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Fog-based caching in software-defined information-centric networks☆

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ABSTRACT

In this paper, we propose a cache replacement approach for Fog applications in Software Defined Networks (SDNs). Our approach depends on three functional factors in SDNs. These three factors are: age of data based on periodic request, popularity of on-demand requests, and the duration for which the sensor node is required to operate in active mode to capture the sensed readings. These factors are considered together to assign a value to the cached data in a software-defined network in order to retain the most valuable information in the cache for longer time. The higher the value, the longer the duration for which the data will be retained in the cache. This replacement strategy provides significant availability for the most valuable and difficult to sense data in the SDNs. Extensive simulations are performed to compare our approach against other dominant cache replacement policies under varying circumstances such as data popularity, cache size, network load, and connectivity degree.

1. Introduction

A Software-Defined Network (SDN) is a virtual network capable of acquiring knowledge about its users/inhabitants and its surroundings, and uses such knowledge to help its inhabitants achieve their goals and desires in a context-sensitive manner [1,2]. This definitely improves inhabitants' quality of life, and helps in optimizing and controlling the dramatically increasing consumption rates of resources in smart environments. Inhabitants (users) of a large smart environment (such as a city) could be people, systems, devices, services, or agents, occupied with smart enabling technologies such as RFIDs, sensors, nano-technology, etc. With the evolution of the information-centric IoT the global data networks are interconnected and accessed over cloud systems. The increasing demand for highly scalable and efficient distribution of content/information has motivated the development of future Internet architectures based on named data objects (NDOs), for example, web pages, videos, documents, or other pieces of information. The approach of these architectures is commonly called information-centric networking (ICN). In contrast, current networks are host-centric where communication is based on named hosts, for example, web servers, PCs, laptops, mobile handsets, and other devices. Information-Centric Networks serves as a Data-based model which focuses on client's demands disregarding of the data's address or the origin of distribution. ICN is the next generation model for the *Internet* that can cope with the user's requests/inquiries regardless of their data-hosts' locations and/or nature. The current *Internet* model is suffering from the exchange of huge amounts of data while still relying on the very basic network resources and IP-based protocols. Meanwhile, ICNs promise to overcome major communication issues related to the massive amounts of distributed data in the Internet. ICNs adopt a Data-centric architecture which focuses more on the networked data itself rather than the meta-data. This kind of network architectures are known usually by the Content Oriented Networks (CONs) term [3]. Luckily, these CONs architectures match a lot with the emerging communication trend that aims at

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exchanging Big-data over tiny and energy-limited wireless sensor networks (WSNs) in order to realize numerous attractive projects such as the Smart-planet and the Internet of Things [4,5]. Thus, a new platform is needed to meet these requirements. A new platform, called Fog Computing [6], or, simply, Fog because the fog is a cloud close to the ground, has been proposed to address the aforementioned requirements. Fog is a Mobile Edge Computing (MEC) that puts services and resources of the cloud closer to users to be facilitated in the edge networks.

Unlike Cloud Computing, Fog Computing enables a new breed of light applications and services, that can be run at particular edge networks, such as WSNs. In order to enable WSNs to support this trend in communication and function in a large-scale application platform, such as the Fog Computing, we proposed the cognitive framework from our previous work [7]. In [7], we use smart in-network devices with the capabilities of making decisions based on the information obtained from WSNs to put forward a new information-centric system. The knowledge and reasoning used to dynamically determine the appropriate route where knowledge is defined using value and attribute, and reasoning is represented using the analytic hierarchy process (AHP) technique. The authors in [8,9] point out that the upcoming WSN properties such as reliability and delay shall use AHP in their Quality of Information (QoI) assessment. This cognitive Information-Centric Sensor Network (ICSN) framework is able to significantly outperform the *non-cognitive* ICSN paradigms. However, this cognitive ICSN framework did not consider yet the in-network caching feature. Caching in multitude of nodes in ICNs has pivotal role in enhancing the network performance in terms of reliability and response time. In this paper, we propose the use of Value of sensed Information (VoI) cache replacement strategy. It identifies the most suitable data to be replaced in order to maintain prolonged data availability periods while enhancing the network performance. However, authors in [10] and [11] claim that the conventional cache replacement strategy has been intended for IP-based networks and data-centers, which have different data positioning characteristics against the future networks, such as the ICSNs. Moreover, different caching strategies have different effects on the overall performance of the network, and hence, a given caching strategy can influence publishers' load, hit-ratio, and time-to-hit metrics. Numerous attempts in the literature have reviewed each of these metrics independently. However, a single ICSN has the ability to handle multiple users with different designs. Accordingly, a generic dynamic utility function with the ability to consider all the metrics mentioned above while emphasizing on the application itself should be used.

To this end, we provide a novel utility function that sets a value to each cached data item in an ICSN framework. This utility function can determine which data item to drop from the cache while experiencing limited hardware resources for caching. Furthermore, we provide a cache replacement strategy that depends on the VoI in choosing the most appropriate data to be replaced in the cache. We compare our VoI approach against three dominant cache replacement approaches: Node Role-based Caching (RC), Data-based Caching (CC), and Geo-based Caching (GC) with regard to various performance metrics under a variety of parameters including cache size, data popularity, in-network cache ratio, and network connectivity degree.

The rest of this paper is organized as follows. Section II provides an overview of the existing caching approaches in ICSNs. Section III talks about our ICSN-specific system model which we use to build the proposed VoI caching policy. We provide a detailed explanation for the VoI approach in Section IV. Section V presents the detailed simulation results obtained from comparing VoI against other caching approaches. Section VI summarizes our concluding remarks.

2. Related work

In Fog paradigm, data has to *be close* to the consumers/users. This is the purpose of caching approaches in this paradigm. Caching is associated usually with naming and data delivery approaches/architectures. For instance, the Data-Oriented Network Architecture (DONA) is coupled with naming tuples and labels. Other architectures differ in the basis of retaining data and which entity in the network can keep a copy of the data. Recently, data caching based on how long it was it was in the network is recommended. However, it is quite difficult to claim efficiency when the overhead messages cannot traverse the network. We look at the different Information Centric Sensor Networks caching approaches in this article. Also, we classify the existing caching in ICSNs as follows: A) Geo-based caching, B) Data-based caching, and C) Role-based caching.

2.1. Geo-based caching (GC)

In Geo-based caching, data is cached mainly based on the geographical location of the caching node. For example, Chai et al. in [12] recommended caching in less spaces in ICSN against caching everywhere. Their policy claims that data should only be cached in nodes with the highest cache-hit rate. Meanwhile, the Cache Aware Target idenTification (CATT) is a topology aware caching policy proposed by Eum et al. [13] where a downloading path is selected given that it has the highest connectivity degree. Nevertheless, this can make this kind of node behave like a geographical bottleneck in the network. Moreover, the authors in [14] have looked into the performance of topology based replica on internet router-level topology and concluded that the router-level fan-out is almost as good as the greedy placement of replica. The node degree used by the work done in [13–15] cannot be considered as a sufficient solution for replica replacement because most of the nodes contain similar, and relatively low degree or fan-out. The author in [14] proposed the use of self-organizing cache management systems, where nodes make globally similar decisions. This system has proven to have reduced delays against the conventional ways and smaller per-node cache. Li et al [20] proposed a selective neighbor caching system, in which a subset of neighboring proxies are selected such that the minimum mobility cost is experienced. This approach is grounded on caching data requests and their corresponding meta-data in a subset of proxies one hop away from the data publisher. Authors in [21] suggests a probabilistic approach for ICNs. They claim that the probability of a file being cached should be increased as it travels from source to destination by considering the following parameters: i) The distance between source and current node, ii) Distance between destination and current node, iii) Time-To-Live for the routed data content, and iv) the Time-Since-Birth. Authors also