25. Analysis of mHealth Systems with Multi-cloud Computing Offloading

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1 Introduction

Owing to the latest technologies in wireless communication and the development of mobile devices, related issues in mobile computing are becoming more and more concerned [1-2]. However, it is challenging to run very complex applications on the mobile devices because of the strict constraints on their resources such as memory capacity, network bandwidth, CPU speed and battery power [3]. This is not just a temporary limitation of current mobile hardware technology, but is intrinsic to mobility [4]. Cloud computing is becoming increasingly popular these days due to its features like elasticity, scalability and inexpensive. Along with the maturity of cloud computing [5], offloading the data or program from mobile devices to remote clouds is one of the attractive ways to overcome the above problems. Offloading brings many potential benefits, such as energy saving, performance improvement, reliability improvement, ease for the software developers, better exploitation of contextual information and so on.

Mobile healthcare (mHealth) applications, which are supported by mobile devices for delivering medical and healthcare services, can benefit from offloading the computationally intensive operation onto the cloud. Recently, the mobile healthcare market is showing a significant growth. According to a new report from *Research and Markets* [6], the market for mobile health applications and associated devices will grow at a compound annual growth rate of 61% to reach $26 billion in revenue by 2017 due to sales of mobile monitoring devices and integration with mainstream medicine. About 11% of cell phone users and 19% of smartphone users had mHealth apps on their devices in 2012, according to a Pew Internet survey [7]. By 2015, more than 500,000 people are expected to be using healthcare smartphone applications.

mHealth systems frequently use body sensors to collect healthcare data on patients and the data should be transmitted to a nearby or a remote mobile device.

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Thus, minimizing the energy consumption needs to be considered and energy-efficient transmission schemes must be deployed. Fortunately, if we allow individual sensor nodes to cooperate with each other, a cooperative MIMO system can be constructed for the data transfer [8].

The mHealth systems are characterized by low coupling and powerful parallel computing capabilities, therefore offloading can be beneficial in these systems. Since there are a number of multimedia sensor signals to be processed on different servers, a traditional offloading scheme that offloads the program from a single mobile device to a single server is not sufficient. Therefore, finding some suitable offloading schemes is very important for the mHealth cloud systems. One multi-cloud offloading scheme that offloads the program from a single mobile device to a different server at each time is described, but the communication cost for such scheme is very huge since the network bandwidth between the mobile device and the cloud is small. However, the bandwidth between different clouds is much larger, and thus a multi-cloud offloading scheme where the data is shifted among the clouds is presented in this chapter.

The fast growth of cloud computing has attracted more and more companies to migrate their in-house IT applications into cloud and it also occurs in the medical field. A mHealth system with cloud offloading is considered in this chapter and it can be divided into two stages: sensor network and cloud offloading. In the first stage, information collected by body sensors should be transmitted to a remote mobile device. In order to save energy, an energy-efficient transmission scheme called cooperative multi-input multi-output (MIMO) is constructed for data transfer when allowing individual sensor nodes to cooperate with each other. In the second stage, two offloading schemes called self-reliant multi-cloud offloading system and multi-cloud offloading system are proposed and further analyzed based on service topology and optimal graph partition. The former provides stability but with high communication cost, while the latter reduces communication cost but is less stable. Both schemes can be effectively applied to the mHealth systems in which we would like to perform offloading on multiple cloud servers.

This chapter is an extended version of the conference paper [9] presented at IEEE MDM 2013 and it involves the area of sensor network, mobile offloading and mHealth cloud, and the purposes of this chapter are as follows:

1) To make a comparative study of the existing mHealth cloud systems.
2) To construct an energy-efficient transmission scheme in the body sensor network.
3) To find the most suitable architecture of multi-cloud offloading for the mHealth applications.

2 Overview of Mobile Cloud Healthcare Systems

2.1 mHealth

2.1.1 Overview of mHealth

mHealth is defined as the practice of medical and public health supported by mobile devices such as mobile phones, tablet computers and PDAs for delivering medical and healthcare services and information [10]. It is currently being heavily developed to keep pace with the continuously rising demand for personalized healthcare. With the development of wearable medical devices and wireless communication technology, mHealth is getting increasingly popular.

In order to fully utilize wireless technology between the wearable medical devices, we use body sensor network (BSN), which is a kind of wireless sensor network (WSN) around human body. Base on this, the mHealth systems that provide a personalized healthcare based on BSN are further developed. A typical mHealth system includes various body sensors to collect physiological signals specifically for different requirements, a mobile device such as smartphone to facilitate the joint processing of spatially and temporally collected medical data from different parts of the body for resource optimization and systematic health monitoring, and a server cluster with great data storage capacity, powerful analysis capabilities to provide data storage, data mining and visualization [11].

2.1.2 Limitations of Current mHealth Systems

We will explore the limitations of current mHealth systems:

1) Heavy algorithms cannot be run and processed on mobile devices since the mobile devices have limited computational capacity and run on small batteries. Therefore, the performance of mHealth applications is limited.
2) Lack of protection of the healthcare data capture and communication, more attention should be paid to the privacy and security for patients' data.
3) Lack of the design and development standards for mHealth clouds.

2.2 Cloud Computing

2.2.1 Overview of Cloud Computing

The emergence of cloud computing is promising to solve some of the concerns facing mobile computing platforms. Cloud computing refers to an on-demand, self-service internet infrastructure that enables the user to access computing resources such as processing, memory and storage anytime and anywhere in the world [12].

mHealth service is one of the applications that can benefit from the combination of mobile computing and cloud computing technologies. Some healthcare providers have found an opportunity to shift the burden of managing and maintaining complex health information to the cloud or more appropriately to the cloud service providers. For example, Rolim et al proposed a cloud-based system to automate the process of collecting patients' vital data via a network of sensors connected to legacy medical devices, and to deliver the data to a medical center's cloud for storage, processing, and distribution [13].

The special type of cloud computing used for improving patient care is called mHealth cloud and it provides opportunities to solve some of the current limitations facing mHealth systems. In addition to providing independent per-healthcare provider solutions, the mHealth cloud also has the potential to support collaborative work among different healthcare sectors through connecting healthcare applications and integrating their high volume of dynamic and diverse sources of information. By doing this, dispersed healthcare professionals and hospitals will be able to establish networks to coordinate and exchange information more efficiently.

2.2.2 mHealth Cloud Applications

Cloud computing can be one of the most suitable technologies for healthcare infrastructures. However, several serious issues concerning security, data protection and ownership, quality of services, and mobility need to be resolved before cloud computing is widely applied. The strengths and weaknesses of mHealth cloud applications are listed as follows, separately.

- **Strengths**:
  - Provide real-time data collection.
  - Relocate data through embedded database storage.
  - Data pre-processing and intelligent monitored data analysis.
  - User easy access.
  - Reduce spending on technology infrastructure.
- **Weaknesses**:
  - Lack of a strong security mechanism.
  - Weak data privacy protection.
  - Data can only be accessed when the network connection is available.

2.3 Offloading Approaches

Cloud offloading is an effective solution for solving the limitation on mobile devices. When a mobile device needs to run a heavy application, it offloads the heavy application to a cloud server. The result is sent back to the mobile device after executing the particular heavy application in the cloud. Classes for offloading can be divided into weak and strong classes. The weak class requires low security and computation, while the strong class requires complex multimedia processing and security. Therefore, the weak class will be entirely performed in the mobile device while the strong class prefers to be performed in the cloud under varied conditions. Through the approach of offloading, the mobile device is relieved from executing those heavy applications.

Normally, the limitation of mobile cloud computing is the battery life of mobile devices is very low when compared with that of other desktop devices. The main memory available is not enough to run complex applications. When the data storage is outsourced to the cloud servers, it is hard to ensure that the data is absolutely safe and will remain confidential in the cloud. Therefore, lack of trust in data security and privacy is at the heart of the resistance that many customers have to offload the healthcare data to the cloud [14].

Since mobile devices have very limited computational capacity and small battery life, they are unable to run heavy multimedia and security algorithms. A cloud computing framework is proposed in [15] to relieve the mobile devices from executing heavier multimedia and security algorithms in delivering mobile health services. They suggest that we offload the security algorithm to another cloud separately from the cloud where the institute's data is stored. Whereas, the user's mobile device only sends data and receives the result from the cloud through the network. In this way, the power consumption of the mobile device can be reduced, and on the other hand, it increases the database security that is stored in the cloud. In other words, multimedia and security operations can be performed in the cloud, allowing mobile health service providers to subscribe and extend the capabilities of their mobile health applications beyond the existing limitations of mobile.

3 mHealth Systems with Cloud Computing

3.1 Architecture

The architecture of mHealth systems with cloud offloading is shown in Fig.1. It is comprised of three main components: body sensors for collecting physiological signals, mobile devices for joint processing medical information and delivering healthcare services via mobile technology, cloud servers including the database server, data mining server and graphic server for signal processing [11].

This architecture has many advantages: it not only provides round the clock and real-time data collecting from patients, but also eliminates manual data collecting work and the mistakes made during manual data collecting. Medical staff can always access patients' information data through the cloud storage, and thanks to the wireless network connection on these devices, setting up of extra cable is not a must.

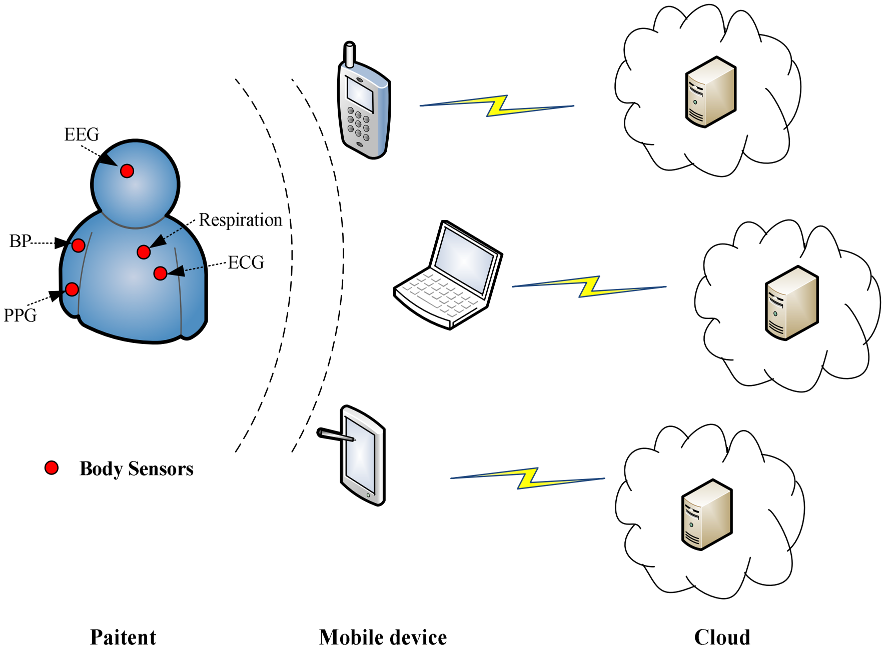


Fig. 1 Architecture of mHealth systems with mobile cloud offloading

Body Sensors*:* The process of a patient's data collection required a lot of manual work. A solution was proposed to attach sensors to medical equipment to automate the processes of the patient's vital data collection and make the patient's information becomes available in the cloud environment. In a typical system, each sensor node collects various physiological signals in order to monitor the patient's health status no matter their location and then instantly transmit all information in real time to the medical or the doctors. In this way, sensors act as data sensing where medical data will be shifted into the mobile devices.

Many body sensors such as electrocardiograph (ECG), photoplethysmograph (PPG) and blood pressure (BP) and so on, can be used for collecting vital signals for further analysis [11]. For example, body temperature can be detected from the patient through the mobile agent and this data is then processed through this intelligent model to produce useful data.

mHealth systems are designed to meet the requirements of different users. For example, the patients with heart diseases who need a long-term monitoring after recovery to prevent its relapse, the hypertension patients who are under the process of medicine adjustment and sub-healthy people who want to have a good knowledge of and follow up their health conditions to prevent some kinds of chronic diseases.

Finally, physiological signals collected by the sensors will be transferred to the mobile device via a sensor network.

Mobile Devices: Mobile devices such as mobile phone, laptop and PDA, aim to jointly process medical information and deliver healthcare services. Some special software is installed in the mobile device. After collecting data through Bluetooth sent from body sensors, we could get preliminary analysis results such as heart rate, abnormalities of a single test, and etc.

With the modern cloud technology, mobile devices can be considered to be a platform for delivering health information. However, there are some challenges to run heavy applications on a mobile device. No matter how powerful a smartphone device can be, it will not be as powerful as a computer. Because of the size constraint of a mobile device for portability purpose, a mobile device has a very limited battery capacity. This becomes the main reason why mobile devices may have the computation and memory limitation, and it will be an issue when a mobile device has to run a heavy application such as delivering health information.

Therefore, heavy multimedia and signal processing are unable to run on the mobile devices. In order to get further insights, the processing is offloaded to the server in the cloud [15].

The mobile devices mediate interaction between a wireless sensor network and a back-end intelligent cloud platform.

Clouds: Recently, there are a large number of cloud platforms appearing in the "sky" with different cost patterns and conditions, such as Amazon's EC2 [16], Apple's iCloud [17], Microsoft's Azure [18], Google's App Engine and so on for data storage and processing. These systems use a proprietary cloud platform to provide a personalized service. The cloud data center specifically designed for healthcare service can provide a platform for large data storage and parallel computing capabilities for data mining. It can support tens of thousands of people login and upload data simultaneously with response time of less than 1 second.

Healthcare data that is collected by the sensors will be transferred to the cloud middleware through the mobile device. At this stage, the data are analyzed, processed in the cloud middleware. Three different functions of clouds can be used for mHealth systems, *Security Cloud* that consists of security algorithm to encrypt the data, *Data Storage Cloud* for storing the patient data, and the *Application Cloud* to run the calculation and services provided by the applications.

3.2 Stages of mHealth Systems

The whole mHealth system can be divided into two stages.

First of all, we need to transmit the information collected by the body sensors to a mobile device. In some cases, the mobile device may be close to patients, where the Bluetooth can be used, but in most situations, the distance may be a challenge. For example, mobile devices used by the hospital are far from patients at home. In such cases, other transmission methods should be used to save energy consumption and reduce transmission time.

In fact, the body sensors can be seen as sensor networks, and the data collected by multiple body sensors need to be transmitted to a remote mobile device. If the sensors do not cooperate with each other, this is actually the case of multiple SISO (single input single output) transmission from an individual sensor to the mobile device. The energy cost would be huge due to the long distance between the local nodes and the remote mobile device. Therefore, a new strategy is required to minimize the total energy consumption of the entire nodes and transmission instead of reducing the energy cost of the individual node.

3.2.1 Cloud Offloading Stage

In this stage, programs in the mobile devices should be offloaded to the cloud servers for further processing.

The traditional scheme for cloud offloading is constrained by offloading data or computation from a single mobile device to a single server in cloud. However, it can't be applied to full range of scenarios in which we would like to perform offloading. For example, it is not suitable in the above healthcare system since different signal processing methods such as ECG, PPG, BP and so on, could not be completed only in one server and thus multiple offloading servers should be considered. Therefore, new offloading schemes should be further explored to overcome such complex signal processing.

The above two stages will be analyzed in detail in the following sections.

4 Analysis of Sensor Network Stage

In this section, we will study the sensor network stage of mobile healthcare systems as illustrated in Fig.1, i.e., transferring the collected information from local sensors to the remote mobile devices.

4.1 System Model

In the sensor network stage, a sensor network can be abstracted as a mathematical model, and it is depicted in Fig.2.

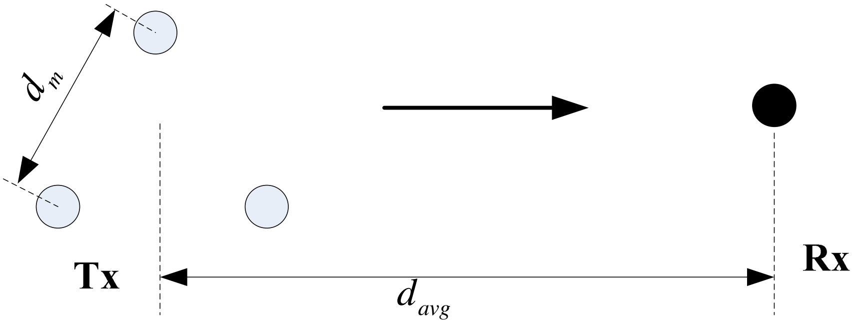


Fig. 2 Architecture of a sensor network

From Fig.2, we assume that there are three body sensors at Tx side, which are abstracted as three nodes, and the mobile device at Rx side is also abstracted as a node. The local distance between each node at Tx side is d_m, and the average distance from the sensors to the mobile device is d_{avg}. Since the mobile device is far away, we usually have $d_m \ll d_{avg}$ that the local distance is negligible when compared to the transmission distance..

4.1.1 Non-cooperative Approach

For the non-cooperative approach, the model in Fig.2 can be treated as M_t mutually independent SISO schemes. Each node at Tx side just transmits information to the remote node at Rx side on its own, and the local nodes do not cooperate with each other. The total energy consumption per bit in transmission and circuitry for a single SISO scheme with uncoded MQAM modulation is easily found to be [19]:

$$E_{SISO} = E_{tr} \frac{\gamma_0 d_{avg}^2}{bB} + E_c \frac{2}{bB} \tag{1}$$

where γ_0 denotes the SNR required in SISO scheme, $b = \log_2 M$ is bits per symbol in modulation and M is the constellation size, B is the bandwidth for a fixed transmission, E_{tr} is a constant factor for transmission, and E_c is a constant factor for circuitry.

We assume that there are M_t nodes at Tx side and each has L_i bits to transmit, where i =1, · · · , M_t. As a result, the total energy consumption for the non-cooperative approach is given by:

$$J_{Non-coop} = \sum_{i=1}^{M_t} L_i E_{SISO} \tag{2}$$

4.1.2 MISO Approach

As far as we know, MIMO (including MISO and SIMO) can save energy in fading channels [8]. Thus, if the multiple local nodes work together in transmission to the destination node, they can be treated as multiple antennas and an equivalent MIMO system can be constructed. As shown in Fig.2, only one receiver is given, therefore, we construct an equivalent MISO for example, and the other equivalent SIMO and MIMO can be constructed accordingly.

In order to make the cooperative transmission possible, the M_t nodes at Tx side will cooperate before the long transmission. Information on each node is broadcasted to all the other local nodes in different time slots. After each node receives all the information from other nodes, they encode the transmission sequence according to the STBC [20].

As for the MISO strategy, according to the reference [21], the total transmission energy and circuitry energy consumption per bit is:

$$E_{MISO} = E_{tr} \frac{d_{avg}^2}{bB} P_e^{-\frac{1}{M_t}} + E_c \frac{M_t + M_r}{bB} \tag{3}$$

where P_e is bits error rate (BER).

When the system in Fig.2 is treated as a cooperative MISO, in addition to the transmission and circuitry energy cost in Equation (3), the energy consumption at the Tx side due to the cooperation overhead needs to be considered. We denote the energy cost per bit for local information flow at the Tx side as E_i, which can be expressed as:

$$E_i = E_{tr} \frac{\gamma_0 {d_m}^2}{b_i B} + E_c \frac{M_t}{b_i B} \tag{4}$$

where $b_i = \log_2 M_i$ is bits per symbol in modulation and M_i is the constellation size during the local transmission at the Tx side.

Therefore, the total energy consumption for the cooperative MISO approach is calculated as

$$J_{MISO} = \sum_{i=1}^{M_t} L_i (E_i + E_{MISO}) \tag{5}$$

4.2 Numerical Results

To give numerical examples, we assume that M_t=3, M_r=1, and the distance between each sensor is d_m=1m. The information is transmitted from the sensors to the mobile device by using QPSK modulation, and thus we have M=4. We also set the fixed bandwidth and the BER as B=10KHz and P_e=10^{-3}, respectively. Besides, the energy constants E_c=40uJ and E_t=10nJ.

The data to transmit in each node is L_1=500Kb, L_2=1Mb, L_3=2Mb. In the broadcast process of each node, we use 4QAM, 16QAM and 64QAM modulations, respectively. From the BER for SISO scheme $P_e = \frac{1}{2} \cdot \left[1 - \sqrt{\gamma_0 / (1 + \gamma_0)}\right]$ [22], we can calculate the γ_0 for a certain P_e.

In order to compare the energy consumption in Equation (2) and (5), we obtain the numerical results as shown in Fig. 3.

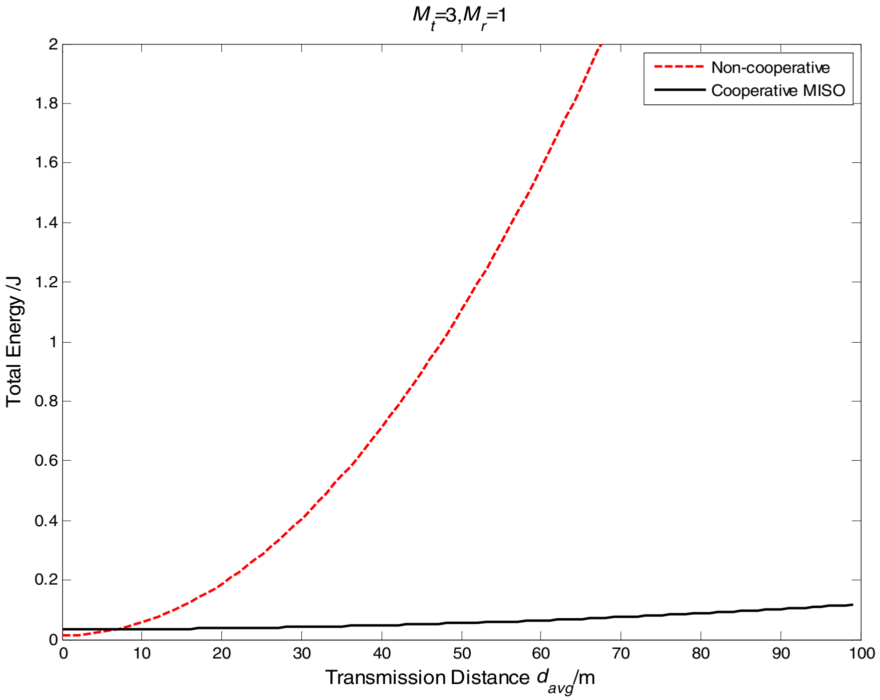


Fig. 3 Total energy consumption over d_{avg}

As shown in Fig.3, the total energy cost of the non-cooperative approach and the MISO scheme are plotted over the average transmission distance d_{avg}. It can be seen obviously that when d_{avg} is very small (e.g., $d_{avg} < 8$m), the non-cooperative transmission can still be more energy efficient than the scheme with MISO. However, when d_{avg} becomes larger, the transmission energy dominates the energy consumption, and the MISO approach becomes much more energy efficient than the scheme without cooperation.

5 Analysis of Cloud Offloading Stage

In this section, we will investigate the second stage of the mHealth systems as illustrated in Fig.1, i.e., offloading the program from the mobile devices to remote clouds for further execution.

The traditional scheme for cloud offloading is constrained by offloading computation from a single mobile device to a single server in the cloud. However, it cannot be applied to full range of scenarios in which we would like to perform offloading. For example, it is not suitable in the above healthcare system since different signal processing options such as ECG, PPG and BP could not be finished only in one server and it requires distribute across multiple offloading servers.

Therefore, a new scheme called multi-cloud offloading for mobile healthcare systems is proposed, which offloads portions of the program to multiple remote clouds.

5.1 Self-reliant Multi-cloud Offloading System

A self-reliant multi-cloud offloading system is described as Fig.4. Actually, it is equal to multiple offloading from single mobile device to a single server one by one.

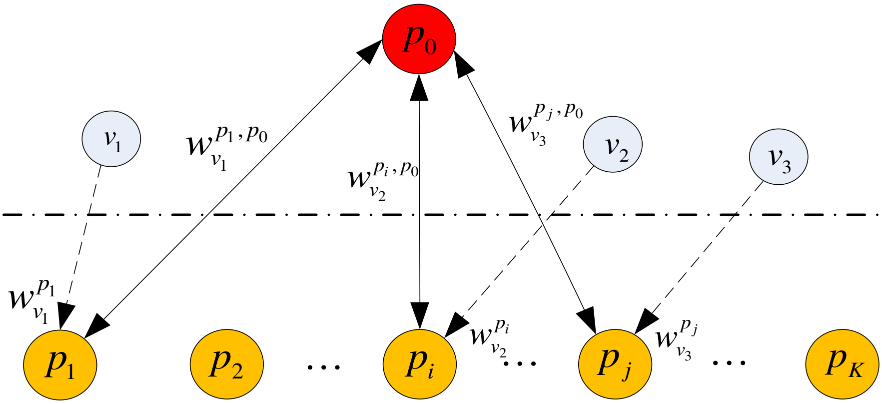


Fig. 4 Self-reliant multi-cloud offloading system

We assume that the number of available remote servers is k, $V=\{v_1,v_2,v_3\}$ means that there are three tasks named v_1, v_2, v_3 in a mobile device that need to be offloaded to cloud servers, $P=\{p_0,p_1,\cdots,p_k\}$ where p_0 represents the mobile device, and $p_1,\cdots,p_k$ represent the offloading servers. The dotted-line arrow denotes the allocation of tasks, and with a computation cost on it, while the solid-line arrow denotes the communication between each element of P. Besides, $w_v^{p_i}$ is the computation cost when v is assigned to server p_i and $w_v^{p_i,p_0}$ is the communication cost between p_i and p_0 when task v is assigned to p_i.

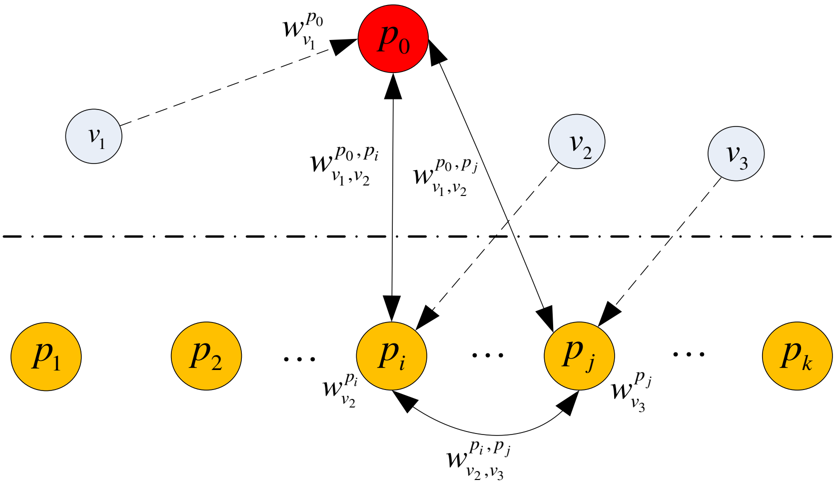
Here, the tasks of v_1, v_2 and v_3 are allocated to p_1, p_i and p_j, respectively, the mobile device offloads the computation to each server separately, and after executing the program, the server then sends the result back to the mobile device.

The disadvantage of the self-reliant multi-cloud offloading system is that the programs can only be offloaded to different servers one by one, separately and the approach cannot support more complex offloads, e.g., parallel offload of different application parts to different servers.

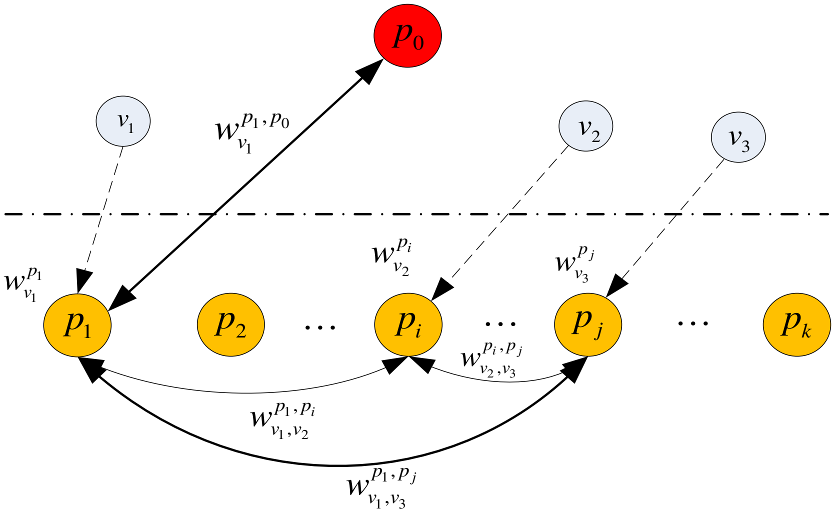
5.2 Multi-cloud Offloading System

5.2.1 Architecture

In order to overcome the limitations of self-reliant multi-cloud offloading system, another multi-cloud offloading system is depicted in Fig.5, where $w_{v_m,v_n}^{p_i,p_j}$ is the communication cost between p_i and p_j when v_m is assigned to p_i and meanwhile v_n is assigned to p_j.



(a) Partial offloading



(b) Entire offloading

Fig. 5 Multi-cloud offloading systems

The system depicted in Fig.5a expresses a partial offloading scheme that partial programs are offloaded to servers while partial programs are executed locally by mobile device. It can be seen that the task of v_1 is allocated to the mobile device p_0 while the tasks of v_2 and v_3 are allocated to p_i and p_j. We compare the self-reliant multi-cloud offloading system in Fig.4 with the scheme in Fig.5a, it is found that the clouds with the tasks can communicate with each other and also communicate with the mobile device in Fig.5a while the clouds only communicate with the mobile device in Fig.4.

The system shown in Fig5b indicates an entire offloading scheme where all the tasks are offloaded to different servers. It can be seen that the tasks of v_1, v_2 and v_3 are allocated to p_1, p_i and p_j, respectively. The difference between Fig.4 and Fig.5b is that the clouds with the tasks communicate with each other in Fig.5b while the clouds only communicate with the mobile device in Fig.4.

Since the communication between two cloud-resident servers such as p_i and p_j may be very fast, while the communication between the mobile and the cloud may be much slower [23], the servers communicates with each other when executing the allocated tasks.

5.2.2 Case Study

An example of multi-cloud offloading is depicted in Fig.6. It can be seen that in addition to the mobile device, three different kinds of clouds named *data storage cloud*, *security cloud* and *application cloud* are combined together to overcome the limitation of mobile device: small memory, low security and small battery, respectively [23].

Data storage cloud: it is used for storing the patients' healthcare data.

Security cloud: or private cloud, such a cloud should be protected and can only be visited by the user. The security cloud uses security algorithm to encrypt the healthcare data before it is sent to the data storage cloud.

Application cloud: it contains main algorithms to run the calculation and services provided by the applications.

The workflow is such that, first, the healthcare data are put into the mobile device through the embedded sensor from the patient. And then the mobile device sends the data to the security cloud to encrypt them before they are stored in the data storage cloud. When the patient requires a service, the application cloud is invoked to acquire necessary data from the data storage cloud and then it decrypts the data for further processing. The result of the process is sent to the patient's mobile device in encrypted form, and it needs to be decrypted by the user.

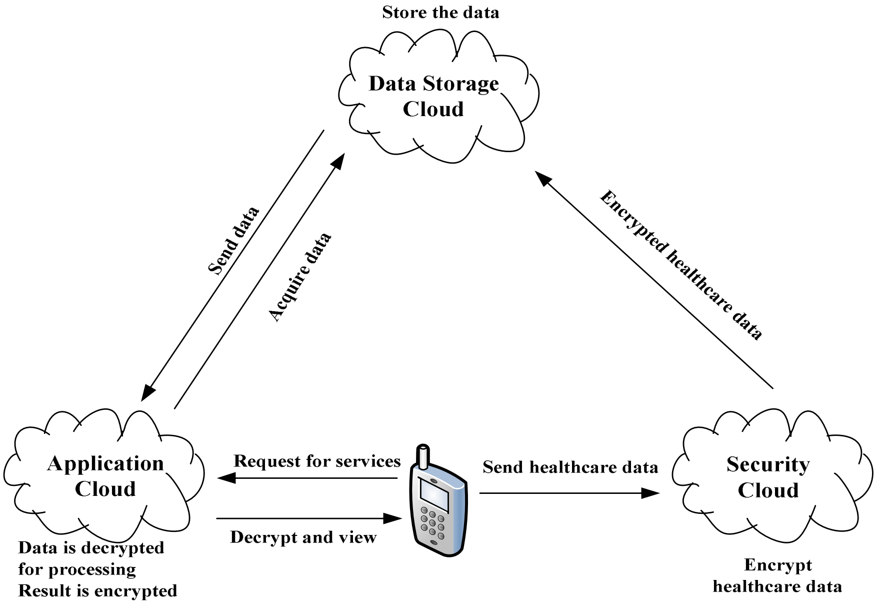


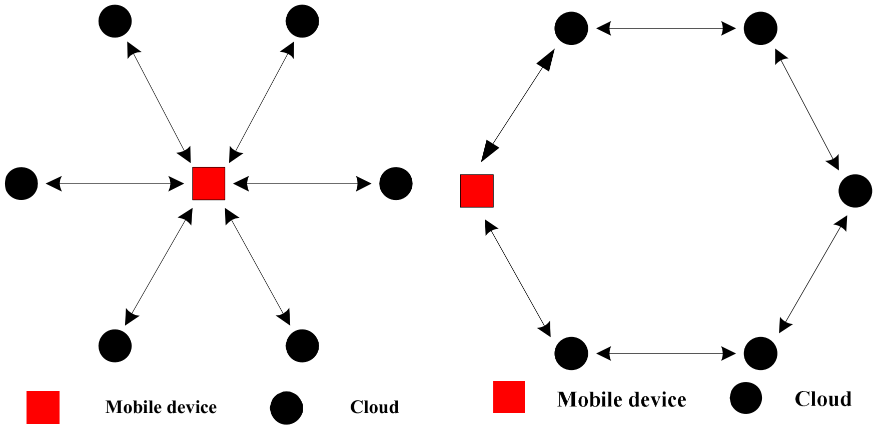
Fig. 6 Example of multi-cloud offloading

This architecture provides several benefits:

1) **Better performance**: Through offloading, the mobile device is prevented from running complex and massive algorithms that require a lot of memory and CPU power. The mobile device only receives the healthcare data from the patient, sends them to the security cloud, invokes the application cloud and decrypts the result. This could solve the limitations of small battery and memory of mobile device, and meanwhile provide better performance.
2) **Better security**: It is very crucial to protect the patient's healthcare data. In order to keep the healthcare data confidential and secure in the cloud, all the data are transferred in the encrypted form except the sending of raw data from the mobile device to the security cloud. It is difficult for the intruder to get the right decryption key to the right set of data since the encryption key in the security cloud is specific to the user. Therefore, it can provide better security.
3) **High dependence**: It provides loose coupling among the components. The mobile device and each cloud have their own responsibility in the architecture. If any failure occurs, it only affects one of the components, the other components are still workable and would not be greatly affected.

5.3 Service Topology

In order to compare the difference between the self-reliant multi-cloud offloading system and multi-cloud offloading system much more vividly, service topologies of multi-cloud offloading systems are depicted as Fig.7.



(a) Self-reliant multi-cloud offloading system (b) Multi-cloud offloading system

Fig. 7 Serve topology of multi-cloud offloading systems

It can be found in Fig.7a that the service topology for the self-reliant multi-cloud offloading system is star. The mobile device needs to communicate with different servers one by one. Thus, a lot of time and energy are spent on communication especially when the network condition is bad. However, it is very stable due to its separate offloading.

From Fig.7b, it can be seen that the service topology for the multi-cloud offloading system is ring. The mobile device only needs to communicate with two servers. Since the communication among clouds usually is very fast, while the data transfer between the mobile and the cloud may be much slower, this topology woks much fast than the star topology. However, its stability is much worse since it depends on every server, and if any failure happens in one of the middle servers, the program couldn't be executed successfully.

5.4 Partition Problem

We can formulate the multi-cloud offloading as a graph partitioning problem with $G=(V, E)$, where V is the set of vertices and the set of edges $E \in V \times V$. Each cloud has different computational and storage capacities, and hence it requires different weights of nodes. Besides, it requires different edge weights for communication since the network bandwidths are different [24].

We can cast this partition problem as an optimization problem, and the optimization goal can be to minimize the battery consumption, minimize the local storage needs while keeping communication low, or minimize the computation time.

The optimization problem for given tasks V and servers P [25] is shown as follows:

$$C = \underset{V,P}{\text{minimize}} \left[\sum_{v\in V}\sum_{p_i\in P} w_v^{p_i}\cdot m_v^{p_i} + \sum_{v_m,v_n\in V}\;\sum_{p_i,p_j\in P} w_{v_m,v_n}^{p_i,p_j}\cdot m_{v_m,v_n}^{p_i,p_j} \right] \tag{6}$$

where $\sum_{v\in V}\sum_{p_i\in P} w_v^{p_i}\cdot m_v^{p_i}$ is the total cost of computation and $\sum_{v_m,v_n\in V}\sum_{p_i,p_j\in P} w_{v_m,v_n}^{p_i,p_j}\cdot m_{v_m,v_n}^{p_i,p_j}$ denotes the total cost of communication, $m_v^{p_i} = \begin{cases} 1 & \text{if } v \text{ is assigned to } p_i \\ 0 & \text{otherwise} \end{cases}$ and $m_{v_m,v_n}^{p_i,p_j} = \begin{cases} 1 & \text{if } v_m \text{ is assigned to } p_i \text{ and } v_n \text{ to } p_j \\ 0 & \text{otherwise} \end{cases}$. $\forall v \in V$, we further have $\sum_{p_i\in P} m_v^{p_i} = 1$, which enforces that each vertex is assigned to exactly one partition.

Each node and each edge are assigned a different cost depending on the partition of the application graph where it finally ends up in.

The example given in Fig.5b can be expressed as a cost matrix:

$$\begin{array}{c|cccccccc|}
 & p_0 & p_1 & \cdots & p_i & \cdots & p_j & \cdots & p_k \\
\hline
p_0 & 0 & w_{v_1}^{p_1,p_0} & \cdots & w_{v_1,v_2}^{p_1,p_i} & \cdots & w_{v_1,v_3}^{p_1,p_j} & \cdots & \infty \\
p_1 & w_{v_1}^{p_1,p_0} & 0 & \cdots & \infty & \cdots & \infty & \cdots & \infty \\
\vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
p_i & \infty & w_{v_1,v_2}^{p_1,p_i} & \cdots & 0 & \cdots & w_{v_2,v_3}^{p_i,p_j} & \cdots & \infty \\
\vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
p_j & \infty & w_{v_1,v_3}^{p_1,p_j} & \cdots & w_{v_2,v_3}^{p_i,p_j} & \cdots & 0 & \cdots & \infty \\
\vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
p_k & \infty & \infty & \cdots & \infty & \cdots & \infty & \cdots & 0 \\
\hline
\end{array}$$

where the graph partition is assumed as undirected and the edge weights that do not exist are set as ∞.

6 Conclusion

A typical mHealth system with cloud offloading is investigated and it can be divided into two stages of sensor network and cloud offloading.

Sensor nodes are attached to patients' medical equipment to transmit and collect data through wireless network communication. In order to save energy consumption on the entire sensor nodes, an energy-efficient transmission scheme is constructed for the data transfer when allowing individual nodes to cooperate with each other. The cooperative MISO approach seems to be much more energy efficient than the scheme that without cooperation when the mobile device is far away from the mobile device.

The proposed two new schemes of multi-cloud offloading for mobile healthcare infrastructure are analyzed and compared based on the graph partitioning and service topologies. There is a tradeoff between the stability and communication cost. Both schemes can be applied to other range of scenarios in which we would like to perform offloading on multiple servers. An example of multi-cloud offloading architecture that combines three different kinds of clouds are proposed, which can solve the limitations of computation, security and memory for the mHealth systems.

Through these systems, people can have knowledge of their own health information and even the risk factor of some chronic diseases in the future.

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