Computers and Electrical Engineering 67 (2018) 58–69

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Towards energy-aware fog-enabled cloud of things for healthcare☆

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ARTICLE INFO

Article history:
Received 5 January 2018
Revised 28 February 2018
Accepted 28 February 2018

Keywords:
Application allocation
Cloud of things
Energy efficiency
Fog Computing
Internet of Things
Healthcare

ABSTRACT

The Internet-of-Things (IoT) represents the next groundbreaking change in information and communication technology (ICT) after the Internet. IoT is concerned with making everything connected and accessible through the Internet. However, IoT objects (things) are characterized by constrained computing and storage resources. Therefore, the Cloud of Things (CoT) paradigm that integrates the Cloud with IoT is proposed to meet the IoT requirements. In CoT, the IoT capabilities (e.g., sensing) are provisioned as services. Unfortunately, the two-tier CoT model is not efficient in the use cases sensitive to delays and energy consumption (e.g., in healthcare). Consequently, Fog Computing is proposed to support such IoT services and applications. This paper reviews the most relevant Fog-enabled CoT system models and proposes an energy-aware allocation strategy for placing application modules (tasks) on Fog devices. Finally, the performance of the proposed strategy is evaluated in comparison with the default allocation and Cloud-only policies, using the iFogSim simulator. The proposed solution was observed to be more energy-efficient, saving approximately 2.72% of the energy compared to Cloud-only and approximately 1.6% of the energy compared to the Fog-default.

1. Introduction

The convergence of the Cloud and IoT (CoT) represents a vision of the future Internet and supports a new and richer portfolio of smart services. However, such combination does not fit services with real-time, delay-sensitive and energy efficiency requirements due to the inherent limitations of these aspects of the Cloud. To this end, Fog computing was proposed

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. D. Puthal.

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https://doi.org/10.1016/j.compeleceng.2018.02.047
0045-7906/

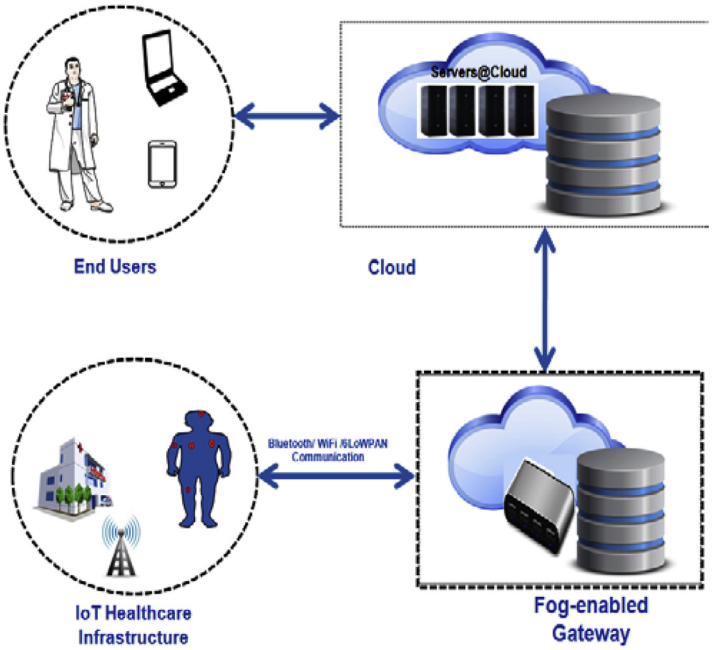

Fig. 1. An illustration of Fog-integrated CoT-based healthcare architecture.

by Cisco for providing such services at the network edge [1]. Many benefits can be attained by using Fog computing, such as reducing the energy consumption and the load on data centers, in addition to conserving the network bandwidth [2,3].

A recently proposed integration of Fog computing with IoT-based healthcare (see Fig. 1) represents a new trend in innovative e-health solutions. This combination enables healthcare services with improved latency, energy consumption, mobility, and Quality of Service (QoS). Such improvements result from the key characteristics of Fog, such as (i) proximity to end-users/IoT devices, and (ii) Mobility support of end-users, enabled by a geographically distributed architecture. The proximity to end users supports real-time responses and reduces latency, whereas mobility significantly promotes ubiquitous healthcare by enabling patients to obtain healthcare services efficiently regardless of location. As a Fog server can process the data gathered from IoT devices without reliance on the Cloud, it can effectively save the network bandwidth and cloud storage for vital data and processes [4,5].

To achieve an efficient scheduling and resource allocation in a Fog-enabled CoT system, suitable metrics should be considered according to the required objectives, such as application types, user mobility, and energy efficiency. Accordingly, the scheduling strategy should determine the location where applications or tasks are offloaded, either the Fog or the Cloud. It also determines the priority of applications' execution at a particular Fog instance according to the respective delay constraints. Furthermore, the scheduling strategy should consider various possible scenarios of application tasks execution, taking the primary objectives into account [6]. The primary contributions of this paper are summarized as follows:

- The related literature on CoT and Fog-enabled CoT system models is reviewed with a particular focus on energy efficiency.
- An allocation strategy to reduce the energy consumption of Fog devices (i.e., fog servers) based on the remaining CPU capacity and available stored energy, while ensuring efficient performance of real-time task execution, is proposed.
- A performance evaluation of the efficiency of the proposed strategy and the resulting gains in energy efficiency is conducted.

The remainder of the paper is organized as follows. Section 2 provides the background information on CoT, Fog, and Fog-enabled CoT. In Section 3, the most relevant related studies on the topic are discussed, while Section 4 describes the proposed algorithm. In Section 5, the simulation tool, the scenario used to evaluate the proposed solution, and the performance evaluation study are presented, while the analysis of the obtained results is discussed in Section 6. Finally, Section 7 concludes the paper and provides insights for future research.

2. Background

2.1. Cloud of Things (CoT)

The Cloud of Things (CoT) [7,8] is a promising computing model in which IoT capabilities are preserved as on-demand services. In CoT, the Cloud and IoT complement each other. For instance, IoT can overcome resource constraints by taking