



# Fog computing for Healthcare 4.0 environment: Opportunities and challenges<sup>☆</sup>

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## ABSTRACT

Internet of things provides interaction with billions of objects across the world using the Internet. In Internet of thing era, Healthcare Industry has grown-up from 1.0 to 4.0 generation. Healthcare 3.0 was hospital centric, where patients of long-lasting sickness suffered a lot due to multiple hospital visits for their routine checkups. This in turn, prolonged the treatment of such patients along with an increase in the overall expenditure on treatment of patients. However, with recent technological advancements such as fog and cloud computing, these problems are mitigated with a minimum capital investment on computing and storage facilities related to the data of the patients. Motivated from these facts, this paper provide an analysis of the role of fog computing, cloud computing, and Internet of things to provide uninterrupted context-aware services to the end users as and when required. We propose a three layer patient-driven Healthcare architecture for real-time data collection, processing and transmission. It gives insights to the end users for the applicability of fog devices and gateways in Healthcare 4.0 environment for current and future applications.

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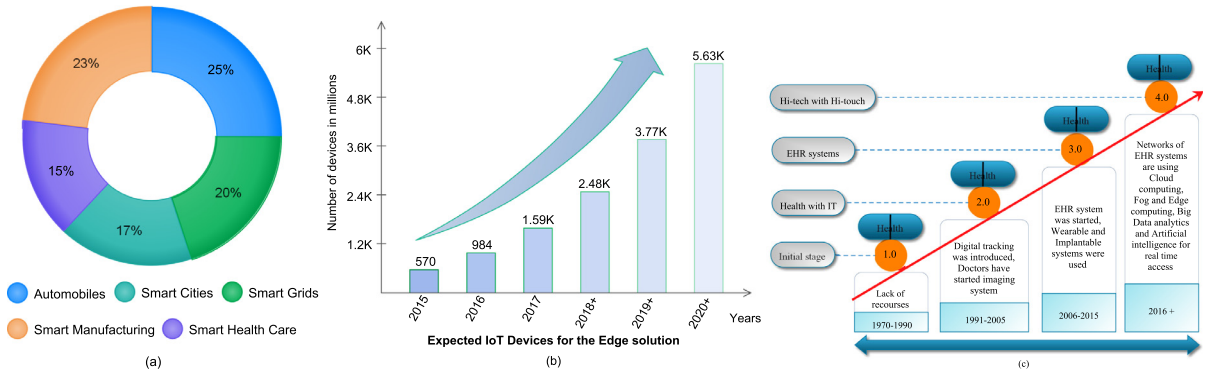
## 1. Introduction

From the last few decades, we have witnessed various trends in the Industry standards and applications. For example, Industry 1.0 focused on Mechanical Engineering and automation followed by Industry 2.0, which was electrical energy oriented. The next generation consists of Industry 3.0 having telecommunication and information communication technology (ICT) as its core components. But, with the evolution of Internet of thing (IoT) and cloud computing (CC), current form of Industries, i.e., Industry 4.0 is based on intelligent devices deployment and their usage. Advances in Industries allow interaction with billions of objects across the global world. According to an Industrial survey conducted by Grand View Research [1] as shown in Fig. 1(a), it was confirmed that the revenue obtained from automobile Industry segment was more than

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**Fig. 1.** Scenarios of: (a) Application based Global FC market in 2016, (b) Growth in number of IoT devices, and (c) Revolution in Indian Healthcare Industry.

25% in 2016. Also, it is observed that Healthcare sector garnered good revenue which is more than 15% in 2016. In order to fulfill the requirements of Industry 4.0, the acceptance of IoT devices is growing at a rapid pace [2] as shown in Fig. 1(b).

To make the environment eco and user friendly, Healthcare Industry needs to be prioritized with respect to service availability (as compared to the other Industries as mentioned above). Similar to other Industries (Mechanical, Electrical, or Civil), Healthcare Industry categorized from 1.0 to 4.0 generation. Healthcare Industry is still in its nascent stage as it marked its beginning in the year 1970. The efforts were preliminary and resources were limited, therefore, this stage was termed as Healthcare 1.0. Subsequent gain in the momentum of information technology (IT) field and medical technologies development of advanced medical imaging and tracking systems and the Healthcare 2.0. The advent of new and effective treatment methods has started with the intervention of computational methods and data processing systems. In this context, the period of 2006–2015, Healthcare 3.0, became popular due to use of electronic health records (EHR), an alternative version of patients data-chart. This generation has adopted the EHR to help doctors to get the relevant information on time. The revolution in Indian Healthcare Industries [3] is shown in Fig. 1(c). Artificial intelligence (AI) and strong communication interface is into Healthcare environment doctors with the abilities of data portability, useful and efficient analytic anywhere. Such value-based system enables Healthcare Industry to improve in providing the quality of service (QoS) with well-informed decisions. Healthcare 4.0 is being considered in USA where 90% of the Healthcare system has been planned to turn towards value-based system. In India, it is expected to run with an estimated budget of 6000 million US\$ by year 2020. Number of Healthcare IoT devices are producing a large amount of data at regular intervals, therefore, storage and security of such a vast/enormous data are the major issues in this environment. Physical data storing in a hospital may not be possible in every situation so, an emerging technology, CC can handle the situation easily.

Having high storage capabilities and flexible processing services, CC has considerably expanded the application scenario of wearable medical sensors (WMS)-based systems [4]. Across the globe, investigators, and institutions have engaged in developing prototypes to employ WMS-based technologies and services offered by the cloud. Regardless of the multifaceted advantages, the cloud fails to address various issues for the following sensitive applications:

- In real-time, the hindrance in data transfer and processing over cloud and relay of the final outcome back to the users are unacceptable.
- In some cases, just a little delay or lack of application availability due to any reason (power failure, loss of Internet connectivity, cloud failure etc.) may become life-threatening.

In order to rectify the above mentioned issues of CC, a recently emerged computing paradigm, fog computing (FC) is introduced between IoT devices and CC [5]. Depending upon the sensed information, smart e-Health gateway process it to either CC or FC. Emergency situation can be handled by the experts using fog gateway to have minimum delay in information gathering. For better performance against delay, a strong communication infrastructure is always needed to get a better outcome. FC is used for interactive surroundings to facilitate the devices to access the prerequisite data using a cloud network.

FC extends the CC paradigm to the edge of the network. The idea is to migrate few CC data centers tasks to fog nodes (FNs). FC empowers service delivery on-time with consistency while overcoming difficulties related with CC such as cost overheads, delays or jitters while information is transferred to the cloud. Moreover, it is a distributed flat architecture that enhances the storage, computational and networking resources along the CC. It provides quick access to resources such as computing and storage for Healthcare applications. Hence, CC and FC is passionately applied to the IoT field, which takes into account latency sensitive multimedia services and other real-time services such as Healthcare. There is a fog layer (FL) in FC, which covers most of the challenges of Health Industry 4.0 by associating with CC, Big Data analytics, AI, and EHR system. FC offers few major benefits in comparison to the CC approaches:

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