as the balance requirement of synchronization speedup and energy saving and the trade-off between real-time transmission and communication overhead, may need to be further developed. Garg and Sharma [48] deployed an RSA-based encryption scheme over mobile cloud storage services to strengthen the system security and reliability. In their paper, they also provided an assessment towards the overhead spent on such ciphering and deciphering procedures. Farrugia [43] distinguished and evaluated different mobile cloud storage offloading strategies. Relying on various metrics, a comprehensive assessment towards different migration scenarios was completed. Lee *et al.* [77], in their study, developed a data synchronization method, with which data was bundled in groups for transmission periodically. In such a way, network traffic could be well controlled and data consistency could be achieved efficiently.

Mobile Cloud storage systems have been widely employed on a large scale to facilitate healthcare services. Doukas *et al.* [39] developed a mobile cloud based storage system to help manage patient health records and medical images effectively. Somasundaram *et al.* [120] proposed a mobile cloud based medical image administration system. Relying on such a system, both physicians and patients could easily access medical data. Relying on Hospital Information System (HIS), Tang *et al.* [124] established a mobile cloud storage service to offer homecare to patients, through which physicians could access the patients record and was able to give feedback timely. Estuar *et al.* [42] deployed a mobile cloud based Electronic Medical Record (EMR) system, within which the issue of data interoperability has been addressed. Lai *et al.* [76] proposed a cloud-based mobile nursing information system, the purpose of which was to enable nurses to complete nursing information system operations among wards through the all-in-one touch personal computer attached in each mobile nursing cart. The system was proven to be able to reduce response time, enable nurses to perform better services, and increase user satisfaction. Chuang [29] proposed a mobile cloud based wellness management system, in which users' body metric and diet record were tracked so that users would be notified for their fitness. Teng *et al.* [126] developed a mobile cloud infrastructure for medical images stored and transmitted in a secure manner. Lo'ai *et al.* [87] investigated the utilization of mobile cloud storage system for healthcare services, especially serving for health record related big data analysis. Chen *et al.* [23] proposed an innovative mobile cloud data storage strategy for tele-health services. In their presented architecture, customized storage scheme has been established for both mobile devices and cloud centers to boost the performance in terms of reductions of timing delay and energy consumption.

C. HYBRID MOBILE CLOUD COMPUTING AND STORAGE FOR HEALTHCARE

There are some application scenarios, in which both mobile cloud computing and storage have been involved and incorporated. Those hybrid scenarios have been discussed in [99], [115]. Chen *et al.* [22] discussed the connection topology variance situation in both mobile cloud computing and storage circumstances. Specifically, they proposed a light-weighted task scheduling scheme to achieve both fault tolerance and energy efficiency for data processing and storage. Yang *et al.* [146] designed a dynamic application partition scheme for both mobile cloud computing and storage scenarios. Relying on such a method, data stream applications could be deployed on the mobile cloud infrastructure with large throughputs.

Specifically, many healthcare services have also taken advantage of both the computational ability and the storage capacity of mobile cloud infrastructure. Xu *et al.* [144] designed a multi-layer mobile cloud infrastructure for patient antimicrobial drug usage monitoring, where mobile cloud computing and storage resources have been employed to provide healthcare service access management, user data format interoperability setup and patient record analysis. Zhang *et al.* [152] proposed a hybrid mobile cloud infrastructure to store and analyze health data collected from different resources and presented in various formats. They leveraged big data techniques to provide professional analysis and suggestions towards patients' health status. Badawi *et al.* [17] devised a hybrid mobile cloud system to record people's energy consumption daily by calories. The designed system encouraged people to keep or increase their workout intensity to stay healthy. Sung *et al.* [123] established a mobile cloud based health alert system, which first collected multiple groups of vital signs and stored them in the database. Then the warning level would be set based on the analysis of historical physiological signals in the database. Finally, an alarm would be triggered as long as the physiological measurement data entered the zone of risk. Pouladzadeh *et al.* [103] designed a mobile cloud system to deploy food recognition and calorie calculation. The food recognition was performed based on machine learning algorithms, for which the training set of images had to be stored in cloud. With such a system, users could monitor their calorie intake and keep themselves from obesity. Hussain *et al.* [61] developed a mobile cloud system to perform activity recognition for users, where multi-source sensory information were firstly collected and processed in the smartphone. After that, activity labels together with other monitoring traces were sent to the cloud for further analysis. At last, big data techniques were deployed over cloud to perform long-term and context-aware analysis towards users' behaviors.

V. OPTIMIZATIONS OF MCC FOR HEALTHCARE

As many research investigations have been performed towards migrating resource-intensive tasks from mobile to cloud [5], [32], [60], [71], [89], [117], some researchers have expressed their concerns about the time and energy overhead during the data transmission from mobile to cloud, especially under the highly complicated, usually unpredictable, network situations [36]. Ahmed *et al.* [6] provided a comprehensive analysis towards the influence of network conditions on mobile cloud computation offloading and concluded that network-related information should be definitely incorporated when establishing the migration scheme. At the same time, different dynamic task scheduling schemes in MCC have also been greatly advocated to make mobile battery sustain longer [75], [80].

A. MULTI-OBJECTIVE OPTIMIZATION OF MCC

Enayet *et al.* [41] designed an optimized mobile cloud offloading scheme for big data applications in smart cities. They analyzed the influence of user mobility, connection stability and cloud resource heterogeneousness on mobile cloud offloading procedures. Based on that, they proposed an adaptive resource distribution method, with which resources would be selectively assigned to the appropriate application request. Wu *et al.* [141] proposed a multi-level mobile cloud migration system, in which an optimized decision making approach was provided, and also developed an application partition scheme to organize the data for transmission in an efficient way so that minimum energy consumption could be achieved while the timing requirement was satisfied. Yu *et al.* [149] discussed the MCC circumstances, in which cloud centers were geographically distributed in different locations. They utilized the game theory approach to model the resource sharing procedures among cloud service providers. Based on such an approach, service providers either competed or collaborated with others to provide satisfied quality of service to users and at the same time, restricted cloud resources could be exploited to the largest extent possible. Tseng *et al.* [129] presented an alternative strategy for task offloading in an MCC system. The objective of

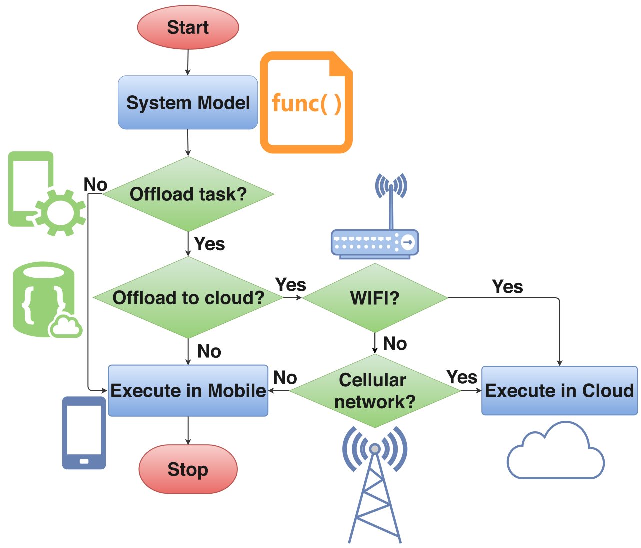

FIGURE 5. Flow chart of the mobile cloud computing task scheduling.

their optimal offloading selection would either be choosing the most efficient connection link for data transmission so migration time between mobile and cloud could be maximally decreased, or be choosing appropriate virtual and physical machines so a specific application resource request could be satisfied. In either way, application execution performance could be boosted at an even lower energy cost level. Barbera *et al.* [18] investigated and gave a precise evaluation towards the cost of mobile computation offloading and mobile data back-up onto the cloud. They presented different methods to reduce the communication connection overhead and extra energy consumption during network interface maneuvering.

More research groups tend to propose dynamic offloading schemes to enable their systems to make adaptive decisions, so as to intelligently manage energy consumption for MCC while still satisfying the timing constraint, as showed in Table 1. A general flow chart of the Mobile Cloud Computing task scheduling method is shown in Fig. 5. Yang *et al.* [147] proposed an optimized mobile cloud offloading strategy at the code level. According to their proposed method, based on some code compiling techniques, only critical heap and stack data would be transferred to cloud so as to decrease the overall transmission data size. Therefore, the cost of offloading could be reduced in terms of timing latency and power consumption. Lin *et al.* [83] proposed a mobile cloud system, which utilized a dynamic, multi-layer task migration scheduling method to achieve a maximum extent of energy savings while still satisfying the task prioritization and timing performance requirements. Besides offloading the tasks to the cloud, their proposed method also incorporated the task migration to the local mobile processors. Through deploying the dynamic voltage and frequency scaling (DVFS) technique on the mobile end, the system performance could be further optimized and improved. Wang *et al.* [138] performed an extensive analysis

TABLE 1. Dynamic scheduling optimizations for mobile cloud computing.

Papers	Architecture Description	Algorithm	Partition Type	Influence Factors	Objective Optimized
[3]	Hybrid granular cloud-based resources (coarse-,medium-, and fine-grained)	Statistical regression (linear,quadratic,cubic)	Task level	Mobile application computation intensity	Performance timing, energy
[20]	Combination of local mobile , nearby cloudlet, remote cloud server for multi-user mobile cloud offloading	Game Theory	Task level	User number, cloudlet server number	Execution time
[27]	Multiple mobile device mobile cloud offloading	Game Theory	Task level	Homogeneous, heterogeneous wireless access	Performance timing, scaling
[46]	Cloudlet-based mobile cloud computing	Dynamic Programming	Task level	Networking environment	Energy
[65]	Cloud offloading for multi-core mobile device	Graph theory, Lyapunov optimization	Task level	Mobile CPU core number/frequency, wireless data rate	Energy consumption, time delay
[72]	Vehicular mobile cloud data forwarding	Bayesian Coalition Game	Virtual Machine level	Velocity/density of vehicle	Data dissemination success rate, throughput
[83]	Offloading to cloud or heterogeneous local cores in mobile device	Graph theory, DVFS	Task level	Task precedence, wireless data rate, task amount	Energy consumption
[95]	Mobile device with multiple access points and servers in data centers	Game Theory	Module level	Bandwidth, server number	Revenue
[132]	Cloud based mobile grid computing	Cost analysis model	Task level	Energy, connectivity, uncertainty (device availability,etc)	Battery drain, battery usage fairness
[142]	Multi-cloud offloading	Topology, Graph partition	Task level	Network bandwidth	Energy
[147]	Mobile cloud offloading	Graph theory	Code level	Network type, mobile workload	Execution time, energy consumption
[151]	Mobile cloud offloading	Graph theory, LARAC	Task level	Mobile/Cloud CPU frequency, network rate	Energy consumption
[153]	Cloudlet for multiple mobile users	Graph theory	Code level	Mobile workload	Cloudlet throughput, performance timing
[154]	Mobile ad-hoc network cloudlet and public clouds	TOPSIS	Code level	CPU speed/usage, network rate	Performance timing, energy

towards the cost of offloading application from mobile to cloud. They proposed a joint optimization method to strive for both minimum timing delay and lowest power dissipation. Jiang and Mao [65] proposed a mobile cloud offloading scheduling scheme, which aimed at minimizing energy consumption and timing latency as the optimization goal. In their study, they focused on mobile devices which had multiple cores and also analyzed both the uplink and downlink situations between mobile and cloud. Zhang and Wen [151] divided the mobile applications into sub-tasks and managed to find optimal offloading strategies for each sub-task. They proved that their proposed method could achieve minimal power dissipation within the required timing delay constraint. Shi *et al.* [116] discussed the situation, in which mobile devices could form their ad-hoc local cloud as the computation offloading destination. Based on that, they proposed a dynamic task migration scheduling method to minimize the power consumption while satisfying the timing performance requirement. Their proposed method equipped the system with the capability to fine tune the timing constraint according to the ever-changing network conditions. Abolfazli *et al.* [4] discussed the influences of distance and intermediate hops between mobile and cloud on an MCC system. Their study indicated that distance between mobile and cloud had limited effect on the system performance while intermediate hops would impose negative impact on both the timing delay and power dissipation of the mobile cloud system. Othman *et al.* [98] provided a generic development model for mobile cloud based applications, which addressed several challenges within mobile cloud applications, such as energy dissipation, timing latency, security and privacy.

Beck *et al.* [19] investigated a scenario of MCC usage for E-commerce, where cloud centers would receive the order request from customers all over the world. In that case, the cloud centers faced a challenge of responding to geographically distributed customers in an equally timely manner. Therefore, they proposed to perform data partitioning before assigning them to the established proximate proxy servers. In this way, mobile customers could receive responses faster and the cloud side throughput could also be increased. Xu *et al.* [145] proposed an optimization strategy for task allocation in mobile social cloud computing. They established a metric to express the extent of trust, based on which tasks could be selected by their owners to be outsourced to other groups of mobile users for execution. Skourletopoulos *et al.* [119] proposed a method to help improve the operation efficiency of the mobile cloud services leasing business. They established a cost benefit model to analyze the profit loss situation, especially due to the cause of resource under utilization. They were able to provide the prediction towards the resource utilization rate variance caused by the ever-changing scale of user requests so that the optimal resource allocation scheme could be presented to the leasing business owner.

Kumar *et al.* [72] utilized a game theory based method to optimize the vehicular mobile cloud offloading procedures. Their approach has been testified based on various mobility and density of vehicles under different network situations. Relying on their method, it has been proved that the system performance has been improved in terms of timing delay, data throughput and control information transmission overhead. Kaur and Sohal [69] proposed an optimization method for application offloading in mobile cloud environment. Their presented method partitioned the application into processes and established a timing delay based offloading cost function. Through dynamically adjusting the timing constraint threshold, optimal decision could be made for offloading procedures.

Abolfazli *et al.* [3] presented a hierarchical architecture to optimize the mobile cloud offloading procedures. Through selectively offloading computation tasks to different aiming resources, it was proved that both responding time and energy dissipation could be saved. Niyato *et al.* [95] presented a game theory based approach to improve access control scheme for users and increase profit for service providers. Similarly, Cardellini *et al.* [20] also proposed a game theory based method to improve the performance of task offloading from multiple mobile users to cloud computing resources. They established multiple levels of migration destinations, based on which optimal timing performance could be achieved for the system. Chen [27] in their work discussed the situations, in which mobile users may have access to different extent of communication resources. Based on that, they proposed a game theory relevant approach to address the issues of scaling and timing delay in mobile cloud offloading procedures. Zhang *et al.* [153] considered the scenarios in which there were constraints with the cloud resources, and thus proposed a joint optimization approach combining the dynamic task partition scheme with an adaptive offloading scheduling method to achieve maximal data throughput and minimal timing delay in different network situations. Gai *et al.* [46] leveraged cloudlets to perform task scheduling under different network situations in order to achieve the maximum extent of energy saving. Zhou *et al.* [154] proposed a dynamic offloading method based on the context information collection for MCC. With their implemented method, mobile tasks would be potentially migrated to groups of targeted resources so as to achieve the maximum level of performance improvement.

Viswanathan *et al.* [132] proposed an adaptive task scheduling approach for cloud based mobile grid computing. Their proposed method was able to solve the uncertainty issues involved within the mobile grid computing environment, such as network connection stability and device accessibility. Wu *et al.* [142] leveraged the copious connection resources among the clouds to provide an optimized multi-cloud offloading scheme for mobile devices and thus achieve a trade-off between the communication cost and the network stability. Ahmed *et al.* [7] in their study, proposed a method to analyze the feasibility of offloading applications from mobile to cloud. They identified and incorporated different factors both internally and externally in the investigation of the condition, such as the size of application executable, the number of instructions for executing the application, the speed of local and remote processors and the status of the communication network. Based on those factors, they were able to provide a generic rule to determine the maximal application size for migration.

B. OPTIMIZATION MODELING OF MCC

Based on those existing dynamic scheduling strategies in MCC, we propose a generic model describing the timing performance and energy consumption of an MCC system with various kinds of affecting factors. A healthcare service algorithm could be defined as a set of basic functional blocks (BFBs). Each BFB consists of various inputs (required knowledge) and outputs (outcomes). As presented in Fig. 6, those BFBs, when deployed in mobile cloud infrastructure, could be divided into three groups: non-offloadable tasks, cloud-offloadable tasks and network traffic. Non-offloadable tasks could only be executed locally; Computing generated network traffic could only be sent to cloud; and cloud-offloadable tasks could be chosen to either be executed in the local CPU or be offloaded to the remote cloud infrastructure. All of these three groups of workload are loaded into the task queue, waiting to be delivered. Given a mobile application A, its call function graph is $G = \{V, E\}$, where each vertex $v \in V$ denotes a BFB in A and an invocation from u to v thereby is denoted by an edge $e = (u, v)$. We reconstruct a new graph $G' = \{V', E'\}$ by applying offloading methods onto V, where $v' \in V'$ represent BFBs being offloaded through $e' = (u, v')$. The execution time of each BFB can be annotated as T_v and $T_{v'}$ in the mobile and cloud respectively. The energy consumed by the mobile system is thus denoted as: P_c for computing, P_i while being idle, and P_{tr} for sending and receiving data. Furthermore, as shown in Fig. 6, multiple wireless network interface scenarios (such as WiFi, WiMAX, and 2G/3G/4G-LTE/5G) would be considered where the mobile device is connected via the most fast and reliable channel when more than one is available. Though both the type of network connection and the level of signal strength will influence the data transmission bandwidth, focus could be put on the actual data transmission rate and denote it as D_n. The size of data to be transferred for BFB v' is given by $n_{v'}$.

More specifically, if the implemented system needs to achieve the optimal performance, the best strategy can be obtained by examining the solutions of the optimization problem described by this generic model:

$$min_{v,v'} \sum_{v \in V} T_v + \sum_{v' \in V'} (\frac{n_{v'}}{D_n} + T_{v'}), \quad T_v \propto O(n), \\ T_v \propto 1/freq_{cpu}, \quad T_v \geq 0, \ T_{v'} \geq 0, \\ n_{v'} \geq 0, \ D_n \geq 0 \quad (1)$$

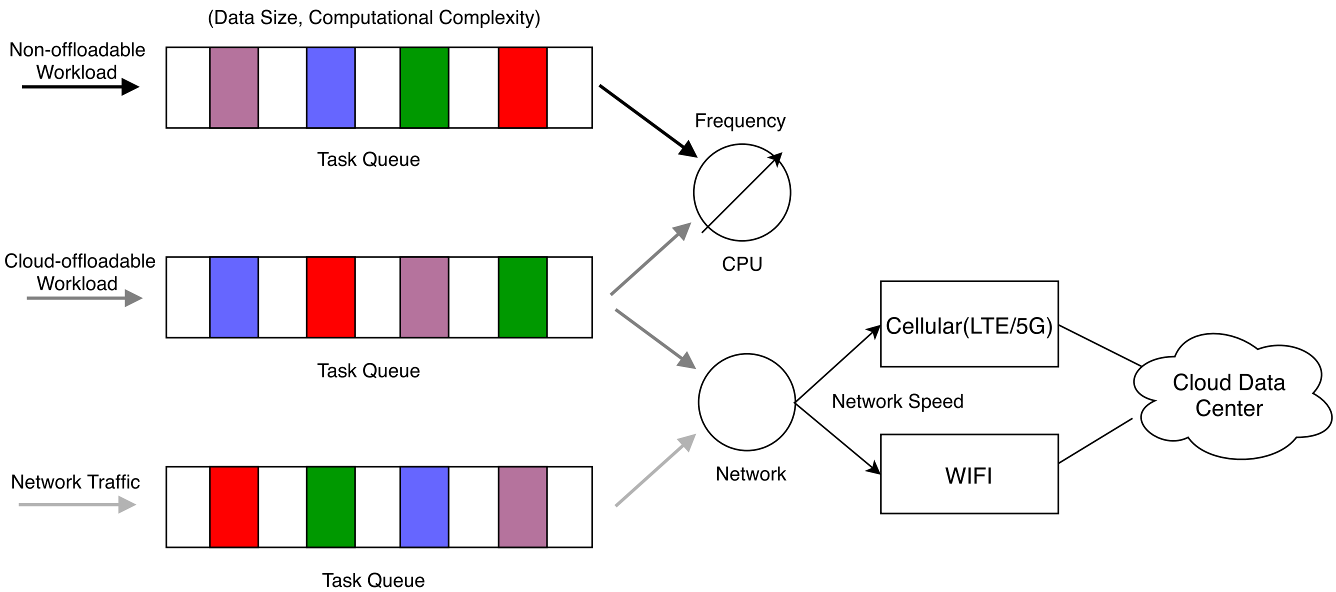

FIGURE 6. Mobile cloud system model.

As shown in Fig. 6, the execution time of a certain BFB v is proportional to its algorithm complexity, which is denoted as $O(n)$ and inversely proportional to the frequency of the mobile CPU.

According to Equation (1), we could find that the processing performance largely relies on the type of algorithms used by BFB, since different algorithms possess different complexity $O(n)$ and mobile CPU frequency. Also, the size of data to be transferred due to offloading for BFB v', which is given by $n_{v'}$ and different data transmission rates D_n have impacts on the processing performance.

If the implemented system needs to be most energy efficient, the equation below could be solved:

$$min_{v,v'} \sum_{v \in V} P_c \times v + \sum_{v' \in V'} P_{tr} \times \frac{n_{v'}}{D_n} + \sum_{v' \in V'} P_i \times v',$$
$$P_c \propto freq_{cpu}, \quad T_v \geq 0, T_{v'} \geq 0, n_{v'} \geq 0, \; D_n \geq 0 \qquad (2)$$

where the optimization goal is to minimize the overall energy consumption of the mobile device, including the actual computing portion, the data transmission portion, and the idle portion. According to the equation, we could find that the energy saving can be achieved by decreasing the size of data to be transferred due to offloading for BFB v', which is given by $n_{v'}$. Alternatively, we could find that the energy cost is also influenced by different data transmission rates D_n.

C. OPTIMIZATIONS OF MCC IN HEALTHCARE

In healthcare application scenarios, many fine-tuned techniques have been explored to optimize multiple objectives. Peddi *et al.* [102] investigated a mobile cloud system for food classification and calorie calculation. In their proposed system, they provided an optimized resource allocation scheme for cloud instance assignment in order to achieve higher precision and minimum timing delay for returning the detection result. Wang *et al.* [137] proposed a Hidden Markov Model (HMM) based method to optimize the mobile cloud health telemonitoring system. With their settings, physiological signal processing could selectively be either executed in the mobile end or offloaded to the cloud. Such dynamic task scheduling method could facilitate both energy saving and timing delay reduction for mobile cloud telemonitoring system. Pagán *et al.* [100] developed a mobile cloud based IoT platform for biomedical sensing in ambulant status and migraine prediction in further steps. They provided energy optimization strategies at different levels of the system and a dynamic task allocation scheme for different components within the system. Based on that, a maximum extent of energy saving and economic benefit could be achieved for the provision of health services. Chen *et al.* [26] developed a mobile cloud based emotion-aware healthcare system. Within their system, in addition to incorporating the 5G technique, they presented an extra task partition scheme to reach optimal resource allocation in the ever-changing network conditions. In this way, high quality, smart and personalized services could be offered to users.

Mathew and Obradovic [90] proposed a method, which reorganized the data sequence over the mobile device before sending them to the cloud. With such a way, both energy consumption and timing latency could be optimized for the mobile cloud system. Wang *et al.* [136] investigated a mobile cloud healthcare system for ECG telemonitoring. Within the system, they particularly focused on the duty cost of task scheduling method itself and according to that, they proposed a reinforcement learning based approach to refine the optimization procedures so that the system performance, in terms of energy consumption and timing delay, could be boosted at low expenditure. Islam *et al.* [62] discussed the virtual machine migration issues in mobile cloud based healthcare service providing procedures. They proposed an optimization approach which was capable of dynamically selecting the offloading destinations depending on the user mobility. Based on that, their mobile cloud system was able to achieve an optimal resource utilization rate and a minimal timing delay for a specific task.

VI. SECURITY AND PRIVACY PRESERVING FOR MOBILE CLOUD HEALTHCARE

Potential privacy and security threats and risks for MCC have emerged as a great concern, as more and more enterprise and personal users have heavily relied on MCC services in their daily business and lives. Many prior research efforts have been conducted to address the privacy and security threats. In light of the growing privacy concerns in MCC, Li *et al.* [78] proposed a certificate-aware framework for online access control systems, where users were compensated for their privacy certificate and operation disclosure and were motivated to present more certificate information. Au *et al.* [16] provided an overview towards the mobile cloud privacy threats from different levels, such as information theft and data integrity breakage. Specifically, from the perspective of cryptography, they presented insights into the potential privacy issues which may appear in user operations. Li *et al.* [79] studied the privacy issues which may emerge in profile matching, which was quite significant in different social network applications. They presented a scalable protection scheme which prevented personal information from leakage in the mobile cloud system. Lin *et al.* [81] investigated the mobile cloud based provable data possession scheme deployment, which was critical for establishing data-relevant services. Their motivation was that the existing provable data possession scheme normally consumed a large amount of computing and storage resources, which was not affordable by the mobile devices. Their proposed method has proved to be able to perform accurate information verification procedures at low data transferring cost. Gai *et al.* [45] proposed a secure media data transmission method for vehicular mobile cloud systems with low communication expenditure, in which different security issues have been addressed, such as data tampering in network channels and communication node intrusion. Wu *et al.* [143] presented an efficient authentication scheme for small and medium-sized enterprises when they relied on the mobile cloud infrastructure to provide services to the clients. Their proposed method could protect the mobile cloud system from various kinds of malicious invasions at a relatively low communication cost, such as dictionary attacks and phishing attacks. Due to the recent advances of biocomputing techniques, Sukumaran and Mohammed [122] leveraged DNA computing, based on the general rule of polymerase chain reaction and primer generation, for data encryption in mobile cloud systems.

Particularly, more serious concerns about the privacy and security issues for MCC in the healthcare domain have arisen given the significance and sensitivity of medical data and treatment procedures. Some existing studies have been looking for a variety of solutions to address these issues, as outlined in Table 2. Thota *et al.* [128] developed a mobile cloud based IoT platform to preserve security and privacy in healthcare service provision. Specifically, their proposed method was able to perform surveillance towards the newly connected devices within the network. Liu *et al.* [86] presented a sophisticated authentication scheme for EHR administration based on the mobile cloud infrastructure. Through strategically allocating the encryption tasks onto different stages, either online or offline, the confidentiality of the patients records could be maximally secured at low cost. Al-Muhtadi *et al.* [10] studied the case of social network based mobile cloud infrastructure to provide healthcare services and set up different privacy levels for roles in the healthcare service with the goals of addressing security and privacy issues in the communication network of mobile and multiple cloud healthcare systems. Albuquerque and Gondim [11] analyzed various security issues which may appear in mobile cloud healthcare systems, such as data confidentiality and integrity, and provided a general discussion towards the strategies to resolve those issues. Zhang *et al.* [150] analyzed the security and privacy issues in Mobile Health Networks. Considering the diverse requirements of users towards security and privacy, they provided users with options to alter the protection scheme. They also presented different strategies for security and privacy preserving in various stages of mobile cloud healthcare services, such as data collection and data processing phases. Sajjad *et al.* [113] leveraged mobile cloud infrastructure to encipher the medical images and employed stenography techniques to prevent image content from being exposed to intrusions. Their method has proved to be able to keep image quality and conserve information security at low effort.

Kumar *et al.* [73] presented an efficient authentication scheme for vehicular cloud computing based healthcare services. Their proposed RFID-based method made the system capable of countering cyber attacks, such as replay attacks, tracking attacks, and eavesdropping attacks, etc. Zhou *et al.* [155] investigated a scenario where WBAN-involved mobile cloud systems were utilized to provide healthcare to patients travelling at short distances. They proposed an efficient security protection scheme to offload the resource consuming encryption key administration procedures to the cloud so that the mobile cloud healthcare system was able to resist different time and location based attacks on the mobile device. Liu *et al.* [84] presented an authentication scheme to manage the access to PHRs in a mobile cloud environment. Their proposed method was able to address the cloud security issues for PHR management, especially when receiving a large amount of users' requests at the same time. Hu *et al.* [58] developed a mobile cloud based IoT platform to provide health monitoring services to the elderly, in which they proposed an asymmetric/symmetric encryption based authentication scheme to preserve the privacy for

TABLE 2. Security and Privacy Preserving for Mobile Cloud Healthcare.

Papers	Architecture Description	Security and Privacy Issues	Solutions
[67]	Mobile cloud computing	Privacy leakage, insecure communication	Secure electronic medical records uploading and sharing Secure personal health information transmission
[73]	RFID-enabled vehicular cloud computing	Eavesdropping attack,replay attack, tracking attack, server spoofing, tag masquerading/ spoofing,cloning attack	Use Petri Nets-based model for tag and reader authentication, elliptical curve cryptography (ECC)-based key generation protect tag, server authentication
[82]	Cloud-assisted privacy preserving mobile health monitoring	Privacy breaches (re-identification attack), insider attack	Shift clients' computational complexity to cloud Variant of key private proxy re-encryption scheme
[85]	Protecting mobile health records (MHR) in cloud computing	Anonymous data authentication for MHR	Design of OOABS to protect signers' privacy and anonymity
[86]	EHR for mobile cloud computing	Unauthorized access to EHR	Online/offline CP-ABE scheme, fine-grained EHR access control
[96]	Cloud-based mobile health security management	Insecure mobile software execution environment and data communication	Cloud based Security as a Service (SaaS) for mobile health security
[111]	Connected mobile system in mobile cloud environment	Sniffing, replay, man-in-the-middle attacks	HIPAA-compliant authentication, create secure channel for communication
[113]	Mobile cloud computing	Privacy of medical image transmission	Outsourcing images to cloud for selective encryption while maintaining its security using stenography
[150]	Mobile healthcare networks	Privacy leakage, insecure data access and processing, malicious attacks and misbehavior	Privacy-preserving health data aggregation Authentication and secure access control Misbehavior detection for health mobile social network
[155]	Cloud-assisted WBANs in m-healthcare social networks	Time-based, location-based mobile attack	Embedding human body's symmetric structure into Blom's symmetric key construction, pairwise key updating

health record of the elderly. Rahman *et al.* [109] investigated the scenario when a mobile based peer-to-peer cloud infrastructure was utilized to provide health information sharing. They leveraged the pairing-based cryptography techniques to establish an online data sharing scheme to prevent the system from various malicious attacks, such as target-oriented, man-in-the-middle, masquerade, and message manipulation attacks. Pal *et al.* [101] developed a mobile cloud based patient data exchange platform, in which resource intensive encryption scheme was outsourced to the cloud to increase the execution efficiency.

Mohit *et al.* [92] presented a mobile cloud based lightweight authentication scheme for protecting the Telecare Medical Information System (TMIS) against various malicious attacks, such as impersonation attack and man-in-the-middle attack, and also maintaining anonymity and confidentiality of the patient data. Saleem *et al.* [114] discussed the impacts of virtualization techniques that can be used for strengthening the security level of mobile cloud healthcare systems. Thilakanathan *et al.* [127] proposed an encryption scheme to secure the data exchange in the cardiac arrhythmia monitoring services. Rahman *et al.* [108] proposed a mobile cloud based Deoxyribonucleic Acid (DNA) stenography scheme, in which authentication data could be embedded into the DNA sequence as the encryption phase while at decryption phase, the original DNA sequence could be reconstructed accurately without the need of a reference sequence.

Roy *et al.* [112] provided a sophisticated data access control scheme for the cloud which was equipped with multiple servers and also an efficient user authentication method to prevent the mobile cloud based healthcare system from various adversary attacks. Liu *et al.* [85] presented an efficient and flexible attribute-based signature scheme to secure the access to PHR in a mobile cloud environment. Kotz *et al.* [70] discussed that security and privacy issues had to be addressed appropriately for mobile cloud systems to be utilized for healthcare services at a large scale. Specifically, they proposed that user authentication schemes should be integrated into the normal clinic procedures and also security and privacy preserving should be provided in each individual medical device so that users would be able to build their trust towards the technique driven medical services. Through offloading the executions of intensive multimedia and security algorithms from mobile to cloud, Nkosi and Mekuria [96] established a mobile cloud system to deliver the healthcare service in an effective and energy efficient manner. Lin *et al.* [82] presented an innovative deciphering migration and key private proxy re-encryption scheme to protect both the clients' privacy and the critical information of monitoring service providers in a mobile cloud assisted clinic service. Kang *et al.* [67] investigated different strategies to secure data connection and user privacy in mobile cloud based ubiquitous healthcare services. They provided a multi-divisional privacy preserving scheme to patients based on their social feature distinctions. Through that, patients' health record could be transmitted and shared in a confidential and trustworthy manner. Reinsmidt *et al.* [111] implemented an HIPAA-compliant, secure mobile cloud system for healthcare services that was capable of withstanding various malicious misbehaviors, such as sniffing, replay, and man-in-the-middle attacks.

VII. CONCLUSION

In this paper, we conduct a survey on current mobile cloud computing techniques and how they have been extensively used and deployed in the healthcare applications. Specifically, we provide an overview of the popular healthcare services that have been largely benefited from the emerging MCC technology, the general architecture and design considerations one should take into account while designing an MCC for healthcare scenarios. More importantly, healthcare usually has more strict requirements on the processing performance, system reliability and availability, and trustworthiness of the infrastructure. Given a large number of factors that may affect the performance of MCC and even result in catastrophic consequences in healthcare, appropriate optimization strategies must be explored in order to flexibly and dynamically adjust the operational settings while facing unexpected environmental changes or meeting the ever-changing performance requirements. This study presents the popular optimization approaches on MCC for meeting the diverse priorities and achieving the optimal tradeoff among multiple objectives. Finally, the security and privacy issues of MCC in healthcare, as well as some representative solutions, have been reviewed and discussed. It is anticipated that, through our summarization and categorization, the potential opportunities of how MCC could be further developed, utilized and expanded in healthcare, are well presented. Our work pave the way for future research on employing mobile cloud computing to provide smart, tailored and effective healthcare services.

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