Guest Editorial: Internet of Things for In-Home Health Monitoring

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UNDER the pressure of the growing millennial population and senior citizens are aging, which is one of the top societal priorities in many countries, the provision of healthcare needs to evolve and improve. A roadmap paved by World Health Organization (WHO) in March 2019 called Global Strategy on Digital Health 2020-2024, specified a grand vision of promoting healthy lives and well-beings for everyone, everywhere, at all ages [1]. WHO urges all nations to work hand in hand in developing and delivering Digital Health initiatives supported by robust government strategies that amalgamate financial, organizational, human and technological resources [2]. In particular, there are some niches areas in the strategies such as the adoption of distributed sensors and assisted living emerging in recent years. To this end, a lot of efforts both from the research community and industrial providers are anticipated to put forth in the coming decade, in implementing the concept of assisted living using hardware devices into meaningful solutions for fulfilling the growing needs of assisted living.

Internet of Medical Things (IoMT) is an emerging concept that stands for the internetworking of distributed devices and sensors [3]. Those so-called “medical things” have the ability to collect and exchange data, between users and users, as well as users and machines via the internet. Allowing users and doctors, even machines with artificial intelligence to be informed of a patient’s condition in real-time [4], via the unprecedented sensing ability, IoMT revolutionizes the healthcare landscape. When properly analyzed, the data from IoMT turn into useful insights that add values to the long chain of healthcare processes starting from early diagnosis and disease prevention to health status monitoring and in-patient treatment, for anyone in anywhere at any time.

One profound and prolific application scenario of IoMT is for in-home monitoring and assisted living. Users can stay connected with their doctors or caregivers, virtually, synchronously or whenever an emergency arises ad-hoc. For example, IoMT applications send an emergency signal when a user is detected suffering from an asthma attack, accidents such as falling or choking. Real-time responses and almost zero data transfer latency are performance factors critically required in emergency situation. On the other hand, analytic capabilities of IoMT are equally important [5]. They help doctors in making the right decision automatically or as a decision support aid in prognosis for customizing an appropriate treatment plan based on the symptoms of the disease detected, measured and delivered remotely by the sensing technologies.

Typically, from a system point of view, IoMT embraces healthcare process automation. A large volume of data are collected, even continuously, for different types of diagnosis and subject to analytics and predictive models. The whole system would have to function hand-in-hand, involving data acquisition and collection, computer networking, process automation and its supporting middleware, hardware and software integration to the hospital legacy systems. The connection and integration start all the way from the front-end at the assisted living homes which are usually referred as smart homes where remote sensors and wearable sensors are installed, to the backend computing systems including regional or national PACS, Hospital Information Management Systems, Electronic Healthcare Records (EHR) System and possibly public healthcare systems. IoMT certainly encompasses a wide variety of heterogeneous components that must function dependently on one another. Technical challenges of IoMT exist at all levels ranging from data privacy and security, communication protocols, synchronization, data storage, access management, data sharing to smart assisted-living and telemedicine.

Classical hospital computerized systems were not designed in mind to support IoMT in the dawn of EHR. IoT that first became popular for smart home automation was not made for distributed healthcare systems too, with an unparalleled complexity of diagnostic and analytic for medical use.

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Upon the arrival of IoMT the layout of existing healthcare infrastructure needs to be changed, adopting new functions and fulfilling new requirements of IoT technology. New medical services introduced by IoT will have to interconnect with users interfaces (which may be customized terminals or mobile App), sensor devices, new or modified network services, and healthcare resources through some scalable applications that run compatible on both existing communication infrastructure and forthcoming ones in the near future such as 5G networks.

Riding along with the current technological advancements of IoT and the demands of in-home monitoring as a part of assisted-living strategies, this special issue aims to contribute with the latest research works to this new IoMT paradigm especially for in-home monitoring. The accepted papers in this special issue are themed at three levels: data communication level, network services level and application level. The state-of-the-arts from these papers fill the current gaps of technological shortcomings between the legacy healthcare systems and tomorrow's IoMT applications.

The special issue starts with a tutorial paper addressing Internet of things for in-home health monitoring systems, by Philip *et al.* [6]. Many applications related to the topic have been introduced over the last few decades, thanks to the advances in mobile and IoT technologies and services. Current studies of in-home health monitoring systems presented many benefits including improved safety, quality of life and reduction in hospitalization and cost. However, many challenges of such a paradigm shift still exist, that need to be addressed to support scale-up and wide uptake of such systems, including technology acceptance and adoption by patients, healthcare providers and policymakers. This paper focuses in three main aspects: i) review of key factors that drove the adoption and growth of the IoT-based in-home remote monitoring; ii) present the latest advances of IoT based in-home remote monitoring system architecture and key building blocks; and iii), discuss future outlook and our recommendations of the in-home remote monitoring applications going forward.

The next three papers contribute to revamping the communication protocols in IoMT environment for better efficiency. Cai *et al.* [7] designed a MISO-SWIPT-aided code-index modulated multi-carrier M-DCSK system for e-Health IoT, for facilitating better data communication. Another multi-carrier design by Zhang [8] based on sparse vector coding-based multi-carrier NOMA was made suitable for in-home health networks. Misra *et al.* [9] proposed a new dynamic radio protocol selection scheme called DROPS for supporting the flexible use of energy-constrained wearable devices for IoT healthcare. These new systems endeavor to support the operations of IoT devices for long monitoring use. The common operational requirements for these systems are energy efficiency, robustness and reasonable data rate, which should be balanced at some optimal point. The new systems are supposed to offer a good performance trade-off. The experimentation from these three papers confirms the advantages of most of the three criteria by the new schemes.

The next four papers tackle the security issues at the data communication level of IoMT by presenting new identity authentication and data encryption methods in distributed environments. Deebak *et al.* [10] bring forth a new mutual authentication protocol for cloud-based medical healthcare systems. The contribution enables mutual authentication of identity and access between the backend system which is running on a remote cloud and the ubiquitous IoT devices. The new protocols are smart and efficient suitable for loosely connected IoT devices whose operations should be kept at low-cost and fast response time. Likewise, Alladi *et al.* [11] proposed a 2-way authentication protocol for three entity healthcare IoT networks, called HARCI. After the users authentication is made ready, the following step is to ensure that the data exchange is trustable and the data being exchanged are secured. A trusted data exchange platform for IoT e-Health devices communication is described in [12] by Lu *et al.* Zhang *et al*. [13] proposed an efficient multiple-party identity-based encryption scheme for personal EHR sharing. The researchers made significant steps towards the realization of a holistic and secure IoT medical healthcare system, on which users do not need to worry about security problems such as identity imposing and information leaks when their devices are connected seamlessly over the IoMT networks and the EHR systems.

Building on the secure, robust, energy-aware and efficient data communications as technology cornerstone, communication network services need to be enhanced as well, for running IoMT-oriented applications. The following papers shed light on how computer network services should be improved for supporting IoMT-oriented applications in terms of network offloading and streaming services scheduling. Zhou *et al*. [14] proposed a learning-based URLLC-aware task offloading policy, and Zhang *et al*. [15] compliment the flexibility of offloading policy by allowing the policy to be programmed in multi-stage stochastic manner. Zhou *et al*. [16] looked into cross-modal stream scheduling in an IoMT network. Taking the offloading, scheduling and policing policies to a problem preventive level, Sanabria-Russo *et al*. [17] formulated an on-demand orchestration of services for health emergencies prediction and mitigation called CURATE. The network services ought to be well managed collectively as a whole system even upon events of emergencies. This group of researchers attempts to relieve the performance bottleneck in IoMT network for e-Health which may experience fluctuating workloads since there would be a dynamic but potentially large number of devices connecting to the network; the loads are required to be managed properly in order to avoid hot-spots.

A new network topology called fog is gaining momentum recently as an alternative to cloud network, a step towards decentralizing the processing and control. Fog is perceived as a solution to the bottleneck of overloading at some centralized servers (a central cloud, for example) when the number of devices and users grow phenomenally in IoMT. The data analysis tasks are offloaded from the central processing server to the local servers or at the edge nodes in proximity, burdens are released but the delegate coordination and management become more complicated. Aloi *et al.* [18] has developed simulation-driven platform for edge based Ambient Assisted Living (AAL) system. AAL can take many different configurations and requirements to fit a wide range of different application scenarios. The simulation allows designers to test and verify an edge network design before committing to costly implementation. Ning *et al.* [19] investigated and proposed a mobile edge computing system that is empowered by 5G health monitoring functions for IoMT. They adopted a decentralized game theoretic approach to model complex IoMT and 5G communication scenarios for finding optimal payoffs. To further exploit the power of edge network, Wu *et al.* [20] looked into transfer learning for emotion recognition under cloud-edge-client collaborations. This work has taken the collaboration context with complexity and high standard in machine learning and image processing requirements to a new level among cloud-edge-clients. This work is the epitome of how emotion recognition as an application of AAL can be made possible by sophisticated transfer learning across different nodes and clients in a distributed IoMT network using edge computing technology. It serves as a successful example of implementing distributed AI at IoMT network. Aujla and Jindal [21] contribute to another dimension of edge computing in IoMT with authentication and assess-control. They proposed a decoupled blockchain approach for edge-envisioned IoT-based healthcare monitoring. That would be useful for preserving privacy and enhancing security in IoMT applications running on edge network.

There are ten selected innovative papers on monitoring applications in in-home IoMT environment. The next two papers are about using RFID to monitor respiration in driving environment [22] by Yang, Wang and Mao, and when the user is using his mobile device (supposedly not driving) [23] by Zhang *et al.* Another contribution which is also on wearable sensors in IoMT is by Salem *et al*. [24]; from a Wireless Body Area Network where sensors are attached at different parts of a patient's baby, an anomaly in the signals can be detected by Markov models. Machine learning seems to be a trend in the latest research even in IoMT. The relevant algorithms are enhanced and applied in IoMT for in-home monitoring. Some papers which are in alignment of this trend, are selected as follows: Dourado, Jr. *et al*. [25] developed an open Deep Learning framework for online medical image recognition. Yuan, Han and Guan [26] contributed a solution to ambiguous machine learning based on mislabeled training data for in-home IoMT monitoring. Incomplete data is not uncommon in dynamic situations such as those with distributed IoT which has extreme connectivity functioning in probably noisy environment and with interference from home electrical appliances. Virtual reality (VR) technology was also used for IoMT, for the purpose of enhancing remote monitoring of physical rehabilitation of stroke patients. Postolache *et al*. [27] pioneered in this work combining the advantages of VR and IoMT for application scenarios of rehabilitation. Various monitoring application scenarios of medical diseases or symptoms are also seen in the submission of this special issue. These important works about leveraging the power of IoMT for monitoring the following diseases include: pulmonary nodule classification by Tong *et al*. [28], early diagnosis of neurological diseases by Sciarrone *et al*. [29], and of Parkinson's disease by Raza *et al*. [30], and EEG-based pathology detection as well by [31] Muhammad, Hossain and Kumar.

In conclusion, we are grateful to the colleagues of the IEEE JSAC editorial office who granted us this opportunity for this special issue with their professional supports. We are of course thankful to all the authors who submitted their quality papers in great enthusiasm, with innovative ideas and sound technical knowledge. We thank also the reviewers' team who spent much of their time and effort in carefully and generously shared their knowledge by their constructive comments. All the selected papers have gone through several rounds of meticulous revisions, committing to a very high standard of journal paper writing. We also thank the great support and Special Issue supports from our IEEE ComSoc Technical Committee on e-Health. Last but never the least, the production team deserves a big thank you for their speedy handling, typesetting, editing and publishing this special issue.

It is hoped and anticipated that this special issue will generate much of ripple effects in multi-disciplinary research communities, encompassing e-Health, medical science, IoT and computer network technologies. The future of IoMT for in-home monitoring will look more promising than ever. Inspired by the articles in this special issue, fellow researchers are encouraged to carry on this research momentum to innovate, research and develop, working hand-in-hand with the practitioners for delivering meaningful and useful applications for better health of everyone using IoMT.

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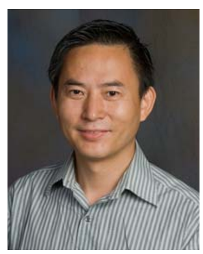

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