Leveraging Mobile Cloud for Telemedicine: A Performance Study in Medical Monitoring

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***Abstract*—Telemedicine has proven to be an effective and promising solution in promoting more affordable and higher quality healthcare. Wearable body sensors and mobile devices have been widely used to monitor health status of patients or elderly and generate alarms in case of imminent medical conditions. However, the limited computation power and energy supply of mobile devices result in either high false alarm rate or short battery life, prohibitive for medical monitoring. Cloud computing embraces new opportunities of transforming healthcare delivery into a more reliable and sustainable manner. In this paper, we propose a mobile cloud telemedicine framework and discuss its potential performance by taking advantage of the real-time, on-site monitoring capability of Android mobile device and the abundant computing power of the cloud.**

***Keywords*-medical monitoring; false alarms; mobile; cloud.**

I. INTRODUCTION

It is well recognized that the skyrocketing health expenditures and the gradually aging population have been the two of the top concerns to the whole society. Telemedicine, leveraging recent advances in sensing, networking, and computing technologies, has proven to be an effective and promising solution. A critical and costly part of healthcare systems is the monitoring of patients' vital signs and other physiological signals, which play significant roles in physicians' diagnostic processes. The highly specialized and extremely expensive medical monitoring equipment found in hospitals is neither easily accessible nor affordable for next-generation patient-centered, pervasive healthcare.

Fast growing mobile technologies have enabled and promoted the use of mobile-based health monitoring and alert systems (usually referred as "mHealth"), aiming at providing real-time feedback about an individuals health condition to either the user or to a medical center, while alerting in case of possibly imminent health-threatening conditions. Over the past decade, mobile phones have become ubiquitous in people's daily lives. Recently, many mobile-based medical monitoring devices have been developed with the capability of processing certain types of physiological signals [1][2]. However, the limited computational power and battery life of existing mobile devices, significantly limit their ability to execute resource-intensive applications. Emerging cloud computing provides an alternative to renovate and promote future use of mobile devices in healthcare.

As shown in Figure 1, mobile devices can be used to acquire various physiological signals from a set of ambient/body sensors. To alleviate intensive computations and extend the battery life of mobile devices, the acquired physiological signals will be transferred to a cloud service environment to perform desired, computation-intensive algorithmic signal processing. The processed results, recognized abnormalities, or diagnostic alarms will be automatically archived in the cloud or sent to the mobile devices owned by patients, physicians, or emergency teams. This application mode can be of particular significance to patients whose physiological signals need to be monitored continuously. For instance, Hsieh and Hsu [3] presented a telemedicine cloud service enabling ubiquitous delivery of inter-hospital ECG records. Shen *et al.* [4] proposed a cloud-based EEG signal analysis system to detect brain disorder diseases, where the computation-intensive functions of feature extraction, feature selection and support vector machine (SVM) classifier are implemented and deployed using cloud services.

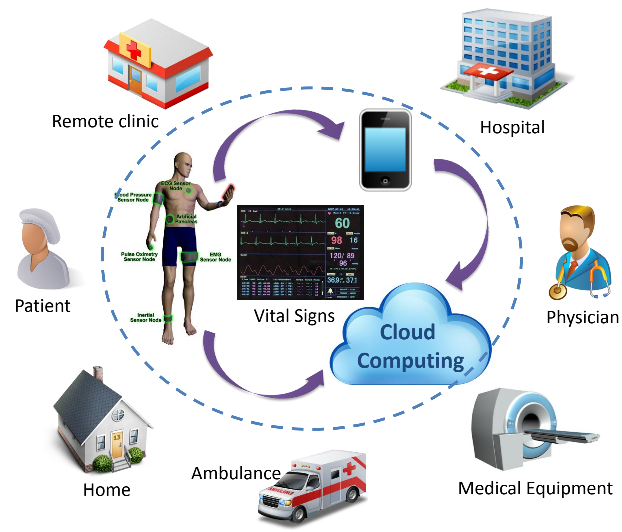

Figure 1. Telemedicine based on Mobile Cloud Medical Monitoring.

In order to explore optimal application model that synergistically leverages the mobile cloud for telemedicine, in this paper, we report our preliminary study results that characterize the performance, energy, and complexity attributes of both mobile- and cloud-based solutions for medical monitoring. Our findings are encouraging and we hope it can inspire the further investigation and development of novel mobile cloud telemedicine architectures to improve the quality and efficiency of health care delivery.

II. SCENARIOS AND RESULTS

The mobile device used in this experiment is a Google Galaxy Nexus smartphone with the Android 4.1 Jelly Bean system. The Galaxy Nexus phone contains a 1.2 GHz dual-core ARM Cortex-A9 microprocessor, 1 GB memory and a 1,750 mAh battery. The computing server used for emulating a cloud environment is a Dell PowerEdge M620 server, equipped with 12 Xeon 2.5 GHz cores and 64 GB memory.

Case 1: Maximizing the Battery Life of Mobile Telemedicine Device: In clinical setting, the vital sign signals are usually recorded, collected and stored in a frequency of one sample per second or minute, like the data in the MIMIC II database [5], we thus emulate the real-time vital sign data inputs of mobile telemedicine device by loading the patients' records of MIMIC II database, in a time interval of 1 minute. We choose the fuzzy logic algorithm [6] to concurrently process four vital sign inputs (i.e., HR, BP, RR, SpO_2) , one of the most computation-efficient processing schemes for multiparamter medical monitoring analysis. During the experiments, all peripherals (i.e., WiFi, Celluar, Bluetooth, and backlight) are turned off to maximize the battery life of the mobile device for telemedicine applications. The fully charged Android smartphone can only sustain for about 33 hours, significantly less than the claimed standby battery life of 270 hours. It shows that even with the most advanced smartphones, it is still infeasible to deploy and rely on the mobile devices for continuous medical monitoring and other telemedicine applications on a daily basis.

Case 2: Maximizing the Performance of Mobile Telemedicine Device: A second goal of this study is to investigate the potential battery life that the mobile telemedicine device could achieve, under the condition of performing computing intensive tasks in a continuous manner. In this experiment, we purposely turned off the automatic power scaling in Android devices to force the microprocessor to remain in power-draining active mode. To emulate the scenario of intensive computation, the vital sign records are continuously loaded and fed into the processing process. The fuzzy logic algorithm (same as Case 1) was adopted to process the four vial sign inputs. The observed battery life is about 6.72 hours, a level that is prohibitive for analyzing large-scale, highly sampled physiological data and deploying more sophisticated processing algorithms on wearable mobile devices. In contrast, when the exactly same process and the same amount of clinical data are executed on the cloud server, it only takes 965 seconds (about 0.27 hours), which represents a 25X speedup and indicates the superior advantage of cloud-based physiological signal processing over the pure mobile-based processing.

Case 3: Maximizing the Diagnostic Accuracy of Medical Monitoring on Cloud: The stringent real-time constraint in medical monitoring significantly prevents or limits the adoption of many sophisticated data processing schemes.

Table I
PERFORMANCE OF TWO REPRESENTATIVE PROCESSING APPROACHES

<table>
<tr><th>Algorithm</th><th>Platform</th><th>Elapsed Time</th><th>True Alarms</th><th>False Alarms</th><th>Missed Detection</th></tr>
<tr><td rowspan="2">Fuzzy Logic</td><td>Mobile</td><td>6.72 hr</td><td rowspan="2">32</td><td rowspan="2">7,994</td><td rowspan="2">409</td></tr>
<tr><td rowspan="2">Cloud</td><td>0.27 hr</td></tr>
<tr><td>SVM</td><td>4.07 hr</td><td>2</td><td>184</td><td>439</td></tr>
</table>

Leveraging the massive computational power of cloud computing infrastructure, more computing intensive approaches can be employed for concurrently processing multiparameter vital signs and physiological signals, and thus better diagnostic accuracy can be achieved by promptly identifying true, clinically-significant medical conditions.

We adopted the support vector machine (SVM) algorithm [7], an effective method for data classification and fusion, to process multiple vital signs. The same clinical data records (as in Case 2) were processed using SVM on the cloud server. The execution process consumes 14,604 seconds (about 244 minutes), representing a significant increase (i.e., $\sim$15X) of computational overhead. Despite the computationally intensive nature of the SVM algorithm, the elapsed time on the cloud server is still far less than the time needed by a mobile device performing the cost-effective fuzzy logic algorithm, whereas the diagnostic accuracy of SVM approach is much better than the accuracy achieved by fuzzy logic solution, as shown in Table I. These findings unveil the potential of cloud computing in facilitating and supporting next generation mobile-based telemedicine and pervasive healthcare services.

III. CONCLUSIONS

Leveraging the recent advances in mobile technologies and cloud computing, telemedicine is on the verge of a substantial transformation that will strengthen the effectiveness and efficiency of healthcare delivery. In this paper, we present a preliminary performance study of mobile cloud to demonstrate its potential in performing continuous health monitoring in daily life and achieving higher diagnostic accuracy. Our findings also unveil the limitations of existing mobile devices in performing telemedicine by themselves.

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