Applicability of Cloud Native-based Healthcare Monitoring Platform (CN-HMP) in Older Adult Facilities

Abu Bony Amin[1], *Graduate Student Member, IEEE*, Shiyang Wang[1], Uchechukwu David[1] and Yeonsik Noh[1,2], *Member, IEEE*

***Abstract*— Over the past few decades, the world has faced the huge demographic change in the aging population, which makes significant challenges in healthcare systems. The increasing older adult population along with the current health workforce shortage creates a struggling situation for current facilities and personnel to meet the demand. To tackle this situation, cloud computing is a fast-growing area in digital healthcare and it allows to settle up a modern distributed system environment, capable of scaling to tens of thousands of self healing multi-tenant nodes for healthcare applications. In addition, cloud native architecture is recently getting focused as an ideal structure for multi-node based healthcare monitoring system due to its high scalability, low latency, and rapid and stable maintainability. In this study, we proposed a cloud native-based rapid, robust, and productive digital healthcare platform which allows to manage and care for a large number of patient groups. To validate our platform, we simulated our Cloud Native-based Healthcare Monitoring Platform (CN-HMP) with real-time setup and evaluated the performance in terms of request response time, data packets delivery, and end-to-end latency. We found it showing less than 0.1 ms response time in at least 92.5% of total requests up to 3K requests, and no data packet loss along with maximum latency (3 ms) in only 2% of total data packets in 24-hour observation.**

***Clinical Relevance*—This study and relevant experiment demonstrate the suitability of the CN-HMP to support providers and nurses for elderly patients healthcare with regular monitoring in older adult facilities.**

I. INTRODUCTION

The Government healthcare expenditure for older adults over the age of 65 accounts for about 30% of the total healthcare expenditure in the USA. Despite the rising trend in population aging and necessity of regular assistance for their daily living [1]–[3], the existing healthcare services are not fully capable to fulfill the demand even at high cost. Various approaches, including community living, virtual care and tele-health, are currently being explored to resolve this problem. Community living and assisted home living are gaining popularity in recent years because of the increasing interest of older adults to live at home for as long as possible. It is still necessary to monitor high-risk older adults in home and notify caregivers or providers timely in case emergency situations are detected. Nursing homes remain the optimal solution for older adults with health problems and eventually facing problems to independently perform activities of daily living (ADL). Nursing homes are cheaper than the others and cost approximately $250 per day for a semiprivate room [4]. Nowadays most of the older adult care facilities are understaffed in an effort to minimize cost as financial constraints are getting focused [3], [5].

In the era of information and communication technology, healthcare technologies and informatics have evolved along with electronic health record, wearable electronics and remote health monitoring/ tele-medicine care. The healthcare sector has been achieving a great attention of researchers to resolve the current healthcare issues, and consequently a number of internet of things (IoT) based [1], [3], [6]–[8] and cloud based [5], [9] remote monitoring systems have been suggested as cost-efficient, and advanced remote healthcare platform, especially in hospitals and smart home settings. Most of these works [6], [10] are patronized by the pervasiveness of the sensor node applications [11], [12] for collecting and monitoring the vital signs of aging population. To store, manage and process these healthcare related data, cloud computing is a fast growing area of development [3], and cloud native architecture is getting focus for its application to in-home healthcare. Cloud native architecture has the advantage of being a modern distributed system environment, capable of scaling to tens of thousands of self-healing multi-tenant nodes. This architecture is an ideal structure for home healthcare systems thaose require the flexible scalability of users, medical parameters, and service areas, and rapid and stable maintenance.

The main benefit of adopting cloud native architecture is that it can accelerate and improve the quality of our software, products, and code changes. Adding new features, and faster bug fixing cycle allow us to iterate in a faster, safer and higher quality manner with finer tooling of the four pillars (Continuous Delivery, Containers, Microservices, and DevOps). In addition, we can achieve better developer productivity, deploy more effectively, and utilize system scalability. In particular, Containers and Microservices provide better isolation and a nimble way to run and operate software stack on the cloud compared to deploying binary on bare metal or virtual machines. New tools like Docker provide a better way to pack software, and Linux container (LXC) provide better isolation. Microservice architecture and container patterns provide technologies like service mesh and enhance the system security, testing, and logging, and also improve observability, etc. Cloud-native architecture facilitates ease of data sharing by encouraging interoperability and improving

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[1]Department of Electrical and Computer Engineering, University of Massachusetts Amherst, Amherst, MA 01003, USA

[2]Elaine Marieb College of Nursing, University of Massachusetts Amherst, Amherst, MA 01003, USA (ynoh@umass.edu)

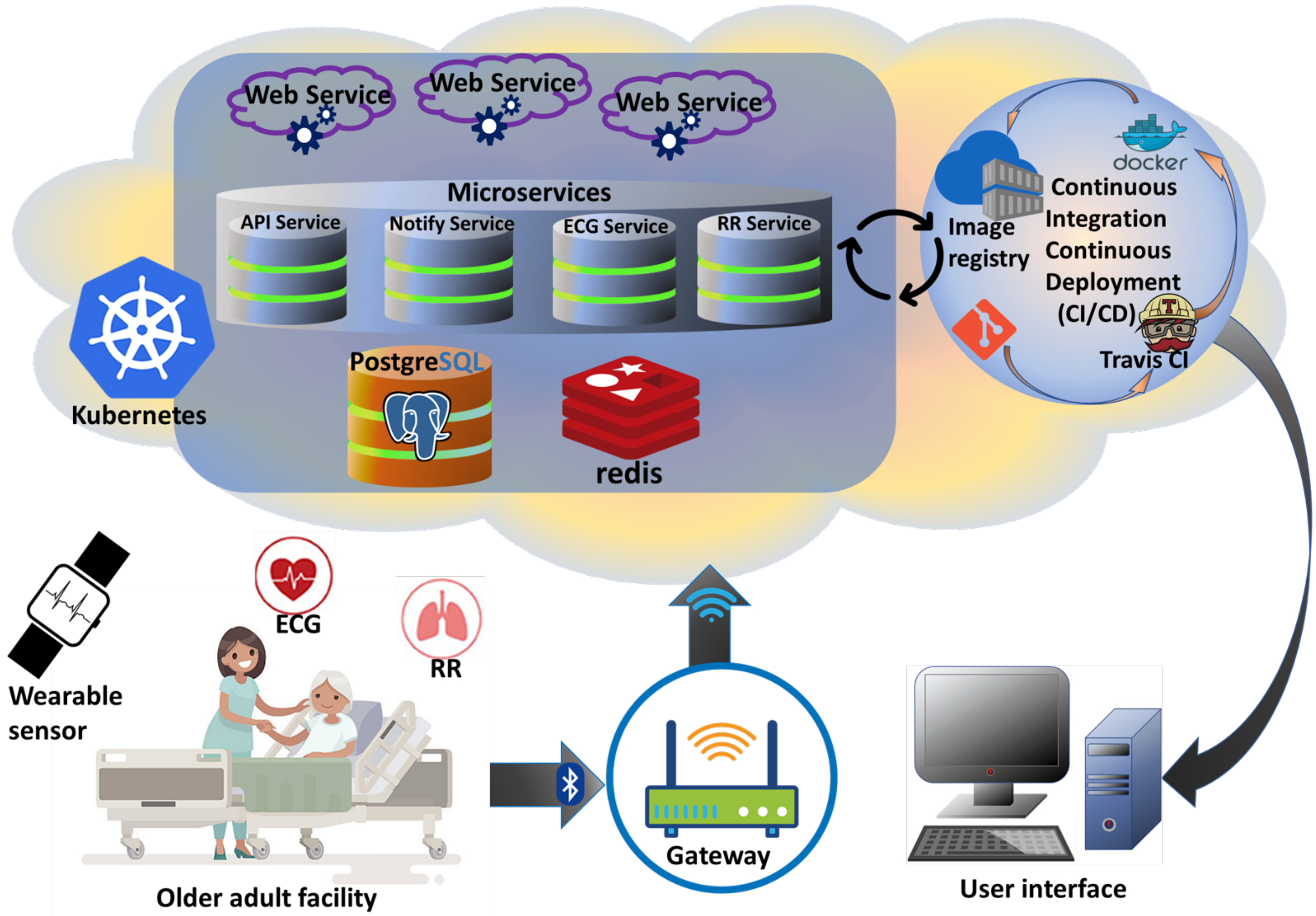

Fig. 1. Prototype of an overall system architecture with CN-HMP to facilitate the low cost continuous monitoring of elderly patients in older adult facilities. The user interface allows doctors along with family members to access the data upon having authorization.

data accessibility across organization boundaries [13]. It's on-demand availability of processing and storage capacity, intelligent data processing and analytics services, and secure and compliant infrastructure help in the rapid development of new applications, cross-domain system integration, and coupling with existing healthcare systems. Hence, it can enable a better access to healthcare data for all stakeholders like consumers, payers, clinicians, and providers [13].

Taking advantage of the cloud native architecture into consideration, we designed our CN-HMP due to its increasing popularity to meet the needs for elasticity and on-demand usage by various applications [14]. Since our focus is to improve the accessibility of healthcare data, we are going to demonstrate our platform superiority and feasibility by illustrating the request response time for packet sent, throughput in terms of successful packet sent over different time duration and end-to-end latency for sending data 24 hour time frame by running real time experiment.

II. CLOUD NATIVE-BASED HEALTHCARE MONITORING PLATFORM (CN-HMP)

According to the definition from [15], cloud-native application (CNA) is a distributed, elastic and horizontal scalable system composed of microservices which isolates state in a minimum of stateful components. In cloud-native architecture, a application is decomposed into independently deployable services where each microservice must have a single function and limited dependency on the other services and these are allowed to make interaction via API-based collaboration [15], [16]. By encapsulating each microservice instance into a "container", it can easily be started, stopped, and migrated which makes managing the data easier [16]. Containers are actively scheduled and managed to optimize resource utilization and many container instances is allowed to launch on a single server or virtual machine (VM) and the startup time can be less than a second. Kubernetes is released by Google as an open source system where the basic unit of scheduling is the pod, a set of one or more Docker-style containers together with a set of resources that are shared by the containers in that pod. When launched, a pod resides on a single server which allows to share storage volumes that are local to the pod [16]. The proposed CN-HMP is mainly comprised of edge nodes for each assisted living home for older adults and a cloud native-based healthcare platform (Fig. 1). In each edge node, The Node device is implemented on a Raspberry Pi Model 3b+ which has built-in Bluetooth low energy (BLE) capability, and it collects health data (ECG, heart rate, respiration, and R-R peaks interval of ECG (RRI)) in real-time from one or more users using the wearable prototype health devices developed in our laboratory at University of Massachusetts (UMass) Amherst. This is then forwarded to the cloud native platform. The application on top of Kubernetes consists of three layers; frontend, data processing service, and database. We will use two different types of databases; PostgreSQL for managing general patient's information, and non-relational key-value based Redis for storing time series data collected from the wearable health devices.

A. *Web frontend*

The CN-HMP designed for any authenticated users (medical stakeholders, patients, and their families)to access the collected data via a web browser using mobile devices (smartphones or tablets) and personal computer. Depending on the user types, the screen view can be modified for ease of use. For example, patients or their family members can access their own information, whereas medical stakeholders can do to all patients. In order to detect emergency or significant medical situation immediately, it has the watch-list area on the top of the web page which is reserved for displaying all users in potentially acute conditions. As new health data comes in, the HealthData service containers (ECG and RR services) check the data to see if this data value falls outside the threshold considered as normal. If it does, the user would have been marked as "potentially acute" and displayed in the watchlist area and then health providers can respond and deal with that situation immediately, which is very useful in a large patient group of users so that providers, nurses, and/or caregivers can immediately identify which users might be in a compromised situation.

B. *Containers (for HealthData and API services)*

A container is a standard unit for operating the application in packages on a cloud native architecture. HealthData (ECE and RR services) containers parse and classify the collected health data and evaluating its risk level according to current evidence-based practices in nursing sciences. Key-value data (ECG, heart rate, respiration, and RRI) are stored in the Redis database and other duplicated and non-key data are stored in the PostgreSQL database so that the data access and distribution can be achieved faster and more efficiently than with the existing monolithic architectures. API containers access databases and transfer the designated data by request from the web frontend. All containers are isolated from one another and bundle their own software, libraries, and configuration files. They can communicate with each other via microservice in a cloud native architecture and can be managed independently, and easily adjusted (up/downscaled) with Kubernetes platform depending on how many homes and patients are to be covered by the proposed platform.

C. *Continuous Integration/ Continuous Deployment (CI/CD)*

In order to define the application in each container, all source codes are developed using Python JavaScript and

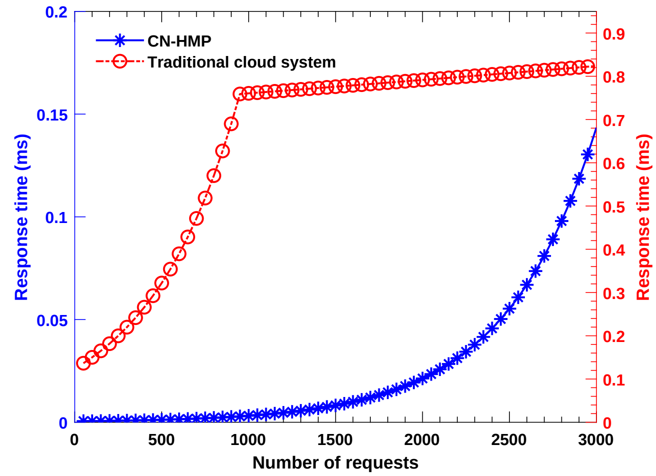

Fig. 2. Comparative demonstration of request response time of the proposed CN-HMP and traditional cloud system. In both cases, the number of requests sent is 3000.

Go programming languages and YAML Domain Specific Language (DSL) and integrated in the GIT software (e.g., GitHub). They are built and tested through Travis CI which is a continuous integration service. Docker is a set of Platform As A Service (PaaS) products that use OS-level virtualization to deliver software, and the developed codes are built as images and pushed into image registry, and then they can be deployed into Kubernetes platform continuously.

III. RESULTS

The main motivation behind proposing this platform is to come up with a system having lower latency for older adult facilities. Hence, the system latency must be well examined to assure that the system can attain sublime performance in dealing with elderly people data and effectively monitor their health in real-time. We have considered two factors defined in [11] for examining the latency dependency of the system. First one is possessed by the hardware components, which can be defined by the response time between the Bluetooth device and the gateway along with the network speed to deliver data from the gateway to Cloud while the other one is created by the software system, performs the data transformation and processing by compressing data during sending and process accumulated data from sensors through each transaction.

Considering these factors, our experiment got placed in the Nursing Engineering Laboratory at University of Massachusetts Amherst (UMass) by using Dell PowerEdge with Intel Xeon @2.4GHz $\times$ 4 CPU of 128 GB memory space and Ubuntu Server (64-bit) operating system. This experiment set up was arranged in real time system with the observation duration of 24 hours long. In same experimental setup, we compared our proposed platform with traditional cloud system and Fig. 2 evidently shows that the response time is less than 0.1 ms for more than 2750 ($\approx$ 92.5%) requests and the others out of 3000 requests are also bounded to 0.15 ms response time in our proposed CN-HMP system.

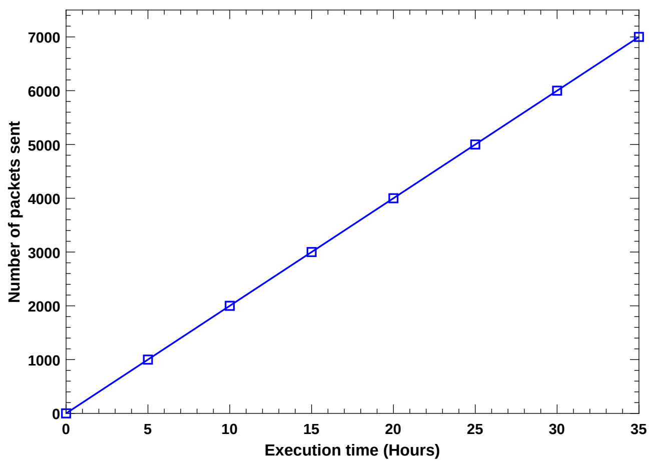

Fig. 3. Depiction of packet sent over the execution time in our proposed platform [11].

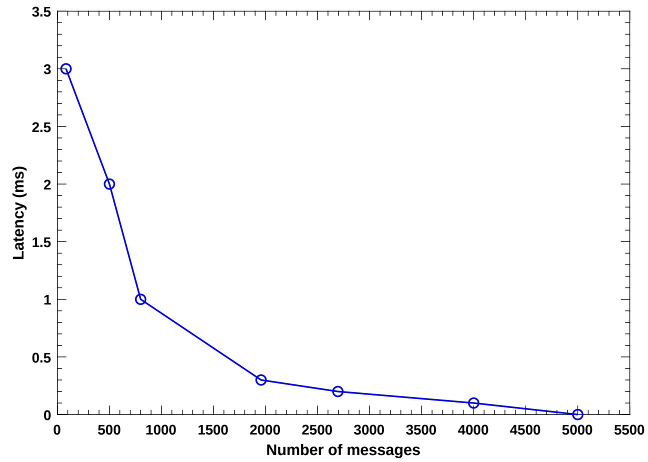

Fig. 4. End-to-end latency of our proposed platform having observed data in 24 hour time-frame.

In contrast, 75% of 3000 requests comes up with more than 0.5ms response time in the tradition cloud system depicted in Fig. 2. The main reason behind this behavior of our platform is that we enabled horizontal pod auto-scaler (HPA), a typical reactive auto-scaler with approach adapting better to fluctuating workload [17], in Kubernetes when receiving higher amount of requests so that the pods are scaling up to reduce the latency.

In Fig. 3, we observe the throughput, which means how many packets delivered out of the total sent packets over the execution time. Fortunately, our system successfully delivers all the packets despite delivering substantially higher number of packets over the execution time. Eventually, we have plotted the number of sent packet in Fig. 3 and we didn't observe any packet drop in our platform over this given time-frame and showed the transcendence of our system in dealing with elderly people data and effectively monitor their health in real-time. The illustration of total end-to-end latency for streaming data continuously over a 24-hour period in Fig. 4 assures the agility of our system. In this case, only 2% of the total packets i.e. 100 messages out of 5000 messages experiences the worst scenario means the highest latency of 3 ms. Our system further yields better performance for higher number of packets.

IV. DISCUSSION

Observing the performance of CN-HMP in terms of latency and throughput in Section III, it is obvious that our system shows promising performance to mitigate our concern raised in Section I for the application in older adult facilities. Furthermore, segmented applications into microservices significantly increases the overall agility and maintainability of applications. As latency is the highly discussed issue for cloud based health monitoring system even for fog assisted cloud infrastructure, our main concentration is to make our system latency immune. Because CN-HMP is solely dedicated for the elderly health monitoring where a very insignificant delay can result a deadly outcome.

The other factor is scalability to reinforce the performance of CN-HMP. Due to the available feature of elasticity in cloud-native architecture, services can be scaled up and down easily from a distributed systems conceptual point of view [15]. Hence, our system offers structural scalability which is the ability of a system to expand in a chosen dimension without major modifications to its architecture [15]. Hence, it is easier to add new features in our system by integrating more monitoring system like SPO2, EMG simultaneously. Furthermore, cloud-native architecture can be scaled on a hybrid-multi cloud environment so that we can spin up tens of thousands of containers across different regions to handle our computing task which can be processing ECG data, RR data, it guarantees our system to achieve high scalability by default.

The noteworthy point is that the node device is lightweight in our system compare to fog node [11] and this allows us to transfer the signal processing to the cloud for real-time health data. To address the data transmission latency we apply cloud-native architecture which gives access to the closest server for node devices to connect, the underneath low latency eventually can be achieved by either in hybrid cloud model or public cloud low latency zone. By moving data processing logic to the cloud without using fog nodes, we reduced edge processing time.

Finally, as an upgraded version of cloud-based deployment, cloud-native architecture is perfectly suitable for reducing the cost of manual operations by exploiting the benefits of software-hardware co-design in need of high-performance hardware [14], [15].

V. CONCLUSIONS

To conclude, our endeavor is to develop a system with lower latency and higher scalability for monitoring the elderly health conditions in older adult facilities and keep the system affordable is supported by the experimental findings. We ascertained the comparative advantages of CN-HMP in our discussion and how it can make the life of old people convenient. Beyond that, the doctors and nurses will also feel essence of this system due to having less workload and timely knowledge about the patient's critical conditions. Consequently, it is conspicuous from the findings that our proposed CN-HMP can be an appealing candidate for fulfilling the requirement to offer convenient life to the older adult facility residents. Our subsequent intention is to adopt this system for vast E-health monitoring in hospital and smart-home using IoT.

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