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Invited Paper

Overview of Multimedia Mobile Edge Computing

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Abstract Recently, to provide a low-latency mobile computing platform, Mobile Edge Computing (MEC) is proposed. In this paper, we first summarized the feature capabilities of MEC, such as content distribution and caching, computational offloading and multimedia Internet of Things (IoT). Then, to understand recent research efforts of multimedia MEC, we briefly highlight the research efforts in terms of above three capabilities: how to achieve edge caching in video distribution, how to schedule computational offloading to the cloud and how the communication quality degradation affects to the user experience of multimedia IoT. Finally, we addressed the emerging research issues of multimedia MEC to improve reliability and robustness of multimedia MEC.

Keywords: Mobile Edge Computing, Multimedia, Internet of Things, Survey

1. Introduction

During the last decade, growing and expanding mobile devices, such as smartphones, have accelerated evolution of Information and Communication Technology, especially cloud computing and wireless communications. In cloud computing, currently, many cloud services, such as file sharing, Content Delivery Network (CDN) service, and machine learning, are provided by several cloud vendors, such as Google[1], Amazon[2] and Microsoft[3]. In wireless communications, the mobile devices equip various network interfaces, such as Long Term Evolution (LTE), Wi-Fi and Bluetooth, and can connect to "the cloud" anytime and anywhere. As a result, the mobile devices, especially smartphones, are selected as a main platform of mobile services, and nowadays, the smartphones' owners can easily experience rich multimedia applications, such as 4K video streaming, Augmented Reality (AR) and Virtual Reality (VR), via the wireless networks.

Moreover, not only the smartphones, but also sensor devices and surveillance video cameras are connected via the wireless networks. In Internet of Things (IoT) services, the sensor devices, including network cameras, are installed everywhere, and enable to monitor city streets, social infrastructures and nature environments in real time. Because the sensor devices have less computational resources and battery, the sensing data and captured videos are uploaded and analyzed in the "centralized" cloud[40]. This behavior is a typical example of "computational offloading." The computational offloading indicates that computational tasks are transferred to external computing environments, such as cloud servers, via wired/wireless networks and executed in the external computing environments instead of an own device.

According to the Cisco's report[4], Cisco forecasts that the mobile traffic will increase seven-fold from 2016 to 2021, and mobile video accounts for approximately 80% of all mobile data in 2021. Thus, due to the centralized cloud, the plenty sensor data and rich contents may trigger the overloaded computing and severe network congestion, especially in the cloud-side backbone network, and invoke longer latency for data exchange between the cloud and end devices.

To reduce the computational load in the cloud and to reduce backbone network traffic, cloudlet based computational offloading is proposed[5]. Cloudlet (like a mini-cloud or a private cloud) is deployed in the physical proximity to users, such as in a shop and a restaurant, and accessed by using Wi-Fi (i.e., Cloudlet covers a small area). Although the cloudlet may provide the low-latency network connection, this tiny cloud has few computation and covers only few users.

Recently, to cover a larger region, and to provide low-latency connectivity and resourceful computing, Mobile

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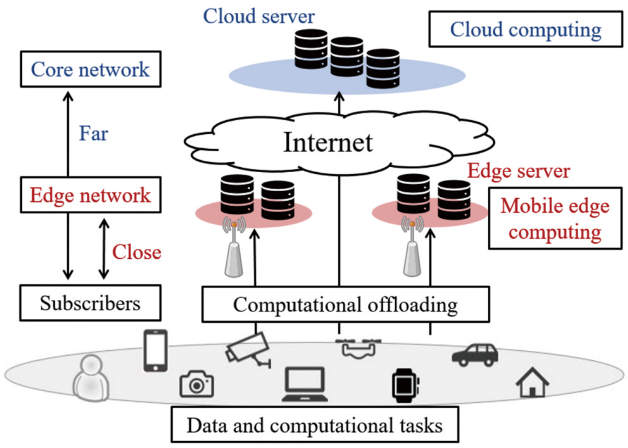

Fig.1 Comparison image of cloud computing and mobile edge computing.

Edge Computing (MEC) and fog computing are proposed[6) 7)]. Figure 1 shows a comparison image of cloud computing and MEC. As shown in the figure, in MEC and fog computing, computing resources, as we called "edge servers", are placed on physical proximity from the mobile devices (i.e., edge of networks), such as at the edge routers, wireless communication base stations, and access points, and cloud-computing capabilities are provided to mobile devices (or MEC subscribers). Therefore, because the edge servers are located close to the subscribers, MEC and fog computing can achieve lower latency compared to the cloud and also provide the similar computational environment to the cloud.

Although several papers already surveyed edge/fog computing[39) 41) 42)], in this paper, we summarize the concept and features of MEC in terms of multimedia (IoT) applications. It should be noted that this paper covers MEC and fog computing equally because they have quite similar concepts. In addition, although European Telecommunications Standards Institute (ETSI) which is one of standardization group of MEC recently re-defines MEC as "Multi-access" Edge Computing, we also regard "Multi-access" as "Mobile".

The rest of this paper organized as follows. Section 2 gives an overview of MEC and introduces three feature capabilities of MEC: content distribution and caching, computational offloading and big data analytics. Section 3 highlights recent research efforts on multimedia MEC in terms of above three features. Section 4 discusses emerging research challenges of multimedia MEC. Finally, Section 5 illustrates conclusions.

2. Mobile Edge Computing

2.1. Overview of Mobile Edge Computing

In this section, we introduce the overview of MEC. According to Orsini[43)], edge computing was firstly proposed by Akamai in 2004[6)]. In this paper, Akamai places a content caching function at the edge node of their content delivery networks. Currently, MEC is given more complex capabilities: not only storage capabilities, but also computing capabilities. According to ETSI, they define that MEC provides cloud-computing capabilities and an IT service environment at the edge of the network[8)].

As described in Section 1, the main goal of MEC is to provide the low-latency mobile computing platform to mobile subscribers, such as smartphone users, automobiles and even sensor devices. To address this objective, in MEC, as shown in Figure 1, computing resources as we called "edge servers" are placed on the physical proximity to the MEC subscribers (e.g., the edge servers will be placed within Evolved Universal Terrestrial Radio Access Network (E-UTRAN) [9)14)15)]). Unlike to cloud computing, the edge servers are distributed to the edge networks, and this decentralize architecture contributes to reduce the backbone network traffic load and provide the low-latency mobile computing platform.

As many researchers report the promising use case scenarios of MEC[10)~13)], we summarize three feature capabilities of MEC: a) content distribution and caching, b) computational offloading and c) big data analytics, and illustrate these capabilities in Figure 2. As shown in the figure, in the content distribution and caching, the edge server plays a role of content server which equips a

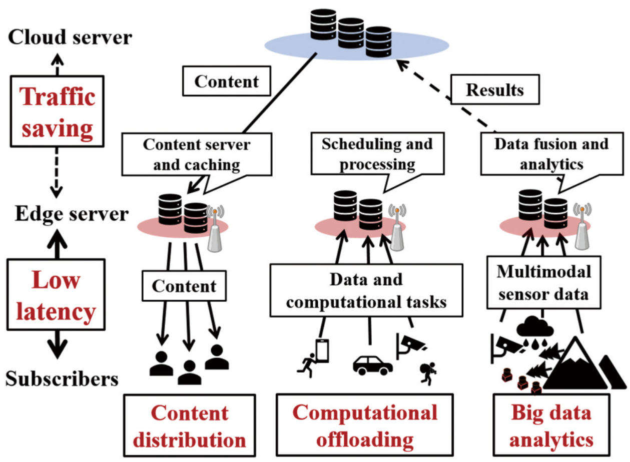

Fig.2 Typical MEC features and capabilities.

content caching capability. In the computational offloading, instead of subscribers, the edge server executes processing tasks which are transferred from the subscribers. In this case, the main processing task represents image processing. Because the processing task is required to each MEC subscriber (i.e., MEC provides personal mobile service to the MEC subscriber), MEC also performs a scheduling in order to optimize the subscribers' processing delays. In the big data analytics, similar to the computational offloading, MEC also performs processing, such as data analytics, including image processing. Extend to the computational offloading, in this case, MEC collects the wide variety of sensor data from multimodal sensors and conducts data fusions. It should be noted that these capabilities are typical examples of MEC, and mobile services compose the combinations of these capabilities.

2.2. Content distribution and caching

First, similar to Akamai's edge computing[6], content distribution and caching is one of important capabilities of MEC (as shown in Figure 2). As reported in Cisco Visual Network Index[4], video streaming service is one of major mobile application, and major cloud vendors, like Amazon[2], provide CDN service on their cloud computing platforms. However, due to the centralized cloud server, rich content (e.g., 4K videos) will easily trigger the backbone network congestion and this will cause Quality of Experience (QoE) degradations (e.g., video playback freezes for long time).

In MEC, to reduce redundant video traffic, the edge server equips video caching and coding capabilities to distribute videos to the MEC subscribers. Because the edge server locates physical proximity to the subscriber, the subscriber can retrieve a video with low latency compared with the cloud. In addition, as the edge server transcodes the video by multiple bitrates, like Dynamic Adaptive Streaming over HTTP (DASH)[16], the edge server can optimize Quality of Service (QoS) for each edge subscriber according to the subscriber's network performance.

2.3. Computational offloading

Second, offloading computation is also essential capability of MEC (as shown in Figure 2). The edge server provides its own computing resource to the MEC subscribers to provide low latency computing for latency-sensitive applications, such as AR, VR and autonomous cars. Due to the limitation of computing power, storage capacity and battery, local devices, such as smartphones and sensor devices, cannot play a role of main computing platform for such latency-sensitive applications. Typically, these applications require high complexity image processing, such as object recognition and tracking. Although the cloud server can perform such resource-hungry processing, uploading images/videos takes wasted time and consumes huge network bandwidth. Thus, offloading to MEC can be the promising platform not only to provide low-latency mobile computing, but also to save backbone network traffic and devices' battery lives.

2.4. Big data analytics

Thirdly, big data analytics, including video analytics, is a unique capability of MEC (as shown in Figure 2). In the upcoming IoT world, various sensors, including surveillance cameras and wearable devices, connect to the Internet via wireless connections and generate sensing/capturing data periodically. In IoT applications, such as monitoring and prediction abnormal events, efficient analysis of these periodical data is mandatory. In addition, as described in the previous subsection, because IoT application also requires plenty computing resources, like video surveillance system, and cannot be performed in the sensor devices. Thus, the edge server performs big data analytics. Because the edge server is placed at the mobile base station, collecting the sensor data at the edge server has a great advantage (sensor devices uploads the data via the mobile base station.) This also means that the edge server covers a same area of the base station for the analytics, and such location awareness has also advantage to the analytics. After the edge server obtains analysis results (e.g., warning), just sending the results to the cloud can reduce network resources and improve network latency because the results generally consist of tiny messages.

3. Research Efforts on Multimedia MEC

In this section, we highlight recent research efforts on multimedia MEC in terms of three categories related to illustrate previous section: a) video distribution and caching, b) computational offloading to mobile cloud, and c) multimedia IoT.

3.1. Video distribution and caching

First, in video distribution and caching, much research conducted on the methodology of proactive content distribute/caching at the edge of networks.

Han et al. proposed an opportunistic content pushing scheme that predicts user's moving route and distributes the requested content to the edge server which placed at a Wi-Fi spot along with the user's moving route[17].

Lobzhanidze et al. proposed a proactive video caching scheme based on video popularity prediction using a topic modeling tool called Latent Dirichlet Allocation and a frequent pattern mining algorithm called Apriori[18]. Tran proposed a collaborative caching scheme to optimize adaptive rate control under the heterogeneity of user capabilities and networking condition[19]. The authors utilize the edge server as a content caching and transcoding platform, and solve the optimization problem that minimizes the backbone network traffic by considering limitations of cache storage and computing power. Islam et al. proposed the edge cloud system called Void for video/audio distribution and transcoding[20]. The authors deployed the proposed system to a private cloud and Amazon EC2 and evaluated the system performance.

Moreover, in Information Centric Networking (ICN), edge caching is one of main research topics. Vasilakos et al. proposed a selective neighbor caching scheme that selects an optimal edge nodes by considering user's mobility[21]. Similarly, Rao et al. proposed a proactive caching approach for seamless user-side mobility support in Named Data Networking (NDN)[22]. The authors of this paper also proposed a proactive content caching scheme utilizing transportations[23]. In the proposal, we placed edge servers at train stations and distribute 50 videos to the edge servers and mobile devices by using Wi-Fi spots.

From these research efforts, the edge server can contribute to reduce backbone video traffic, latency of content retrieving, and improve QoE of video distribution: shorter playback freezing time and higher response time.

3.2. Computational offloading in mobile cloud

Next, in computational offloading, much research conducted on the strategy of offloading scheduling. Essentially, there is no large difference between offloading to the "edge" and offloading to the "cloud". Therefore, we also target offloading strategy for cloud computing in this subsection.

Girod et al. studied mobile visual search system by collaborating to the cloud[24]. The authors introduced three offloading strategies: just uploading compressed image, uploading image feature descriptors instead of image itself, and uploading the descriptors only if there is no matching result in the local cache. Kumar et al. discussed the energy saving performance of cloud offloading[25]. The authors formulated energy consumption of computational offloading and communication. Cuervo et al proposed energy-aware application offloading system called MAUI[26]. MAUI monitors the energy consumption of each executing application and schedules the application offloading timing based on optimization problem by considering device energy characteristic and network condition. The authors validated MAUI energy-saving performance by using real application such as face recognition and video games. Chun et al. presented CloneCloud which equips automatic application segmentation and migration to the cloud[27]. Similar to MAUI, CloneCloud optimizes execution time and device energy consumption by considering cloud computing and communication resources. Kosta et al. proposed a mobile computing framework called ThinkAir which is an improvement version of MAUI and CloneCloud[28]. ThinkAir equips on-demand resource allocation and parallel execution by adopting Virtual Machine (VM) on the cloud. To equip these capabilities, ThinkAir overcomes scalability issues of MAUI and CloneCloud. In addition, ThinkAir considers the payment cost of cloud services to optimize offloading schedule. Chen et al. proposed an offloading strategy based on game theory[29]. Takahashi proposed Edge Accelerated Web Browsing system based on the hybrid of cloud and edge servers[30]. The proposed system achieves to reduce the execution time of web-based application by offloading the web-content fetching and web-page rendering to the edge server.

From these research efforts, the computational offloading can mainly contribute to optimize execution time and battery life in the local device. Most of researches derive formulas of optimization to decide offloading scheduling.

3.3. Multimedia IoT

Thirdly, in multimedia IoT, much research conducted on multimedia system for IoT services, such as video surveillance system, cloud gaming and AR.

In video surveillance system, Wang reviewed the intelligent multi-camera video surveillance system[31]. According to the review, video surveillance system integrated several image processing techniques: computer vision and pattern recognition. In the review, the author listed the recent technologies in terms of multi-camera calibration, computing the topology of camera views, multi-camera tracking, object re-identification and multi-camera activity analysis. Because these technologies are closely related to each other, data fusion and cooperative sensing are key technologies to provide robust video surveillance.

Similarly, Zhu et al. conducted the multi-view action recognition based on a multi-sensor data fusion technique[32].

In interactive multimedia applications, Wang et al. analyzed the challenges of Cloud Mobile Media, especially Cloud Mobile Gaming in mobile cloud computing[33]. The authors proposed a new quality metric for mobile gaming user experience and carried out quantitative evaluations of user experience in a real-time cloud gaming session. From their results, the response time has a serious impact to quality of user experience. Similarly, Satyanarayanan et al. reports influence of network latency and jitter to rendering smoothness (frame rate) of visualization application[5]. From their results, even a modest latency case (33 ms), the frame rates drastically decrease. As a result, the user experience seriously degrades as the network latency increases. Ha et al. proposed an AR based assistive system by using Google Glass devices for users in cognitive decline[34]. To perform real-time image processing, such as face recognition and object recognition, the proposed system utilized the both cloud and edge servers for computational offloading. The authors concluded that the end-to-end low-latency communications is essential to provide real-time cognitive assistance. Floris et al. proposed a QoE model for multimedia IoT applications[35]. To validate the proposed QoE model, the authors evaluated QoE performance of vehicular multimedia applications, and results concluded that the proposed QoE model has a high correlation with subjective quality assessments.

From these research efforts, typical multimedia IoT applications have a latency sensitivity, and these applications require not only high computational environment but also low-latency wireless communication. Thus, offloading to the edge servers via low-latency networks is a promising approach.

4. Research Challenges

MEC is an emerging technology and still has several research challenges. In this section, we briefly summarize research challenges of Multimedia MEC in terms of four topics: a) scalability, b) resource management, c) mobility management and d) security.

4.1. Scalability

Scalability of MEC is one of emerging research issues. Especially in multimedia IoT applications, as described in the previous subsection, the user experience will easily degrad as latencies of computing and communication get increase. Although the edge server will cover various services that offer different quality requirements, the edge server has limited computation compared with the cloud server. In addition, the number of mobile devices, including IoT sensor devices, are growing, and most of them are expected to connect to the edge server and be performed big data analytics. In such circumstances, MEC must ensure service quality requirements to provide a reliable computing platform.

Therefore, the scalability of MEC should be discussed. For instance, limitations of MEC capabilities will be useful information, and these discussions will newly address the MEC deployment scenarios.

4.2. Resource management

Related to the scalability issues in MEC, computing and communication resource management is also mandatory research topic. Mainly, there are two research challenges of resource management: resource sharing and dynamic resource scheduling. Unlike to cloud computing, because MEC distributes to deploy the edge servers, computing resources are distributed everywhere and provided via various network conditions. To offer various services while ensuring user experience, resource sharing is essential[36]. Moreover, although much research conducted on computational offloading as described subsection 3.2, the resources of edge server may be dynamically changed. Thus, efficient management of such distributed and fluctuated resources is an emerging.

Thanks to evolution of virtualization technologies of networking and computing, such as Software Defined Network (SDN) / Network Function Virtualization (NFV) and OpenStack, they are one of promising technologies to overcome the challenges[37]. Prediction methods of the resource usage and code-based segmentation methods of mobile multimedia applications will also be useful research topics to schedule computing offloading.

4.3. Mobility management

Move to the MEC subscriber side, such as smartphone owners and automobiles, providing high quality multimedia application to such subscribers is challenging. This is because the mobile communication quality will fluctuate easily along with the subscriber's mobility. Although MEC will provide more reliable and higher speed mobile connections compared with the cloud, MEC still potentially encounters such quality degradation. Furthermore, in the mobile computational offloading scenario, the edge server must consider the subscriber's next movement (i.e., handover to a next edge server) to schedule the computational offloading. This is because, the mobile subscriber potentially moves to the next edge server when the previous edge server complete the processing, including video distribution. Therefore, to maintain service quality, MEC or mobile services must manage/predict the subscriber's next move and perform mobile computing proactively.

In case of public transportations, such as trains or buses, the next move of the transportations can be easy to predict because it has a fixed time table. For these passengers, proactive distributing video to the edge server can provide increase user experience[23]. Although, in case of pedestrians, it is difficult to predict their movements, combining navigation system may be also a practical approach[38].

4.4. Security

Security is also challenging issue in MEC. Because current multimedia applications demand more personal data to achieve personalized user requirements, the security role in MEC is quite important. To provide the personalized service, MEC gathers the plenty personal data to mobile subscribers, and must protect such applications and stored personal data. In addition, the MEC subscribers, especially sensor devices and surveillance cameras, also need to have an authentication mechanism to access to the edge server[39].

In addition, we briefly summarize the security challenges that ETSI claims as follows: ensuring the edge server isolations, the authenticated and secured communications, and no modification of platform software and firmware by a malicious party[15].

5. Conclusion

In this paper, we summarized the overview of MEC and illustrated the important capabilities of multimedia MEC: edge caching for video distribution, computational offloading and multimedia IoT. Targeting to these three capabilities, we briefly highlight recent research efforts: how to achieve edge caching, how to schedule computational offloading to the cloud and how the communication quality degradation affects to the user experience of multimedia IoT. Finally, to enhance this promising mobile cloud computing platform, we addressed the emerging research issues of multimedia MEC.

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