Medical Edge Devices and a Framework for their Computational Requirements

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ABSTRACT

The emergence of the Internet of Things (IoT) has allowed for increased research into its applications within the medical field. Specifically edge devices have been proposed to increase the capabilities and performance of medical devices. These devices are placed locally and interact with a cloud platform to collect and analyze medical data. Because of the local placement, this network could reduce medical costs and the need for patients to schedule in person visits. The network could monitor patients in their daily lives to ensure patient health is meeting the necessary standards. With the availability of this new network a variety of medical disciplines have been integrated including cardiology and pulmonology. The use and requirements of these medical edge devices is surveyed in this paper.

1 Introduction

Health care has been a driving force in advancing technological capabilities in recent years. This is because with improved health care an increase in quality of life can be accomplished. One aspect of health care that has driven technological improvements is the search for a reduction in patient movement to health care settings. This is beneficial as travel can be difficult for many patients seeking healthcare. Not only does this travel put more stress on patients but also increases the cost of care when taking transportation services into account. The IoT and medical edge devices are a possible solution to increasing health care convenience for patients along with reducing need for scheduling of transportation services.

The IoT is a term used to identify the concept of joining networks, objects, and sensors with connectivity and computing capability used to generate, exchange, and analyze data with minimal human intervention [1]. This concept has been implemented into the health care field through the implementation of medical edge devices.

Medical edge devices have been used more frequently in recent years to improve the health care system. Medical edge devices are computing devices designed to convert conventional medical equipment into IoT-enabled devices [2]. These enable a range of tasks to be completed such as blood pressure and electrocardiogram (ECG) tele-monitoring. This form of monitoring allows for automatic emergency calls and telediagnosis. The network or e-health system formed from these devices includes a body area network (BAN) of sensors, a gateway for internet access, and a cloud server to process and store e-health data [6]. Understanding this network will provide insight into improving its computational efficiency.

The computational efficiency of medical edge devices revolves around the requirements of the device. Two specific requirements of the devices that can alter overall computational efficiency are latency and energy consumption. These requirements need to be balanced effectively for the specific scenario in order to produce a quality implementation. Heterogeneous Systems on a Chip (SoCs) could potentially provide a framework for selecting the proper balance of energy and performance necessary for these devices.

The area of medical edge devices has a wide-reaching impact that is reviewed in this paper. This technology first and foremost includes an e-health network connecting the patient with medical sensors and professional care. Understanding this network can lead to potential improvements in the system itself. The computational requirements of the system are reviewed along with a possible framework that could be beneficial in meeting these requirements. Lastly the paper will review the material discussed in the paper and propose future work to be done in this research space.

2 Medical Edge Device Network

The medical edge device network is structured in a hierarchical manner that can be extrapolated into separate layers. This structure is based on the concept of fog computing. Fog computing is a solution to data processing in IoT that places devices on the edge of a network with more processing power than end devices and closer to the end devices than the more powerful cloud resources [5]. The benefits of this fog computing solution are a reduction in latency and network congestion.

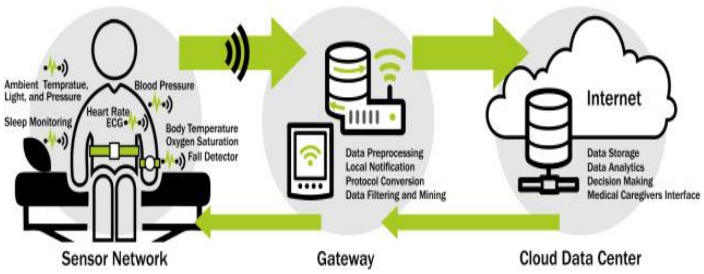

Figure 1: IoT-based e-health monitoring system [4].

The structure of a system utilizing fog computing in the context of health monitoring is demonstrated in Figure 1. The first layer in the system is the Sensor Network. This Sensor Network layer consists of the sensors and monitors forming the BAN that interact with the patient and measure their health-related data. Some of the applications within this BAN use wearable devices to perform the monitoring, while others relay on implantable devices. The importance of this layer is that the caregivers, family members, other authorized personnel are able to check the patient's vitals in real time from anywhere.

The next layer in the system is the Edge/Fog layer consisting of multiple gateways. These gateways act as a hub between the sensors and cloud environment. The gateways are geographically distributed and perform a variety of functions on the incoming data. The gateways perform protocol conversion of the incoming data helping the interaction with the cloud environment. The gateways then perform data filtering, data fusion, and data analysis. Based on this analysis notification of critical conditions can be carried out. Sampling rates can then be adjusted, and the data is then compressed. The gateways also perform security measures by encrypting the data. This encrypted data is then sent to local storage which interacts with the cloud server [4]. As described the gateways are a crucial component helping in a multitude of ways leading to transfer into the cloud layer.

The cloud layer is the final layer described in the IoT-based health monitoring system. The cloud layer holds the cloud server to which the gateways processed data is sent and where professionals are able to see this processed data. The server acts as a storage unit for the data but also is important in allowing for data analytics and decision making to improve patient outcomes through epidemiological medical research. The graphical user interface for medical providers is also contained within this layer which is how providers are able to interact with the patient data and provide necessary updates or changes for the patient. This final layer has many benefits as outlined and is necessary for the understanding of the data that is first monitored in the Sensor layer.

3 Medical Edge Device Computational Requirements Framework

Two important requirements of an IoT-based e-health monitoring system are latency and energy consumption. These two requirements need to be toggled depending on the situational task present for the system. When handling critical tasks the latency must be given full importance, when handling a moderate task there is an equal balance between latency and energy consumptions, and finally when a normal task is being completed energy consumption is given full priority [7]. This structure ensures the needs of the system are met at any given time. A possible framework to meet the needs of a system that performs this type of balancing could include heterogenous SoCs.

The latency of the medical edge device is a key requirement for the health monitoring system. Fog systems offer lower latency than the cloud solutions which is a benefit to implementing fog systems for health monitoring [8]. This low latency is crucial in critical situations such as those presented in elderly care. A fall or deviation from normal health recordings requires immediate action and the low latency of this system can help in providing this through alerts to emergency medical care [3]. The latency is often considered in conjunction with the energy consumption.

The energy efficiency of medical edge devices is another key requirement needed for a properly functioning IoT-based health monitoring system. The fog system architecture tends to outperform cloud computing solutions in terms of energy efficiency highlighting another benefit of this implementation [8]. The energy consumption and efficiency of the system is an important facet of the system because the sensors in the BAN tend to be smaller devices with relatively limited battery capacity. [3]. This low battery capacity and need for low latency in certain situations demonstrates the need for a framework that can handle these varying conditions.

A proposed solution to handling the varying requirements of an IoT-based health monitoring system is the use of heterogenous SoCs. The heterogenous SoCs allows for the use of different kinds of processors or cores to complete computing tasks satisfying the diverse needs of edge computing platforms [9]. The SoC architecture and heterogeneity combines power efficient cores along with massively parallel multi-core-based accelerators to create more comprehensive scaling of power and performance [10]. This scaling effect could be beneficial for use in the medical edge devices.

The processing units (PUs) have started to become commonly used in integrated shared memory heterogenous systems (iSMHS). An important feature of these iSMHS is all PUs can directly access system memory thereby avoiding data transfer costs between the CPU and device memory [11]. This system is optimally used by collocating tasks simultaneously in different PUs and using the system memory as an intermediate medium for inter-PU data communication [9]. This framework would be important in medical edge devices because they must perform signal processing from the BAN along with decision-making continuously while monitoring patient vitals.

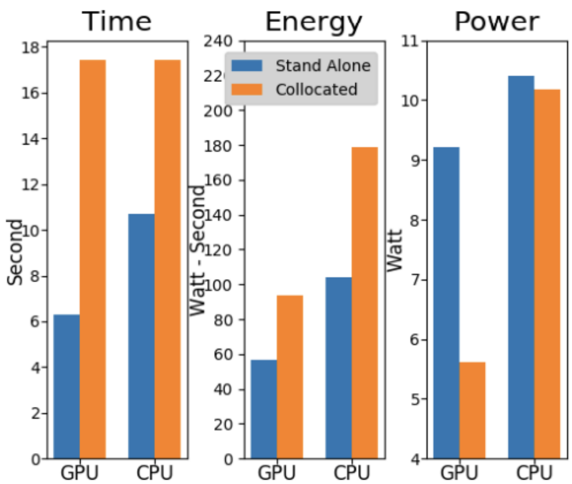

Figure 2: Effect of memory contention on time, energy and power for collocated and stand alone execution on CPU and GPU [9].

A previous study on collocated execution of kernels has been performed in the past to see the tradeoffs between performance and energy and the results are demonstrated in figure 2 [9]. This figure demonstrates that collocation of kernels can have significant effects on power and performance. The time and energy are increased with the presented collocation experiment and power is reduced. These relative trade-offs however can be managed depending on needs. In the paper a per-PU kernel operational intensity was used along with a kernel collocation algorithm to find the optimal collocation to satisfy an energy-performance trade-off (EPTO) [9]. This approach could be beneficial to the EPTO presented previously for medical edge devices.

The medical edge devices could use this approach in their architecture during critical versus normal condition monitoring. For example the framework discussed could prioritize collocation of kernels in a manner that maximizes performance when critical alerts like changes in blood pressure are monitored. When normal resting state conditions are monitored the scheduling of kernels can be done in a way that minimizes energy usage thereby reserving battery capacity.

The EPTO of medical devices present a challenge for implementing this type of system. The latency of medical devices in critical scenarios must be reduced requiring increased performance. This however takes considerable energy which is in short supply due to the limited battery capacity of many of these edge devices. A framework for toggling this performance and energy could be considered through an exploration into kernel collocation on the iSMHS of the edge devices.

4 Conclusion

Medical edge devices are an emerging technology with use cases in a variety of medical disciplines. The network containing the edge devices was reviewed and a framework for handling the various energy and latency requirements was proposed. From this we can then discuss future work in this space.

The IoT-based e-health monitoring system used by medical edge devices was examined in order to understand the needs and structure of the system. The BAN formed the sensor layer, the gateways formed the fog/edge layer, and the cloud data centers formed the cloud layer. These layers interact in a manner that requires prioritization of optimal performance when critical conditions are monitored. This however is constrained by limited battery capacity, meaning during resting conditions energy use must be minimized to keep the system functioning. A possible solution to this paradigm was discussed in the context of the medical edge devices processing units.

The proposed solution for meeting the needs of the IoT-based health monitoring system involved iSMHS. The solution specifically collocated kernels based on the requirements of the system at any specific time thereby conserving energy and still meeting system requirements.

Further exploration into the viability of the proposed solution must be done in future work. This could be through performance testing of a medical edge device such as a ECG monitor. Specifically artificial scenarios could be implemented to reflect the real-life scenarios monitored by an ECG device. System performance could then be measured to ensure that requirements are being met and compare these results to current system configurations to see whether an enhance energy-performance balance is achieved.

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