Future Generation Computer Systems 89 (2018) 89–97

Contents lists available at ScienceDirect

Future Generation Computer Systems

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

Proactive caching for edge computing-enabled industrial mobile wireless networks

Xiaomin Li, Jiafu Wan *

School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou, 510641, China

HIGHLIGHTS

- Considering mobility, a three-layer caching architecture in IMWN is proposed.
- The sojourn time and effective link time of mobile node are determined.
- For delivering large amount of data, the optimal caching strategies are proposed.
- The performances of the proposal are analyzed via a simulation and comparisons.

ARTICLE INFO

Article history:
Received 26 December 2017
Received in revised form 23 April 2018
Accepted 10 June 2018
Available online 27 June 2018

Keywords:
Edge computing
Proactive caching
Industrial wireless network
Mobile node
Big data download

ABSTRACT

As manufacturing systems shift from automated patterns to smart frameworks such as smart factories in Industry 4.0, industrial wireless networks (IWNs) are serving as promising communication systems that can be applied to the manufacturing field. When the mobile elements and static nodes are introduced into the system, large amounts of data downloaded from mobile networks or tele-servers can be one of the greatest challenges for industrial mobile wireless networks (IMWNs). Mobility and industrial properties have rarely been considered by previous research on download strategies and caching methods. In this paper, we present a three-layer cache architecture based on edge computing and other heritage traditional networks. Then, useful spatial and temporal mobility properties are mapped using different groups and edge computing servers that contain mobile nodes. Then, according to the sojourn time, the capacity of edge computing servers and other neighbouring nodes, we propose a proactive caching strategy for large amounts of data downloaded by mobile networks that considers location and mobile trajectories. Moreover, the superiority of our proposed scheme is demonstrated by comparison case studies of widely used classical schemes. The numerical results show that our proposed strategy achieves higher goodput and real-time and other performance.

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1. Introduction

With the increasing progress of information and communication technologies (ICTs) [1–4], growing ICTs are constantly introduced into multiple industry domains. This trend is more prominent in the manufacturing industry. Manufacturing systems are currently shifting from automated patterns to smart frameworks such as smart factories in Industry 4.0 and are further propelled by popular trends [5–8]. In addition, mobile nodes (MNs) are undergoing rapid growth in smart factories, arising from the flexibility, mobility and extendibility of the technology [9,10]. Industrial mobile wireless networks (IMWNs) bridge smart heterogeneous equipment and create a communication channel among users and manufacturers. Because ubiquitous communications exist in the novel system, mobile data traffic is an active research topic and the main challenge associated with IMWNs. Big data or large amounts of data transmission are gradually magnifying this challenge [11,12]. One main effort to meet such a strong demand is to deploy additional access points or base stations. Although this method can increase bandwidth and access choices, it results in heavy traffic to the backbone of the work, particularly between edge nodes and tele-servers. Therefore, traditional methods are not effective to meet manufacturing industry demands. Edge computing and pre-caching techniques [13] offer a potential solution.

Network computing is migrating from cloud computing to fog or edge computing [14], particularly for the Internet of things, which includes numerous edge nodes. Since edge computing allows more accurate structures, this framework can be merged into the mobile network and form mobile edge computing (MEC) systems. These systems have drawn relatively strong attention from academia and industry. Certain studies [15,16] have focused

* Corresponding author.
E-mail address: jiafuwan_76@163.com (J. Wan).

https://doi.org/10.1016/j.future.2018.06.017
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on network computing resource deployment, edge computing or providing the computing service for edge nodes. However, only rarely have studies addressed caching or data storage based on MEC for accommodating big data transmission. MEC provides an alternative option to accommodate large amounts of data communication. The key research issue in caching storage is finding fast wireless networks. Popular content and quality experiences have been developed; the associated methods are provided in [17–19]. Although the IMWN can benefit from these previous studies, the studies can also take on certain new features. Most previous research has focused on static networks and has neglected mobility and industry properties, which are not suitable for the industry scenario.

There are several reasons for this study [20–22]. Firstly, there are great requirements for distributing data from cloud to node. Secondly, moving nodes increase the complexity of the data distribution for dynamic changes of network topology. Thirdly, in industrial wireless networks, real-time data distribution is a key assessment criterion for industrial devices. Most previous works focused on data transmission, but these studies have to the constraints such as communication rate, energy consumption. Proactive data caching technology provided a new option. Distinct from the previous research, we consider mobility and industrial properties to propose a three-layer caching architecture in IMWN. Then, based on MEC, we present a model that can determine the optimal caching strategies of a large amount of data downloaded from tele-servers. Our strategies can be divided into three stages. First, we map the MEC server and neighbouring nodes according to their mobile trajectories. Second, the sojourn time and effective link time are determined. Third, the finishing layer caching is completed. Then, we analyse the performance of the proposal via a simulation and compare the results to the results of other methods.

The remainder of the paper is structured as follows. In Section 2, we briefly review and discuss the related works for edge computing and caching. Then, the three-layer storage architecture and the outline of our strategies are provided in Section 3. Section 4 describes the system model and the solution procedure of the proposed schemes. The performance evaluation and conclusions are presented in Sections 5 and 6, respectively.

2. Related works

In the section, we briefly review the related works about edge computing and caching methods.

Industrial wireless network (IWN): Critical time or real-time data delivery for IWNs has been an active research direction in recent years. A brief survey of previous work can be found in [23,24]. Specifically, in [25], a novel routing protocol that achieves high-quality real-time performance was proposed for uploading data from nodes to a base station; this approach estimates the communication cost to select the best path according to an optimization method. Reference [26] is based on exploiting runtime information for unused pre-allocated bandwidth and dynamic bandwidth management strategies are presented. Article [27] is based on the condition of links and network topologies to find the best schedule for a given link of wireless radio. In [28], the authors proposed a novel medium access control protocol for granting each user channel access based on different priority levels. The solutions that were considered used the critical time data traffic from optimizing MAC, routing, bandwidth or other network resources. However, these approaches are based on static topologies of application systems. They cannot capture industrial properties, and they ignore the mobility of the network.

Mobile edge computing: Computing frameworks are shifting from cloud computing to fog or edge computing. Edge computing provides a new perspective that has become a promising paradigm for accommodating data delivery on a deadline, particularly for mobile wireless networks [29,30]. An MEC-enhanced adaptive bit-rate video delivery scheme that combines the content caching and video streaming technology was proposed in reference [31]. A vehicular delay-tolerant network-based smart grid data management scheme that leverages the MEC paradigm was demonstrated in reference [32]. Similarly, an SDN-enabled network architecture assisted by MEC, which integrates different types of access technologies, was proposed in [33], and a game theoretic approach for achieving efficient computation offloading in MEC frameworks was presented in [34]. This previous work provides us with useful references for addressing time-critical data delivery. However, these approaches do not consider industrial applications and data downloads from tele-servers.

Caching technologies: Network caching techniques were described in [35] to achieve satisfactory performance for large amounts of data traffic. In [36], the authors investigated the exploitation of user mobility information in cache-enabled content-centric wireless networks; they adopted different cashing methods according to their spatial and temporal properties. In [37], the authors introduced a proactive caching architecture for 5G wireless networks by processing a huge amount of available data on a big data platform and leveraging machine learning tools for content popularity prediction. In [38], an optimal proactive caching for mobile networks using user demand properties was proposed. In [39], social-aware edge-caching techniques and associated edge caching schemes were proposed to minimize bandwidth consumption. Previous studies have focused on network computing resource deployment and edge computing and on providing computer services for edge nodes. However, it is rare to find caching or data storage research based on MEC for addressing big data transmission.

3. Architecture of industrial MEC and strategy

In this section, in accordance with manufacturing system properties and previous work on the structure of IWNs, we first construct a single-hop clustered industrial wireless mobile network. Then, we present a three-layer storage system based on cloud and edge computing in the industrial domain for the delivery of large amounts of data. Moreover, we briefly review our strategies for the different stages of big data traffic for working MNs.

Fig. 1 demonstrates the scene of a smart factory, where industrial Internet of things (IIoT) nodes, sensor nodes, automated guided vehicles (AGVs), workers, and machines are deployed in a factory. In contrast to randomly moving traditional networks, IMWN MNs must follow a certain or a fixed path to complete a specific task such as workpiece conveyance, as shown in Fig. 1. When higher real-time data delivery efficiency is required, single-hop and clustered network frameworks are widely adopted in the industrial domain. Therefore, our architecture is based on clustered networks. We deploy an edge computing server (CES) at every cluster head with a storage system. The framework can be divided into three layers: cloud storage, cluster head edge storage and local node storage. Using wireless links to connect nodes and cluster heads and using backbone network links to cloud and edge servers, each edge server can provide communication service within the coverage ranges for MNs and other nodes. Consequently, when an MN must transmit a large amount of data from tele-cloud servers (TCSs), proactive caching methods can be used. The three-layer data storage layer working processes are as following for data distribution for moving nodes. Wireless moving node need big data storing in industrial cloud server (ICS), namely first storage layer. Edge computing server (ECS) cache parts of big data. That is second storage layer. It is known that ECS cannot provide continuous wireless link service, so sensor nodes are employed to store fragment data of big data to make up for ECS insufficiencies. Namely, moving

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