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Leader-Controlled Real Time and Synchronous Multimedia Presentation for Wireless Mobile Group Touring Services using the Multi-Access Edge Computing (MEC) Technique*

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This work designed an innovative group touring service based on the Multi-Access Edge Computing (MEC) architecture and developed the associated group touring APP called "DEH_Narrator". The DEH_Narrator APP allows users to form an Mobile Social Network (MSN) group that contains a group leader and some group members. The group leader can (i) share her/his downloaded text and multimedia contents of Point of Interest (POIs) to all of the group members and (ii) control the playout of these shared contents in the handheld devices' DEH_Narrator APPs of all group members to assist her/his oral explanation work in the group touring scenario. That is, it belongs to the other type of real time and synchronous multimedia presentation because the corresponding multimedia content needs to be displayed to other group members' handheld devices during the group leader's oral explanation of the target POI. To meet the requirement of synchronously control and real time's presenting POI's multimedia content in all of the group members' handheld devices, the proposed group touring service adopted the MEC paradigm and architecture, in which a MEC server is associated with a mobile WiFi router, to provide users better quality of service (QoS) in terms of the data transmission time and quality of experience (QoE) in terms of the response time from selecting a POI to displaying the selected POI's multimedia content to all of the group members' handheld devices. Experimental results demonstrated that the adoption of the MEC paradigm and architecture can significantly improve the performance, *i.e.*, the response time than without adopting the MEC paradigm and architecture.

Keywords: group touring, real time and synchronous multimedia presentation in multiple handheld devices, content sharing, point of interest (POI), mobile digital culture heritage (M-DCH), mobile edge computing (MEC), mobile social network (MSN), location-based service (LBS)

1. INTRODUCTION

Due to the widely deployed wireless mobile network and the popularity of using smartphones, let the tour guide and each member of the touring group have a handheld device, *e.g.*, a smartphone or an iPad, respectively. The tour guide can author and upload the text and multimedia contents, such as image, audio and video files, of related Point of Interest (POIs) to the remote cloud server in the Internet before her/his work. Then, the tour guide can interpret the culture, local custom, and some precious objects or events that have happened in each POI to members of the touring group through the help of her/his authored text and multimedia contents, which are downloaded from the remote cloud

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server through the 4G/5G wireless mobile network and displayed in the tour guides' and members' handheld devices of the touring group. Fig. 1 (a) depicts the networking configuration for the aforementioned wireless mobile digital content assisted group touring scenario, in which the tour guides' and each of the members' handheld devices of the touring group individually connects and downloads the text and multimedia contents of POIs from the remote cloud server through the 4G/5G cellular network.

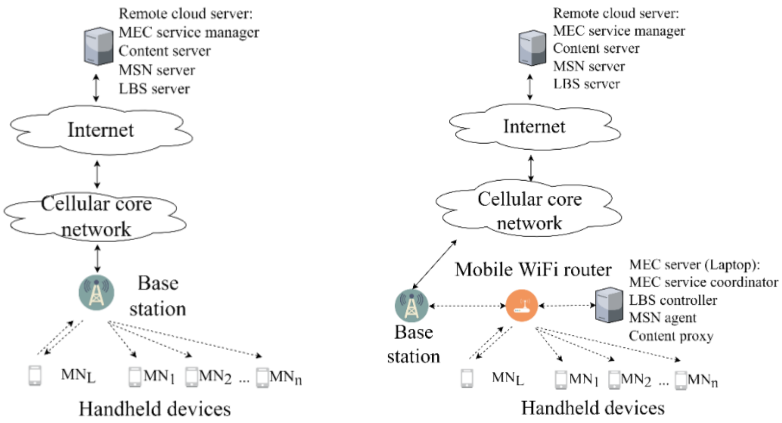


Fig. 1. The networking configuration of downloading text and multimedia contents of POIs from (a) the remote cloud server; and (b) the MEC server.

Nevertheless, the aforementioned networking configuration for group touring has some problems. Let there be one tour guide and n members and thus there are $(n+1)$ handheld devices in the touring group. Since each handheld device needs to connect to the remote cloud server and download the corresponding text and multimedia contents of each POI individually, the first problem is that, it needs to download the same contents for $(n+1)$ times from the remote cloud server to these $(n+1)$ handheld devices that are nearby with each other, which results in the waste of the 4G/5G cellular network's resource and the waste of money expense for these $(n+1)$ users of using 4G/5G cellular network because the same copy of contents has downloaded $(n+1)$ times, although these $(n+1)$ users are nearby. The second problem is that, the presentations of text and multimedia contents of each POI may not be so real time and synchronous among all of these $(n+1)$ handheld devices because each handheld device is controlled by each user and each handheld device's network experiences different network delay. The third problem is that, not all of the members can use their handheld devices to connect to the Internet through 4G/5G cellular network because some of them may not have the 4G/5G cellular network subscription, which especially may happen for tourists from foreign countries.

To tackle the aforementioned problems, this work adopted the Multi-Access Edge Computing (MEC) paradigm and architecture to resolve related issues. The MEC paradigm and architecture have been proposed and standardized by the European Telecommunications Standards Institute (ETSI) [1, 2]. MEC can (1) provide low latency service; (2) reduce the computing overload for the remote cloud server; and (3) provide massive data caching capacity [3, 4]. Y. Mao *et al.* [4] mentioned that the MEC server can be co-located with wireless gateways, WiFi routers, or Base Stations (BSs) of the cellular network depending on the characteristics of the applications and services. Fig. 1 (b) depicts the MEC-based networking configuration of the proposed method that allows the tour leader to control the POI's multimedia presentation in the corresponding group touring members' handheld devices to have the leader-controlled group touring service over the wireless mobile network. The tour guide can prepare (1) a mobile WiFi router that has both 4G/5G cellular networking and WiFi wireless networking functions, in which it can connect to the Internet through 4G/5G cellular network and share the mobile connectivity with numerous wireless handheld devices that are over the WiFi wireless network; and (2) a laptop, which connects to the mobile WiFi router through WiFi wireless network, playing the role of the MEC server that can provide more powerful computing capability and massive data caching capacity. The tour guides' and members' handheld devices of the touring group can connect to the mobile WiFi router through WiFi wireless network. Thus, the MEC server and all of handheld devices can communicate with each other over the WiFi wireless network. The tour guide can (i) cache the text and multimedia contents of POIs, which the tour guide wants to use to assist her/him to interpret POIs, from the remote cloud server to the MEC server; (ii) select and forward the target POIs' text and multimedia contents to all of the members' handheld devices; and then (ii) display the selected POI's text and multimedia contents to all of the members' handheld devices in the synchronous and real time way to have the wireless mobile digital content assisted tour guide, *i.e.*, it belongs to the other type of real time and synchronous multimedia presentation because the corresponding multimedia content needs to be displayed to other group members' handheld devices during the group leader's oral explanation of the target POI.

The advantages of the proposed functional scenario based on the wireless mobile networking configuration are as follows. Let there be one tour guide and n members and thus there are (n+1) handheld devices in the touring group; (1) The traffic load in the 4G/5G cellular network and the expense of using 4G/5G cellular network are reduced to 1/(n+1) of that of using the individual downloading; (2) Since all of the text and multimedia contents of POIs are cached in the MEC server, it can provide low-latency service that can bring the better (i) quality of service (QoS), which is in terms of the transmission delay for multimedia content; and (ii) quality of experience (QoE), which is in terms of the response time from the tour guide's selecting a POI to the displaying of the selected POI's text and multimedia contents to all of the group members' handheld devices, to the tour guide and n members because all of the text and multimedia contents of POIs are transferred between their handheld devices and the MEC server over WiFi wireless network, *i.e.*, Local Area Network (LAN), instead of being transferred over the Internet, *i.e.*, Wide Area Network (WAN); (3) It can significantly reduce the computing load of the remote cloud server and the traffic load of the cellular network with the help of the MEC server; (4) It solves the problem that some of the members' handheld devices are not able to connect to the Internet through 4G/5G cellular network because the corresponding users do not subscribe the 4G/5G cellular network, *e.g.*, foreign tourists.

Based on the aforementioned MEC-based networking configuration, this work designed an innovative location-based Mobile Social Network (MSN) service targeting for the aspect of the group touring using the MEC technique and developed the associated group touring APP called "DEH_Narrator". The DEH_Narrator APP is implemented on the Demodulating and Encoding Heritage (DEH) Platform, which is a touring and navigation platform and can be used for touring, education, *etc.* [5, 6]. When a tour guide is to guide a touring group and explain related information of the specific POIs orally through the help of the handheld devices, the corresponding scenario and main features of using the DEH_Narrator APP are as follows:

(1) The tour guide can create a group in the DEH_Narrator App to become the group leader and let the corresponding touring group members to join the created group in the DEH_Narrator APP. The concept of the group in DEH_Narrator APP is similar to the MSN group provided in Line, WeChat, WhatsApp, *etc.*
(2) The tour guide can control the screens of group members' handheld devices to display the corresponding text and multimedia contents of the specific POI that she/he wants to explain on all of the group members' handheld devices real timely and synchronously, which is called the narrator mode hereafter. In contrast to the narrator mode, the DEH_Narrator APP also keep the function of allowing the group members to download the text and multimedia contents of POIs from the remote cloud server individually without the control of the tour guide, which is called the individual mode and is the existed mode as that in [6].

The rest of the paper is organized as follows. Section 2 introduces related works. The system architecture and the abstract function scenario are provided in Section 3. Section 4 presents the definitions of metadata. Sections 5 and 6 present the control schemes for the pre-touring stage and the touring stage of using the DEH_Narrator APP respectively. Section 7 illustrates the usages and examples of the DEH_Narrator APP. Then, the performance evaluation of the proposed schemes is presented in Section 8. Finally, conclusion remarks and future works are given in Section 9.

2. RELATED WORKS

Many technical problems exist in the location-based touring service. This Section introduces related works of the proposed system presented in this paper, including (1) touring applications; (2) data offloading through WiFi networks using the MEC technique; (3) the contents' caching strategy; (4) the contents synchronization mechanism; (5) the collaborative downloading to have the proximate sharing of downloaded data; and (6) the mechanism that can synchronously present text and the multimedia contents for the DEH_Narrator APP.

Most researches that are related with the touring service focused on providing (i) the personal touring service; (ii) the POI recommendation service; (iii) the tour guide matching service, *etc.* In [7], A. Kountouris and E. Sakkopoulos reviewed 18 popular mobile tour guide applications, analyzed their characteristics, and implemented a touring application. Four provided basic functions, which are similar to other touring applications, as follows; (i) Create and author personal made POIs and routes; (ii) Query nearby POIs based on the geo location of the users; (iii) Display the information of POIs and routes and translate the text to the corresponding language that users are expected using the translation tool; (iv) Navigate to the corresponding POI or route on the e-map. One innovative function is that, since continuous Internet connection to retrieve information may lead high costs of the mobile network, the proposed touring application allows users to cache the information of POIs and routes in the handheld device. In [8] S. Jang *et al.* proposed a flexible POI recommendation method that takes the following three factors into consideration: (i) trajectory; (ii) distance; and (iii) preference. Users can adjust the weight of each factor by themselves during POI recommendation. In [9], M. Zhou *et al.* focused on college students' tourism and proposed a college student online tour guide platform. The motivations of developing the platform are (i) many college tour guides are full of enthusiasm but lack of tour guide experience; and (ii) college tourists often have the will to travel with people of the same age. Thus, the special feature of the proposed platform is to help the college students find the college tour guides. However, seldom researches mentioned about how to have a high technology assisted or a wireless mobile digital content assisted group touring. Therefore, this work concentrated on developing the group touring application that can help a tour guide for her/his on-site interpreting work. In [10] M. Kargar proposed a tour recommendation framework that aims to motivate a number of tourists to explore a new city together. The proposed recommendation framework considers each joined tourist's must-visit POIs and preferred POIs, budget limit per day, maximum daily travel distance and daily time, *etc.*, to come out a multi-day tour that compromises all joined tourists' requirements.

In [11], H. Zhou surveyed four types of the mobile data offloading technologies; (i) Data offloading through small cell networks; (ii) data offloading through WiFi networks; (iii) data offloading through opportunistic mobile networks; and (iv) data offloading through heterogeneous networks. Authors mentioned that data offloading through WiFi networks can reduce costs and traffic load of the 4G cellular networks. Additionally, it also can effectively reduce the monthly bill incurred by cellular data usage for mobile users. In [12], R. Liang *et al.* proposed an energy-saved data transfer model (EDTM). The cloudlets are placed in the proximity of the mobile devices. Since the energy consumption of transfer data using the 4G cellular network is greater than that of using the WiFi wireless network, EDTM allows mobile devices to connect to the cloudlet over the WiFi wireless network and upload or download data through the help of the cloudlet instead of using the 4G cellular network. In this work, data offloading through WiFi networks is adopted. To achieve the goal, a laptop and a mobile WiFi router are used for caching and transferring the contents of POIs/Line Of Interests (LOIs), each of which contains a sequence of POIs/Area Of Interests (AOIs), each of which contains a set of POIs/Story Of Interests (SOIs), each of which can contain a number of POIs, LOIs and/or AOIs, because of easy to carry. In [13], W. Fan *et al.* proposed a joint WiFi and cellular offloading scheme based on the statistical characteristics of the Mobile Terminals task generation of a single application. In the coverage of WiFi and cellular network, mobile terminals can reduce the load and congestion of cellular network's BSs by offloading computation tasks through the WiFi APs.

To determine which content should be cached in the MEC server is an issue to be resolved. In [14], P. Yang *et al.* focused on caching the contents based on the content popularity. The proposed method predicted the popularity using (i) location-dependent factors, such as user interests, the number of users and the social function of the coverage area of the MEC server; and (ii) content-dependent factors, *e.g.*, genre, length, and frame quality for video contents. In contrast to the aforementioned method, this work's proposed method only needs the MEC server to cache the contents of the *k* nearest POIs/LOIs/AOIs/SOIs queried by the user who is using the exploring function. Therefore, to minimize the overhead of transmitting contents between the remote cloud server and the MEC server, the MEC server can store POIs/LOIs/AOIs/SOIs' profiles, which contain the information of geo location, time stamps of contents' modification, *etc.*, that are related with the geo-based caching contents in the MEC server. In [15], J. Xu *et al.* studied joint service caching and task offloading using the MEC architecture. The authors proposed and implemented an algorithm to derive which services need to be cached on the MEC servers. With a given energy consumption constraint, the proposed algorithm can improve system performance.

The other issue is when and how to synchronize contents between the remote cloud server and the MEC server such that the cached contents in the MEC server is consistent with the corresponding ones in the remote cloud server. In [16], G. Lee *et al.* pointed out the disadvantage of the update-triggered and time-triggered synchronization schemes and then proposed a fog-assisted aggregated synchronization (FAS) scheme to reduce the synchronization traffic on mobile cloud storage applications using the fog computing. When the contents stored in the remote cloud server have been updated, the remote cloud server notified the MEC servers that have cached the corresponding contents. After the MEC server received the notification, the MEC server did not update its cached contents immediately. The contents will be synchronized until one of the devices is going to access the corresponding contents from the MEC server. This work considered the issue of contents synchronization between the MEC server and the remote cloud server based on the contents' profiles, which is similar to the aforementioned method. When it needs to update the cached contents, *i.e.*, the user moves to the other location and thus the *k* nearest POIs/LOIs/AOIs/SOIs' contents that need to be cached and updates, this work designed a content synchronization mechanism by updating the contents' profiles stored in the MEC server, deriving the corresponding *k* nearest POIs/LOIs/AOIs/SOIs' contents based on the new location, and then requesting the associated contents from the remote cloud server to remain the contents in the MEC server to be up to date. In [17] M. Alghamdi proposed an edge-based architecture to reduce the delay introduced by cloud computing. Mobile users that are connected with MEC servers can be provided with the intensive computing resources of MEC servers. After that, each mobile user transmits the updated operation to the closer edge server and then the edge server synchronizes the latest version of the shared document with received operations. Finally, the updated operations are transmitted to the cloud server to propagate it to various mobiles users by means of other edge servers. The latency is significantly reduced using the authors' proposed method.

In [18], I. Darmaw *et al.* developed a real-time screen sharing application that allows the presenter to share the screen of the PC or laptop on the screens of the audiences' handheld devices, which is done by connecting with the same wireless network using the WebSocket communication. The screen sharing application (i) captures and encodes the frame of the screen of the presenter's device; (ii) transfers the frame to the audiences' handheld devices using the WebSocket communication; and (iii) decodes and presents the frame on the screens of the audiences' handheld devices. In contrast to the aforementioned method, this work considered the issue of how to quickly deliver and then present the same contents, including both the text and multimedia, *i.e.*, image, audio, and video contents, in the real time and synchronous way in many moving group members' handheld devices, which can use different OSs, *e.g.*, Android and iOS. As far as we know, this paper is the first work to deal with the aforementioned functional scenario.

3. SYSTEM ARCHITECTURE AND THE ABSTRACT FUNCTIONAL SCENARIO

This section introduces the system architecture and the abstract function scenario of the DEH_Narrator APP.

3.1 System Architecture

Fig. 1 (b) depicts the system configuration of executing the DEH_Narrator APP. Five main components for executing the DEH_Narrator APP are (1) group leader's handheld device MN_L; (2) group members' handheld devices MN_i, $i = 1, \ldots, n$; (3) the mobile WiFi router; (4) the MEC server; and (5) the remote cloud server. In the system configuration, MN_L, MN_i, $i = 1, \ldots, n$, and the MEC server are connected with the same mobile WiFi router over the WiFi wireless network.

MN_L represents the handheld device of the group leader. MN_i, $i = 1, \ldots, n$, represents the handheld device of a group member. The mobile WiFi router can connect to the 4G/5G cellular network and share the mobile connectivity to the wireless network devices that are over the WiFi wireless network with the help of two network interfaces. Two network interfaces of the mobile WiFi router are (i) the 4G/5G cellular network interface; and (ii) the WiFi wireless network interface. The mobile WiFi router also provides the service of the dynamic host configuration protocol (DHCP) to the connected WiFi wireless devices.

The MEC server provides the multi-access edge computing service to MN_L and MN_i, $i = 1, \ldots, n$. Four sub-components of the MEC server that are related with the DEH_Narrator APP are (i) the MEC service coordinator; (ii) the Location-Based Service (LBS) controller; (iii) the MSN agent; and (iv) the content proxy. The MEC service coordinator manages those wireless connections with the MEC server. The LBS controller provides the location-based service, for which it (i) owns the complete profiles of POIs/LOIs/AOIs/SOIs storing in the content server; (ii) decides which contents of POIs/LOIs/AOIs/SOIs should be cached in the content proxy and keeps them be synchronized and consistent with the content server; and (iii) manages the status of DEH groups for the group touring service. The MSN agent (i) stores the information of DEH users' profiles and the profiles of these users' joined DEH groups for those users who try to login the DEH_Narrator APP through the MEC server; (ii) provides the authentication function for users who try to login the DEH_Narrator APP through the MEC server; and (iii) manages the DEH groups belonging to the administration range of the MEC server. The content proxy caches contents of related POIs/LOIs/AOIs/SOIs.

The remote cloud server provides all of the functions of the DEH Platform. Four subcomponents of the remote cloud server that are related with the DEH_Narrator APP are (i) the MEC service manager; (ii) the LBS server; (iii) the MSN server; and (iv) the content server. The MEC service manager directs users' handheld devices to connect to the specific MEC server. The LBS server owns the complete profiles of POIs/LOIs/AOIs/SOIs storing in the content server, for which it (i) stores the information of POIs/LOIs/AOIs/SOIs that is related with creating, updating, deleting, *etc.*; and (ii) synchronize profiles of POIs/LOIs/AOIs/SOIs stored in the LBS controller of the MEC server. The MSN server stores the information of DEH users' profiles and DEH groups. The content server stores all of the contents of POIs/LOIs/AOIs/SOIs.

3.2 The Abstract Functional Scenario

Two execution stages in the DEH_Narrator APP are (1) the pre-touring stage; and (2) the touring stage.

The Pre-Touring Stage

Three phases in the pre-touring stage are (i) the group creation phase; (ii) the service initialization phase; and (iii) the service activation phase.

The group creation phase allows the tour guide and all of the touring group members to be able to form a touring group using the DEH_Narrator APP. Initially, the tour guide and each of the touring group members need to create an account respectively in the DEH platform. After that, in order to create a touring group in the DEH_Narrator APP by the tour guide and then let the tour guide and all of the touring group members be able to join the corresponding group, this work adopts the creation and management mechanisms of the DEH group. Details of creating the account and the DEH group are referred in the DEH platform [5, 6].

The service initialization phase is activated when the tour guide is ready to start her/his interpreting work. Two functions that exist in the service initialization phase are (1) the MEC server directing function, which allows the remote cloud server directs users' handheld devices to find out the corresponding proximate MEC server x and connect with x; and (2) the user account authentication function, which allows the MEC server to authenticate the *username* and the *password* when a user tries to login the DEH_Narrator APP.

After the tour guide and all of the touring group members successfully login the DEH_Narrator APP, the tour guide needs to select the corresponding DEH group to activate the group touring service. Two functions that are provided to the group leader and all of the group members are (1) the enabling/disabling service function, which allows the group leader to enable or disable the group touring service of the corresponding DEH group; and (2) the subscribing/unsubscribing service function, which allows each of the group members to subscribe or unsubscribe the group touring service of the corresponding DEH group.

The Touring Stage

After activating the group touring service, the DEH_Narrator APP is changed to the touring stage. Two modes in the touring stage are (1) the narrator mode; and (2) the individual mode. Initially, the touring stage is in the narrator mode and all of the handheld devices of group members who have subscribed the group touring service of the corresponding DEH group are under the control of group leader's handheld device. In the narrator mode, the group leader uses the exploring function to search the nearest public/personal/group POIs/LOIs/AOIs/SOIs in the DEH platform, shares and playouts the text and multimedia contents of the selected POI on all of the group members' handheld devices. In the individual mode, the group leader and all of the group members use the exploring function to search the nearest public/personal/group POIs/LOIs/AOIs/SOIs individually. The group leader can switch the group touring service mode between the narrator mode and the individual mode alternatively.

Five functions in the touring stage are (1) the positioning function; (2) the querying function; (3) the selecting function; (4) the viewing function; and (5) the mode-switching function.

The positioning function allows the user to update her/his location information to the current geo position and then be indicated in the e-map that is displayed on the screen of her/his handheld device. In the narrator mode, since the handheld devices of all group members are under the group leader's control, when the group leader updates his current location information using the positioning function, the updated location information is transferred to and be indicated on the screens' e-maps of all group members' handheld devices of the corresponding DEH group synchronously.

The querying function allows the user to query the *k* nearest public/personal/group POIs/LOIs/AOIs/SOIs that are in *n* kilometers of their locations in the DEH platform. Let XOIs denote POIs/LOIs/AOIs/SOIs, "nearest public XOIs" denote those XOIs whose attributes are "public" and have been successfully verified, "nearest personal XOIs" denote those XOIs that were authored by the associated user of issuing the query and these XOIs' conditions can be private, successfully/unsuccessfully verified or to be verified, and "nearest group XOIs" denote those XOIs that belong to a specific group. The querying function can (i) only be used by the group leader in the narrator mode; and (ii) be used by each user, including the group leader or each group member, individually in the individual mode.

The selecting function for POIs allows the user to select a POI from the nearest/personal / group POIs that the user is interested in and then (i) the selected POI's profile and text content are transferred to the corresponding user's handheld device; and (ii) the selected POI is indicated on the screen of the corresponding user's handheld device. In the narrator mode, since the handheld devices of all group members are under the group leader's control, when the group leader selects a POI using the selecting function, the selected POI's profile and text content are transferred to and be indicated on the screens of all group members' handheld devices of the corresponding DEH group synchronously. In the individual mode, when a user, who is either the group leader or a group member, selects a POI using the selecting function, the selected POI's profile and text content are transferred only to the corresponding user's handheld device and is indicated on the screen of her/his own handheld device.

The viewing function for POI allows the user to display the text and multimedia contents of the POI, which is selected using the selecting function for POI, on the screen of her/his handheld device. In the narrator mode, since the handheld devices of all group members are under the group leader's control, when the group leader uses the viewing function to display the text and multimedia contents of the POI, which is selected using the selecting function for POI, the selected POI's text and multimedia contents are transferred to and displayed on the screens of the group leader's and all of the group members' handheld devices of the corresponding DEH group. In the individual mode, when a user, who is either the group leader or a group member, uses the viewing function to display the text and multimedia contents of the POI, which is selected using the selecting function for POI, the selected POI's text and multimedia contents are only transferred to and displayed on the screen of the corresponding user's own handheld device.

The processing for LOI/AOI contains three steps. Step 1, the selecting function for LOI/AOI allows the user to get the (i) profile; (ii) text content; and (iii) the profiles of the contained POIs of the LOI/AOI, and then the title and text content of the LOI/AOI and the titles of the contained POIs are displayed on the screen of the user's handheld device. Step 2, the user can use the selecting function for POI to select one of the contained POIs of the selected LOI/AOI to be displayed. Step 3, the user can use the viewing function to display the text and multimedia contents of the selected POI. In the narrator mode, Steps 1 and 2 are executed in the group leader's handheld device and it is nothing with the handheld devices of the group members. In the individual mode, Steps 1, 2 and 3 are executed in each user's handheld device.

The processing for SOI is similar to the processing for LOI/AOI, except that it needs one more iteration of using the selecting function for LOI/AOI.

The mode-switching function lets the group leader of the corresponding DEH group be able to switch the group touring service mode between the narrator mode and the individual mode alternatively.

4. DEFINITIONS OF METADATA

This Section introduces the metadata that are used in the DEH_Narrator APP. The metadata are for (1) the POI/LOI/AOI/SOI Content and the Multimedia Content; (2) the POI/LOI/AOI/SOI Profile; (3) the relation table of LOI_POIs, AOI_POIs, and SOI_XOIs; (4) the User Profile, the Group Profile, and the relation table of Group_Users, and Group_XOIs; (5) the Group_Service Profile; (6) the MEC Server Profile; and (7) the modified contents record table.

Table 1 depicts the metadata for the POI/LOI/AOI/SOI Content and the Multimedia Content. The metadata of the POI/LOI/AOI/SOI Content and the Multimedia Content are defined in the DEH platform [5, 6]. In addition, the "Lastly modified time" attribute is newly added to record the lastly modified time of the corresponding POI/LOI/AOI/SOI Content or the Multimedia Content.

Table 2 depicts the metadata for the POI/LOI/AOI/SOI Profile. The metadata for the POI/LOI/AOI/SOI Profile used in the DEH_Narrator APP are the needed attributes for (i) the touring stage; and (ii) synchronizing the contents of POIs/LOIs/AOIs/SOIs stored in the MEC server with that in the remote cloud server. The "Owner" attribute is used to recognize the personal POI/LOI/AOI/SOI. The "Lastly modified time" attribute is used to recognize whether the corresponding POI/LOI/AOI/SOI Content stored in the MEC server is the up-to-date one or not. In addition, the "Cached" attribute is added to recognize whether the corresponding POI/LOI/AOI/SOI Content is cached in the Content Proxy of the MEC server or not.

Table 1. The metadata for POI/LOI/AOI/SOI content and multimedia content.

POI Content	ID, Title, Latitude, Longitude, Description, Address, Subject, Keyword, Format, Owner, Verification, Open, Language, and Lastly modified time
Multimedia Content	ID, Format, Name, Type, URL, FK_POI_ID, and Lastly modified time
LOI/AOI/SOI Content	ID, Title, Description, Owner, Verification, Open, Language, and Lastly modified time

Table 2. The metadata for the POI/LOI/AOI/SOI Profile.

POI/LOI/AOI/SOI Profile	ID, Latitude, Longitude, Owner, Lastly modified time, and Cached

Table 3. The relation table for LOI_POIs, AOI_POIs, and SOI_XOIs.

LOI_POIs	ID, Sequence, FK_LOI_ID, FK_POI_ID, and Lastly modified time
AOI_POIs	ID, FK_AOI_ID, FK_POI_ID, and Lastly modified time
SOI_XOIs	ID, FK_SOI_ID, FK_AOI_ID, FK_LOI_ID, FK_POI_ID, and Lastly modified time

Table 3 depicts the relation table for LOI_POIs, AOI_POIs, and SOI_XOIs, which are defined to map the relationship of a LOI or an AOI with its contained POIs, and the relationship of a SOI with its contained POIs/LOIs/AOIs. The “Sequence” attribute is the sequence number of the POI in the corresponding LOI. The “FK_POI_ID”, “FK_LOI_ID”, “FK_AOI_ID”, and “FK_SOI_ID” attributes are the foreign keys to the associated POI/LOI/AOI Content respectively. The “Lastly modified time” attribute, which is newly added for the DEH_Narrator APP, is the lastly modified time of the corresponding LOI_ POIs, AOI_POIs, or SOI_XOIs.

Table 4 depicts the metadata for the User Profile, the Group Profile, and the relation tables for Group_Users, and Group_XOIs. The metadata for the User Profile and the Group Profile are defined in the DEH platform [5, 6]. The relation tables for Group_Users and Group_XOIs are defined to map the relationship of a DEH group with its belonged members and POIs/LOIs/AOIs/SOIs respectively. The “Identifier” attribute can be “leader” or “member”, which is used to identify that the user is the group leader or the group member in the corresponding DEH group. The “Type” attribute can be “POI”, “LOI”, “AOI”, or “SOI”, for which the “FK_XOI_ID” attribute is the foreign key to the POI/LOI/AOI/SOI Content. The “FK_Group_ID”, “FK_User_ID”, and “FK_XOI_ID” attributes are the foreign keys to Group, User, and POI/LOI/AOI/SOI Content respectively. The “Lastly modified time” attribute, which is newly added for the DEH_Narrator APP, records the lastly modified time.

Table 4. The metadata for the User Profile, the Group Profile, and the relation tables for Group_Users, and Group_XOIs.

User Profile	ID, Username, Password, and Lastly modified time
Group Profile	ID, Name, and Lastly modified time
Group_Users	ID, FK_Group_ID, FK_User_ID, Identifier, and Lastly modified time
Group_XOIs	ID, FK_Group_ID, Type, FK_XOI_ID, and Lastly modified time

Table 5. The metadata for the Group_Service Profile.

Attribute	Description
Group ID	The foreign key to the Group ID of the specific DEH group which is enabled.
Leader_ID	The connection ID of the group leader.
Connection_IDs	The list of the connection IDs of the group leader and members.
Mode	The group touring service mode of the corresponding DEH Group, which can be “Narrator” or “Individual”.
Latitude	The latitude of the current location of the group leader.
Longitude	The longitude of the current location of the group leader.
POI	The foreign key to POI_ID of the POI selected or viewed by the group leader.
Is_Selected	The status denoting whether the group leader has selected a POI or not. “True” or “False”.
Is_View	The status denoting whether the group leader has viewed a POI or not. “True” or “False”.

Table 5 depicts the metadata for the Group_Service Profile that records the status of the corresponding DEH group for the group touring service. Table 6 depicts the attributes of the metadata for the MEC Server Profile that records the information of the MEC servers. Table 7 depicts the modified contents record table that records whether the content of the POI/LOI/AOI/SOI has been created, updated, or deleted in the content server or not.

When the content of a POI (LOI/AOI) has been modified, the associated LOIs/AOIs/SOIs (SOIs) which contain the corresponding POI (LOI/AOI) will update the lastly modified time of the profiles and mark the modification in the table of the "modified contents record". For example, let a POI whose ID is 1 be created on t_1, a LOI whose ID is 2 be updated on t_2, and an AOI whose ID is 3 be deleted on t_3; then, three modified contents records are created, which are depicted in Table 8 and stored in the content server of the remote cloud server.

Table 6. The metadata for the MEC Server Profile.

Attribute	Description
BSSID	The BSSID of the Mobile WiFi Router to which the MEC Server is connected.
IP	The IP address of the WiFi wireless network interface of the MEC Server.

Table 7. The modified contents record table.

Attribute	Description
ID	The ID of the Modified Record.
Event	The modified event (create, update, delete) of the content data.
Type	The type of the modified content data.
FK_ID	The ID of the modified content data.
Lastly modified time	The modified time of the modified event.

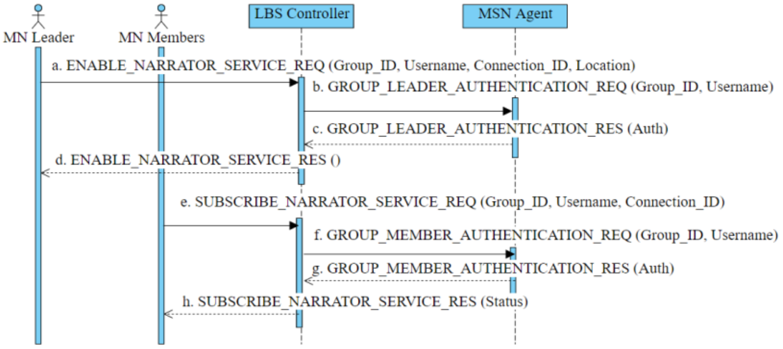


Fig. 2. The message flow diagram of the control scheme for the enabling service function and the subscribing service function.

5. THE CONTROL SCHEMES FOR THE PRE-TOURING STAGE

This Section introduces the control schemes needed for the service initialization phase and the service activation phase in the pre-touring stage. Two control schemes designed for the service initialization phase are (1) the MEC server directing function; and (2) the user account authentication function. Two control schemes designed for the service activation phase are (1) the enabling service function and the subscribing service function; and (2) the disabling service function and the unsubscribing service function.

Table 8. An illustrated example of the modified contents record table.

ID	Event	Type	FK_ID	Lastly modified time
1	create	POI Content	1	t_1
2	update	LOI Content	2	t_2
3	delete	AOI Content	3	t_3

5.1 The Control Scheme for the MEC Server Directing Function

Initially, MN_L, which denotes the group leader's handheld device, MN_i, $i = 1, \dots, n$, which denotes group members' handheld devices, and the MEC server, connect to the mobile WiFi router using WiFi network and then receive the BSSID, which is the MAC address of the WiFi wireless network interface of the mobile WiFi router. Then, the mobile WiFi router allocates an IP address to each device using the DHCP protocol. After the connection setup, the MEC Service Coordinator registers the BSSID of the WiFi wireless network interface of the mobile WiFi router and the IP address of the MEC server allocated from the Mobile WiFi Router to the MEC Server Manager. Next, MN_L and MN_i, $i = 1, \dots, n$, query the IP address of the MEC server, which is denoted as MEC_IP, from the MEC server manager. Using the received IP address, MN_L and MN_i, $i = 1, \dots, n$, can connect to the MEC server and activate the group touring service.

5.2 The Control Scheme for the User Account Authentication Function

After typing in the login information and pressing the login button, MN_L and MN_i, $i = 1, \dots, n$, send the login request with *Username* and *Password* to the MSN agent. The MSN agent requests and then receives the user information and the group information that the user has registered in the DEH platform from the MSN server. Then, the MSN agent authenticates the *Username* and *Password*. If both of them are valid, the MSN agent responses the login-successful message with the list of the login-users' joined DEH groups and the information of the corresponding DEH groups; otherwise, the MSN agent responses the login-failed message.

5.3 The Control Scheme for the Enabling Service Function and the Subscribing Service Function

After successfully login the DEH_Narrator APP, the group leader selects a specific DEH group to enable the group touring service through the LBS controller. After the LBS controller receives the enabling service request, the LBS controller authenticates whether the user is the group leader of the corresponding DEH group or not through the help of the MSN agent. If the role of the group leader is verified, the LBS controller keeps the connection ID of the group leader and enables the group touring service of the corresponding DEH group. Then, all of group members can select the group to start subscribing the group touring service of the corresponding DEH group through the LBS controller. In order to subscribe the group touring service, all of the group members need to send the subscribing service request to the LBS controller. After the LBS controller receiving the request, the LBS controller authenticates whether the user is one of the corresponding DEH group's valid users or not through the help of the MSN agent. If the role of the group member is verified, the LBS controller keeps the connection ID of the group member and allows the group member to subscribe the group touring service of the corresponding DEH group. Finally, the LBS server replies the status of the corresponding DEH group for the group touring service back to the group member. Fig. 2 depicts the message flow diagram of the control scheme of the enabling service function and the subscribing service function.

5.4 The Control Scheme for the Disabling and the Unsubscribing Service Function

When the group leader wants to disable the group touring service, MN_L sends the request to the LBS controller. Then, the LBS controller notifies MN_i, $i = 1, \ldots, n$, which has subscribed the group touring service, to unsubscribe the group touring service of the corresponding DEH Group. After that, each of the group members can unsubscribe the group touring service manually by himself / herself. Fig. 3 depicts the message flow diagram of the control scheme for the disabling service function and the unsubscribing service function.

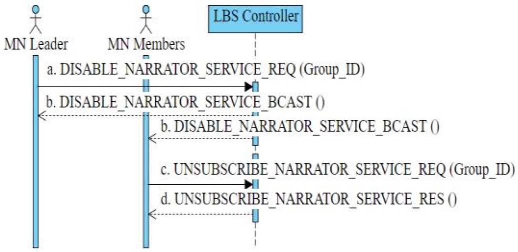


Fig. 3. The message flow diagram of the control scheme for the disabling service function and the unsubscribing service function.

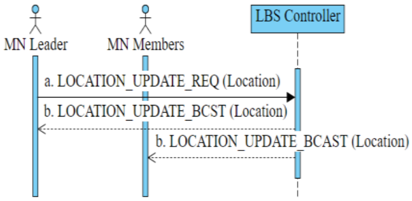


Fig. 4. The message flow diagram of the control scheme for the positioning function in the narrator mode.

6. THE CONTROL SCHEMES FOR THE TOURING STAGET

This Section introduces the control schemes needed in the touring stage for achieving the aforementioned functional scenario. Five control schemes are designed for (1) the positioning function; (2) the querying function; (3) the selecting function; (4) the viewing function; and (5) the mode-switching function.

6.1 The Control Scheme for the Positioning Function

The group leader can (i) press the location button to get the location information of the current geo location or (ii) hit any location on the e-map displayed on the screen of her/his handheld device. Then, MN_L sends the request with the location information to the LBS controller of the MEC server. The LBS controller notifies MN_i, $i = 1, \ldots, n$, to show the group leader's location in the e-map displayed on the screen of each of the members' handheld devices. In the individual mode, the user, who can be either the group leader or a group member, can update her/his individual location information using the same way. Fig. 4 depicts the message flow diagram of the control scheme for the positioning function in the narrator mode.

6.2 The Control Scheme for the Querying Function

After using the positioning function to change to the target location that the user wants, the user can use the querying function to get the *k* nearest public/personal/group POIs/LOIs/AOIs/SOIs that are in *n* kilometers of the location the user set, in which *k* and *n* are set by the user [19].

Messages and parameters for three categories of the querying function are as follows:

1. The *k* Nearest public POIs/LOIs/AOIs/SOIs: The query request message is "NEAREST_PUBLIC_XOI_REQ (Location)", where *x* can be "P", "L", "A", or "S", and "Location" is the latitude and the longitude of the central location of the target region.
2. The *k* Nearest personal POIs/LOIs/AOIs/SOIs: The query request message is "NEAREST_PERSONAL_XOI_REQ (Location, Username)", where (i) *x* can be "P", "L", "A", or "S"; (ii) "Location" is the latitude and the longitude of the central location of the target region; and (iii) "Username" is the *username* of the user who issues the querying.
3. The *k* Nearest group POIs/LOIs/AOIs/SOIs: The query request message is "NEAREST_GROUP_XOI_REQ (Location, Group_id)", where (i) *x* can be "P", "L", "A", or "S"; (ii) "Location" is the latitude and the longitude of the central location of the target region; and (iii) "Group_id" is the ID of the associated group to which the target POIs/LOIs/AOIs/SOIs belong.

To query the *k* nearest public XOIs, *x* = P, L, A, or S, the user presses the query nearest public XOIs, *x* = P, L, A, or S, button to query the *k* nearest public XOIs, *x* = P, L, A, or S, in the searching area, which is the circular region with the radius of *n* kilometers centered on her/his target location on the e-map, and then the handheld device of the user sends the request with the location information to the LBS controller.

To query the *k* nearest personal XOIs, *x* = P, L, A, or S, the user presses the query nearest personal XOIs, *x* = P, L, A, or S, button to query the *k* nearest personal XOIs, *x* = P, L, A, or S, created by the user herself/himself in the searching area, which is the circular area with the radius of *n* kilometers centered on her/his target location on the e-map, and then the handheld device of the user sends the request with the location information and the *username* to the LBS controller.

To query the *k* nearest group XOIs, *x* = P, L, A, or S, the user presses the query nearest group XOIs, *x* = P, L, A, or S, button to query the *k* nearest group XOIs, *x* = P, L, A, or S, which belong to the corresponding DEH group in the searching area, *i.e.*, the circular area with the radius of *n* kilometers centered on her/his target location on the e-map, and then the handheld device of the user sends the request with the location information and the Group_id of the corresponding DEH group to the LBS controller.

When the LBS controller receives the query request message Q, the LBS controller of the MEC server needs to synchronize with the LBS server in the remote cloud server to get the up-to-date profiles of POIs/LOIs/AOIs/SOIs such that the content proxy of the

MEC server can synchronize with the content server in the remote cloud server to have the most up-to-date contents of POIs/LOIs/AOIs/SOIs.

Five steps that are executed for profiles' and contents' synchronization when the LBS controller receives the query request message Q are as follows:

1. The LBS controller in the MEC server finds the maximum value t_{max} of the attribute "Lastly modified time" in the profile of the XOI, x = P, L, A, or S.
2. The LBS controller in the MEC server queries the table of the Modified Content Record stored in the LBS server of the remote cloud server to find those XOIs, x = P, L, A, or S, that are created, updated, or deleted after t_{max}.
3. The LBS controller in the MEC server synchronizes the profile of the XOI, x = P, L, A, or S with the profile of the XOI, x = P, L, A, or S, stored in the LBS server of the remote cloud server.
4. The LBS controller in the MEC server executes the query request message Q and find the result of the profiles of the k nearest XOIs, x = P, L, A, or S, based on the category, *i.e.*, public, personal or group.
5. The LBS controller notifies the content proxy in the MEC server to (i) update the corresponding contents of the XOI, x = P, L, A, or S, based on the profiles that have been synchronized in Step 3; and (ii) download and cache the contents that are not stored currently based on the query result derived in Step 4 from the content server of the remote cloud server.

Table 9 depicts an illustrated example for profiles' synchronization of POI. Table 9 (a) depicts the profiles of POIs cached in the LBS controller of the MEC server before profiles' synchronization. Table 9 (b) depicts the Modified Content Record Table stored in the LBS server of the remote cloud server. Let $t_1 < t_2 < t_3 < t_4 < t_5$. Step 1, the LBS controller of the MEC server found that t_{max} is t_2. Step 2, the LBS controller of the MEC server queried and found three modified contents records on which the "Lastly modified time" is greater than t_{max} in the LBS server of the remote cloud server. Step 3, the LBS controller of the MEC server synchronized its POI Profiles with that in the LBS server of the remote cloud server based on "FK_ID" queried from the modified contents records in Step 2. Step 4, the LBS controller executed the query request message Q based on the most up-to-date POI profiles and found the profiles of the k nearest POIs based on the category, *i.e.*, public, personal or group. In the example, let POIs whose IDs are "2" and "3" be queried. Step 5, the LBS controller notifies the content proxy of the MEC server to synchronize its contents of POIs for which (i) the profiles that have been synchronized in Step 3 and whose attribute "Cached" is "True"; and (ii) the profiles that have been queried in Step 4 and whose attribute "Cached" is "False", with the content server of the remote cloud server. Finally, set the attribute "Cached" as "True". Table 9 (c) depicts the profiles of POIs cached in the LBS controller of the MEC server after profiles' synchronization.

Table 9. The example for synchronizing the POI profile.
(a) POI profile cached in the MEC server before synchronization.

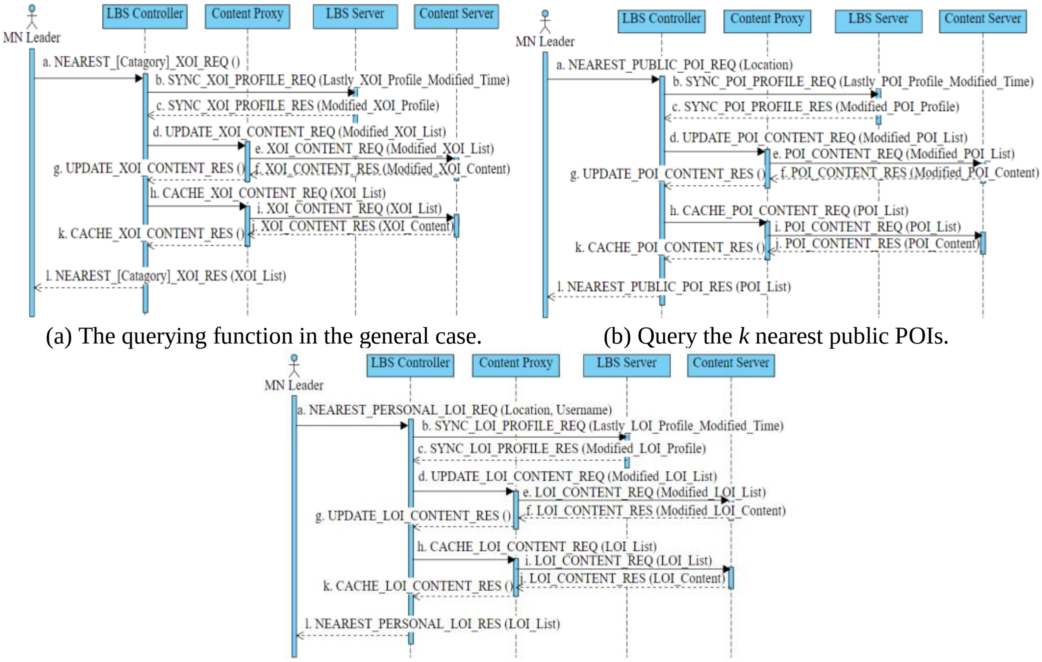
ID	Lastly modified time	Cached
1	t_1	False
2	t_2	True

Table 9. (b) Modified record profile stored in the remote cloud server.

Event	Type	FK_ID	Lastly modified time
create	POI Content	3	t_3
update	POI Content	2	t_4
delete	POI Content	1	t_5

(c) POI profile cached in the MEC server after synchronization.

ID	Lastly modified time	Cached
2	t_4	True
3	t_3	True

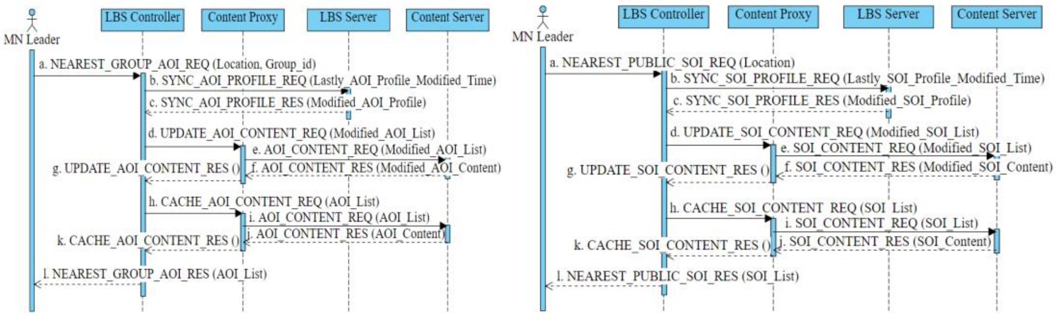


(a) The querying function in the general case. (b) Query the *k* nearest public POIs.

(c) Query the *k* nearest personal LOIs.

Fig. 5. The message flow diagrams for the control schemes of different querying functions in the narrator mode, part A.

After executing the synchronization mechanism, the LBS controller replies the result to the corresponding user's handheld device. For convenient understanding, the query of the *k*; (1) nearest public POIs; (2) nearest personal LOIs; (3) nearest group AOIs; and (4) nearest public SOIs in the narrator mode are illustrated to execute the control scheme for the corresponding querying function. Figs. 8 and 9 depict the message flow diagrams of the control schemes for the querying function in the narrator mode. Fig. 5 (a) depicts the message flow diagram of the control scheme for the querying function in the general case. Category can be either "PUBLIC", "PERSONAL", or "GROUP". XOI can be either POI, LOI, AOI, or SOI. POI's content consists of text, in which the description of the POI is contained, and multimedia content. LOI's/AOI's/SOI's contents are the nested structure. LOI's/AOI's content consists of text, in which the description of the LOI/AOI is contained, and a list of the contained POIs. SOI's content consists of text, in which the description of the SOI is contained, and a list of the contained POIs, LOIs, and/or AOIs. Fig. 5 (b) depicts the message flow diagram of the control scheme for querying the *k* nearest public POIs. Fig. 5 (c) depicts the message flow diagram of the control scheme for querying the *k* nearest personal LOIs. Fig. 6 (a) depicts the message flow diagram of the control scheme for querying the *k* nearest group AOIs. Fig. 6 (b) depicts the message flow diagram of the control scheme for querying the *k* nearest public SOIs.



(a) Query the *k* nearest group AOIs. (b) Query the *k* nearest public SOIs.

Fig. 6. The message flow diagrams for the control schemes of different querying functions in the narrator mode, part B.

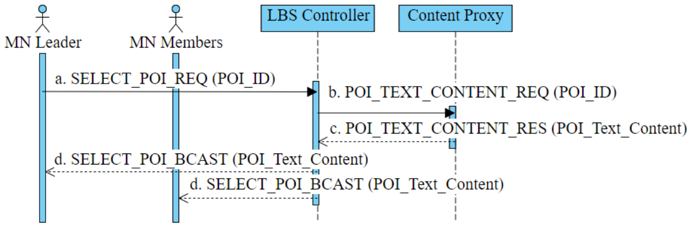


Fig. 7. The message flow diagram of the control scheme for the selecting POI function in the narrator mode.

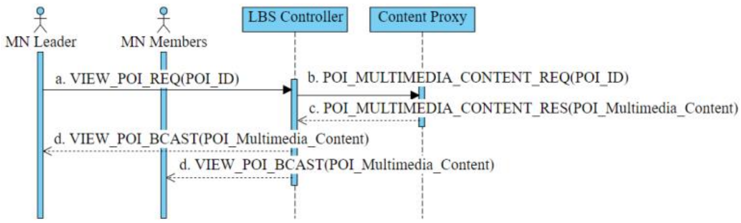


Fig. 8. The message flow diagram of the control scheme for the viewing function in the narrator mode.

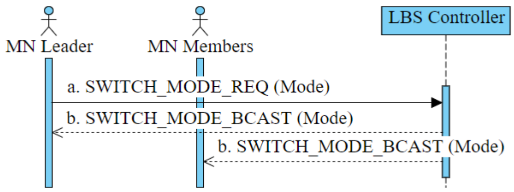


Fig. 9. The message flow diagram of the control scheme for the mode-switching function.

6.3 The Control Scheme for the Selecting Function

The processing for selecting a POI in the narrator mode is as follows:

1. The group leader selects one of the POIs in the list for interpretation to members of the touring group in the narrator mode.
2. MN_L sends the request with the ID of the selected POI to the LBS controller of the MEC server.
3. The LBS controller of the MEC server requests and receives the text content of the selected POI from the content proxy, replies the text contents of the selected POI to MN_L and MN_i, $i = 1, \ldots, n$, and displays the location of the selected POI on the e-map shown in the screens of the group leader's and all of the members' handheld devices.

The processing for selecting a LOI/AOI/SOI is similar to the processing for selecting a POI in the narrator mode. The difference is that the text content of the selected LOI/AOI/SOI is not transmitted to the members of the corresponding group. After executing the control schemes for the selecting LOI/AOI/SOI function, it can use the control scheme for the selecting POI function to get the target POI. In the individual mode, the user, who can be either the group leader or a group member, can execute the selecting function using the same way. Fig. 7 depicts the message flow diagram of the control scheme for the selecting POI function in the narrator mode.

6.4 The Control Scheme for the Viewing Function

The group leader presses the POI information button to get more information of the selected POI for interpretation to members of the touring group in the narrator mode. MN_L sends the request with the ID of the selected POI to the LBS controller. The LBS controller requests and receives the multimedia contents of the selected POI from content proxy, replies the multimedia contents of the selected POI to MN_L and MN_i, $i = 1, \ldots, n$, and displays the text and multimedia contents of the selected POI to the handheld devices of the group leader and group members. In the individual mode, the user, who can be either the group leader or a group member, can execute the viewing function using the same way. Fig. 8 depicts the message flow diagram of the control scheme for the viewing function in the narrator mode.

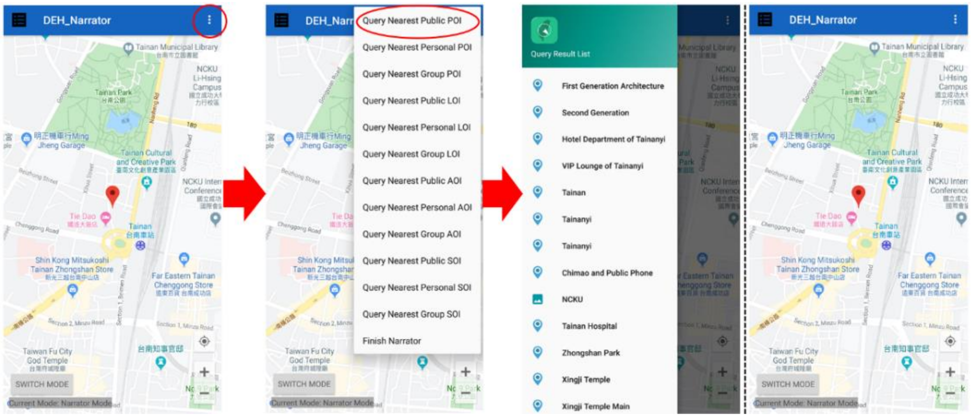
6.5 The Control Scheme for the Mode-Switching Function

The group leader can switch the group touring service mode between the narrator mode and the individual mode. The group leader presses the switch mode button, then, MN_L sends the request to the LBS controller. After that, the LBS controller notifies MN_i, $i = 1, \ldots, n$, to switch the group touring service mode. Fig. 9 depicts the message flow diagram of the control scheme for the mode-switching function.

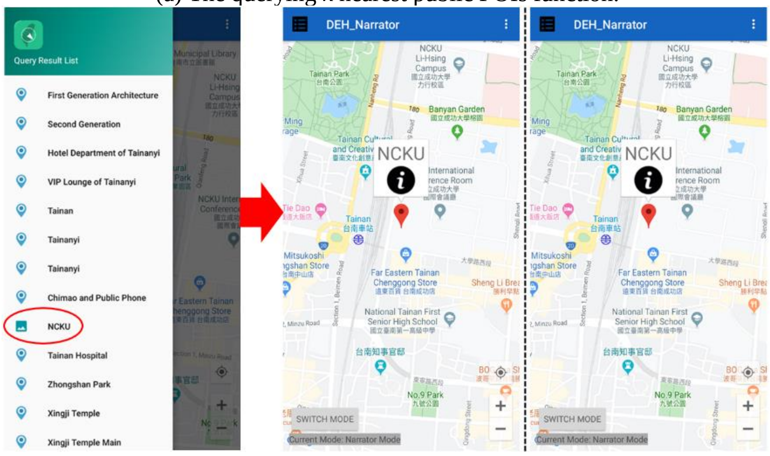
7. USAGE AND EXAMPLES

This Section demonstrates the usage and examples of the DEH_Narrator APP.

Fig. 10 depicts the illustrated example of the touring stage for exploring the k nearest public POIs in the narrator mode. In Fig. 10, the snapshots on (i) the left of the dotted line depict the screen of the group leader's handheld device; and (ii) the right of the dotted line depict the screens of group member's handheld device. Fig. 10 (a) depicts the illustrated example of using the query function for the *k* nearest public POIs. The group leader presses the query-nearest-public-POIs button to query the *k* nearest public POIs in the searching area, which is the circular region with the radius of *n* kilometers centered on her/his target location displayed on the e-map of the screen of her/his handheld device currently. Then, the query result is listed on the screen of the group leader's handheld device. Fig. 10 (b) depicts the illustrated example of using the selecting POI function. The group leader selects one of POIs shown in the list of the query result. In the example, the group leader selects the POI for which the title is "NCKU". Then, the group leader's and each of group members' handheld devices display the location of the selected POI on the e-map shown in the screen. Fig. 10 (c) depicts the illustrated example of using the viewing POI function. The group leader presses the POI information button to get more information of the selected POI. Then, the group leader's and each of group members' handheld devices display the text and multimedia contents of the selected POI on the screen.

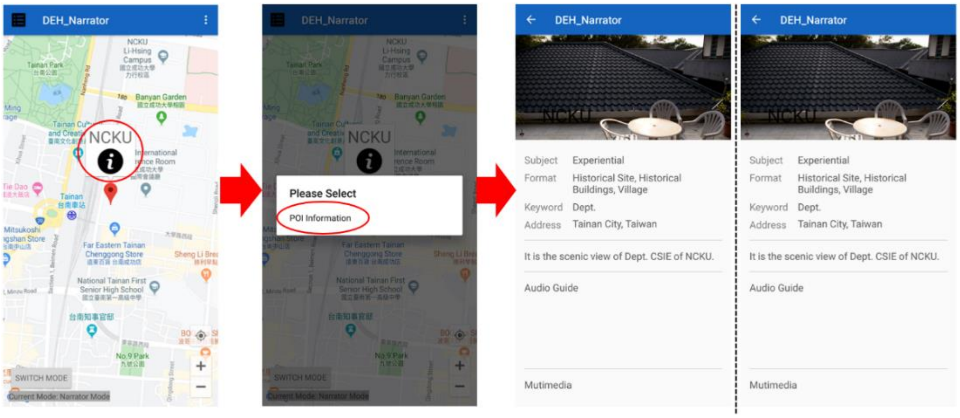


(a) The querying *k* nearest public POIs function.



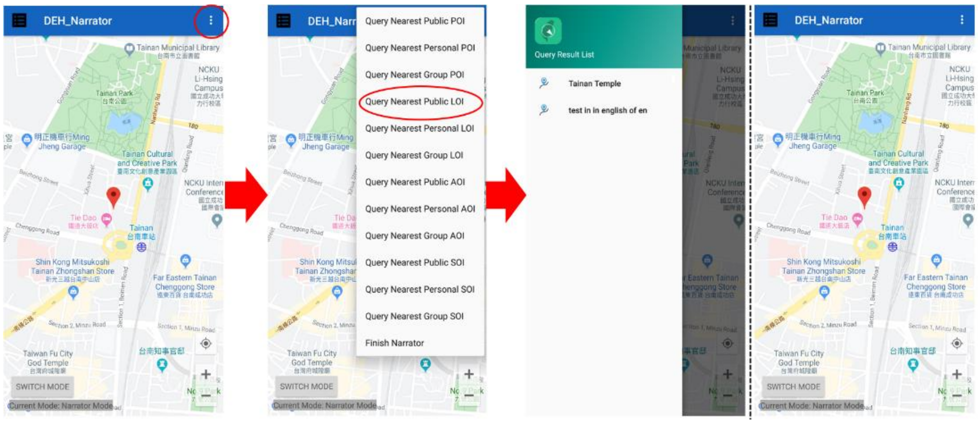
(b) The selecting POI function.

Fig. 10. An illustrated example of the touring stage for exploring the *k* nearest public POIs in the narrator mode.

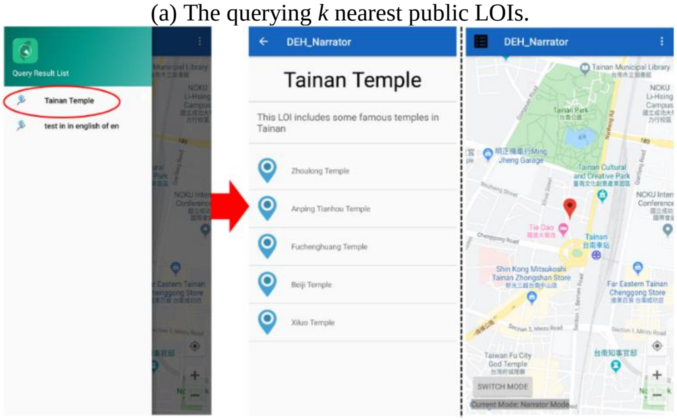


(c) The viewing POI function.

Fig. 10. (Cont'd) An illustrated example of the touring stage for exploring the k nearest public POIs in the narrator mode.



(a) The querying k nearest public LOIs.



(b) The selecting LOI function.

Fig. 11. An illustrated example of the touring stage for exploring the k nearest public LOIs in the narrator mode.

Fig. 11 depicts an illustrated example of the touring stage for exploring the *k* nearest public LOIs in the narrator mode. In Fig. 11, the snapshots on (i) the left of the dotted line depict the screen of the group leader's handheld device; and (ii) the right of the dotted line depict one of the screens of group members' handheld devices. Fig. 11 (a) depicts the illustrated example of using the query function for querying the *k* nearest public LOIs. After using the positioning function, the group leader presses the query nearest public LOIs button to query the *k* nearest public LOIs in the searching area, which is the circular region with the radius of *n* kilometers centered on her/his target location displayed on the e-map of the screen of her/his handheld device currently. Then, the query result is listed on the screen of the group leader's handheld device. Fig. 11 (b) depicts the illustrated example of using the selecting function for selecting a LOI. The group leader selects one of the LOIs in the list of the query result. In the example, the group leader selects the LOI for which the title is "Tainan Temple". Then, the text content of the selected LOI and the list of the contained POIs are displayed on the screen of the group leader's handheld device. Selecting a POI from the LOI's contained POIs in the narrator mode on the touring stage and viewing the selected POI contained in a LOI are similar to the ones depicted in Fig. 10. In the example, the group leader selects the POI for which the title is "Fuchenghuang Temple". Then, the group leader's and each of group members' handheld devices display the location of the selected POI on the e-map shown in the screen.

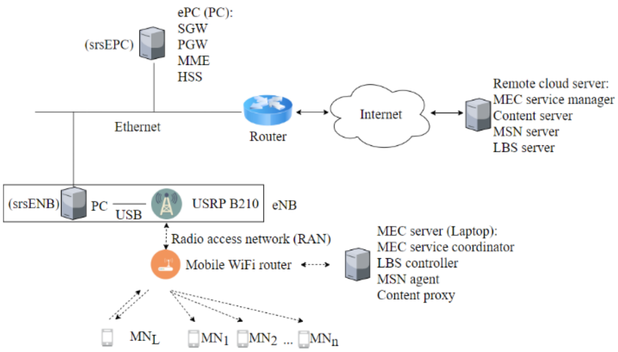


Fig. 12. The networking configuration of the experiment.

8. PERFORMANCE EVALUATION

This section presents the performance analysis. The execution environment and the performance metrics are explained at first; then the performance results are presented.

8.1 The Execution Environment and the Performance Metrics

Fig. 12 depicts the networking configuration of the experiment. One Linux PC that connects with the USRP B210 Board using the USB cable is in charge of executing the srsENB application, which is a complete SDR LTE Evolved Node B (eNB) application, to simulate the eNB of the 4G LTE network. The USRP B210 Board, which was designed and sold by Ettus Research and its parent company, National Instruments, is a software defined radio device that can provide a fully integrated, single-board, Universal Software

Radio Peripheral platform with continuous frequency coverage from 70MHz to 6GHz [20]. One Linux PC that is in charge of executing the srsEPC application, which is a light-weight LTE Evolved Packet Core (EPC) cellular core network implementation with the components of MME, HSS, SGW, and PGW, is used to simulate the EPC in the 4G LTE cellular core network. Both srsENB and srsEPC applications belong to the srsLTE software suite, which is a free and open source 4G LTE software suite. The srsLTE software suite, which was developed by Software Radio Systems Company in Irish, can build an end-to-end Software Defined Radio (SDR) mobile network [21]. One Windows laptop is used as the MEC server and one Windows PC is used as the remote cloud server. One mobile WiFi router is used. One Android handheld device is used as the DEH group leader's handheld device. Six Android handheld devices and six iOS handheld devices are used as DEH group members' handheld devices.

A bus path consisting of five bus stops in the Tainan city is used for testing. The experiment executed the following four functions in each of the bus stop: (1) Positioning: The group leader updates her/his location to the location of the corresponding bus stop. All of the group members' handheld devices receive the location update message and display the group leader's current location on the e-maps of their handheld devices' screens; (2) Querying: The group leader queries the 50 nearest public POIs based on her/his current location and receives the list of POIs from the service server; (3) Selecting: The group leader sequentially selects four nearest public POIs in the list to share and display the location information of the selected POI on the e-maps of the screens of the group leader's and group members' handheld devices in each bus stop; (4) Viewing: The group leader shares and displays the text and multimedia contents of the selected POI on the screens of the group leader's and group members' handheld devices after each POI's selecting.

Four methods used for the comparison are as follows. In Method A, the MEC server is associated with a mobile WiFi router. The DEH_Narrator service is provided by the MEC server. Users' handheld devices and the remote cloud server are in the same country. In Method B, there is no MEC server. The DEH_Narrator service is provided by the remote cloud server. Users' handheld devices and the remote cloud server are in the same country. In Method C, the MEC server is associated with a mobile WiFi router. The DEH_Narrator service is provided by the MEC server. Users' handheld devices and the remote cloud server are in different countries. In Method D, there is no MEC server. The DEH_Narrator service is provided by the remote cloud server. Users' handheld devices and the remote cloud server are in different countries.

Two metrics that are used to evaluate the performance are (1) the data volume; and (2) the response time of each function. The data volume contains (1) the transmission data volume; and (2) the migration data volume. The transmission data volume is the data volume of sending (i) the request from MN_L to the service server; and (ii) the result from the service server to MN_L and MN_i, $i = 1, \ldots, n$. The migration data volume is the data volume of migrating the text and multimedia contents of POIs from the remote cloud server to the MEC server, which is the data volume of the MEC server's synchronizing profiles and contents of POIs with the remote cloud server. The response time contains (1) the computing time; (2) the transmission time; and (3) the migration time. The computing time is the time for processing requests in the service server. The transmission time is the time for sending (i) the request from MN_L to the service server; and (ii) the result from the service server to MN_L and MN_i, $i = 1, \ldots, n$. The migration time is the time for migrating the text and multimedia contents of POIs from the remote cloud server to the MEC server, which is the time for the MEC server's synchronizing profiles and contents of POIs with the remote cloud server.

Table 10. The comparison of the data volume (Unit: bytes) using method A and method B (*n* = 2, 4, 6, 8, 10, and 12).

	n = 2		n = 4		n = 6		n = 8		n = 10		n = 12	
Method	A	B	A	B	A	B	A	B	A	B	A	B
positioning_transmission	693	693	1,057	1,057	1,421	1,421	1,785	1,785	2,149	2,149	2,513	2,513
querying_transmission	4,727	4,727	4,727	4,727	4,727	4,727	4,727	4,727	4,727	4,727	4,727	4,727
querying_migration	25,063,188	0	25,063,188	0	25,063,188	0	25,063,188	0	25,063,188	0	25,063,188	0
selecting_transmission	2,881	2,881	4,729	4,729	6,567	6,567	8,405	8,405	10,243	10,243	12,081	12,081
viewing_transmission	3,219,558	3,219,558	5,365,834	5,365,834	7,512,110	7,512,110	9,658,386	9,658,386	11,804,662	11,804,662	13,950,938	13,950,938

8.2 Experimental Results

Table 10 depicts the comparison of the data volume using method A and method B when $n = 2, 4, 6, 8, 10$, and 12, in which n denotes the number of group members' handheld devices. The transmission data volume of all functions is increased when the number of group members' handheld devices is increased because of the increased number of the transmitted packets. In addition, the transmission data volume of positioning, querying, and selecting functions is very low and is smaller than that of the viewing function because these functions do not transfer multimedia contents. The migration data volume of the querying function using method B is zero when the number of group members' handheld devices is increased because there is no MEC server in method B. The migration data volume of the querying function is high using method A because the MEC server needs to download the contents of the 50 nearest public POIs. Nevertheless, the migration data volume of the querying function using method A remains the same when the number of group members' handheld devices increases because the MEC server caches the same contents. Considering the data volume in the Internet, method A contains the migration data volume of using the querying function, and method B contains the transmission data volume using all of the functions. The data volume in the Internet using method B is more than that of using method A when (i) the number of members' handheld devices is big enough or (ii) the POIs that have been cached in the MEC server during the querying function are selected and viewed by the group leader for many times.

Fig. 13 depicts the comparison of the response time using method A and method B when $n = 2, 4, 6, 8, 10$, and 12. The transmission time of the viewing function is increased obviously when the number of members' handheld devices is increased because of the increased data volume of the transmitted packets. In addition, both of (i) the transmission time and (2) the increased transmission time of the viewing function using method A from $n = 2$ to 12 is smaller than that of using method B because the MEC server is in close proximity to the users' handheld devices using method A. The transmission time of positioning, querying, and selecting functions using method A is smaller than, but is similar with that of using method B. The transmission time of using both method A and method B in fact does not show the obvious increase when the number of group members' handheld devices is increased. The reason is that the data volume of positioning, querying, and selecting functions is too small such that they do not show the obvious difference on the transmission time.

The computing time of positioning, selecting, and viewing functions is similar using either method A or method B; but, the computing time of the positioning, selecting, or viewing function is longer than that of the querying function using either method A or method B. The reason is that the results of positioning, selecting, and viewing functions need to be transmitted to not only the group leader's handheld device but also all of group members' handheld devices, and thus the service server, *i.e.*, the MEC server for method A and the remote cloud server for method B, spends some time to find out all of the correct handheld devices before transmitting the results. Method A needs to spend the migration time for caching POIs' contents in the MEC server, for which Method B doesn't need, when the querying function is executed, *i.e.*, Method A has the longer response time for executing the querying function. Nevertheless, it results in Method A having the shorter response time for executing the viewing function because the corresponding POIs contents are retrieved from the proximate MEC server; in contrast, Method B needs to retrieve the corresponding POIs contents from the remote cloud server individually. The migration time of the querying function remains the same using method A when the number of group members' handheld devices increases because the number of group members' handheld devices does not affect the volume of the cached POIs, *i.e.*, the response time of executing the querying function using Method A is almost the same when the number of group members' handheld devices is increased.

Fig. 14 (a) depicts the comparison of the response time using method A and method C when $n = 2$. The response time of the querying function using method A is shorter than that of using method C because the transmission path between the MEC server and the remote cloud server is in the same country using method A but the transmission path is across different countries using method C. The response time of positioning, selecting, and viewing functions using method A is similar to that of using method C because the same transmission path between the MEC server and the users' handheld devices is used.

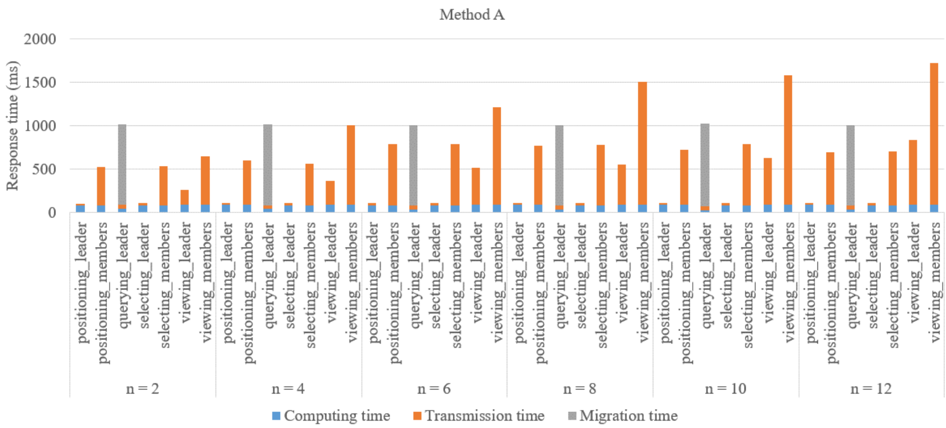


Fig. 13. The comparison of the response time using method A and method B. (n = 2, 4, 6, 8, 10, and 12).

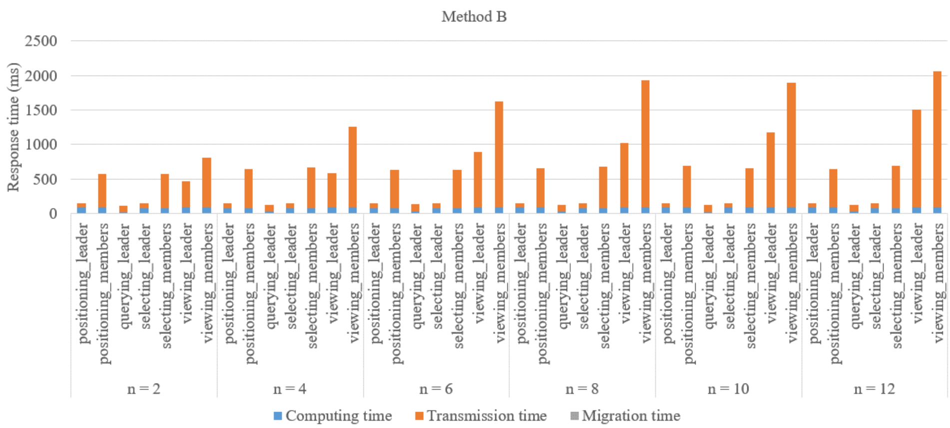


Fig. 13. (Cont'd) The comparison of the response time using method A and method B. (n = 2, 4, 6, 8, 10, and 12).

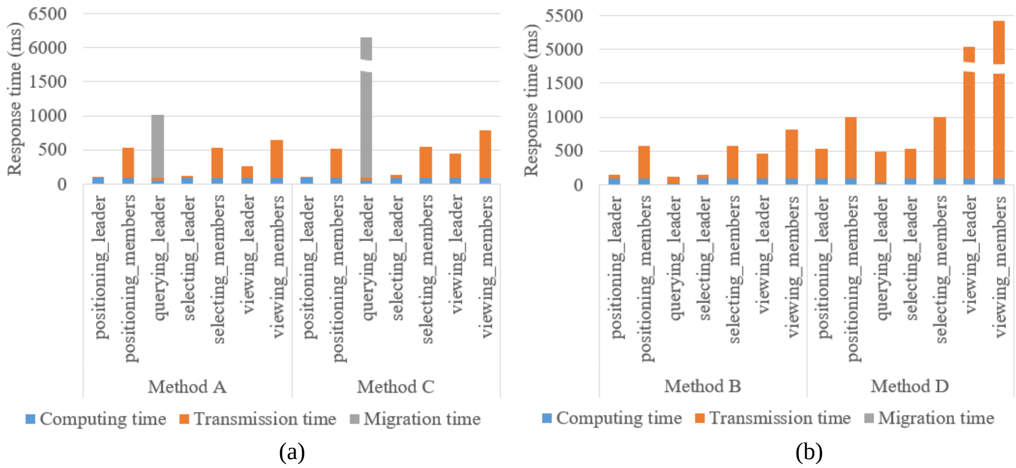


Fig. 14. (a) The response time using method A and method C (n = 2); (b) The response time using method A and method D (n = 2).

Fig. 14 (b) depicts the comparison of the response time using method B and method D when n = 2. The response time of all of the functions using method B is shorter than that of using method D because the transmission path between the MEC server and the remote cloud server is in the same country using method A but the transmission path between the MEC server and the remote cloud server is across different countries using method C.

Observing the aforementioned results, (i) with the placement of the MEC server, even if users' handheld devices and the remote cloud server are in different countries, the response time of most of the functions may not be influenced, the only impact is on the migration time of the querying function; (ii) without the placement of the MEC server, the response time of all of the functions becomes longer. Therefore, the DEH_Narrator APP adopting the proposed MEC-based architecture can provide low latency and much stable service using the wireless mobile network over Internet.

9. CONCLUSION AND FUTURE WORKS

In this paper, a group touring APP called DEH_Narrator that can have leader-controlled real time and synchronous multimedia presentation in all group members' handheld devices based on the MEC architecture has been proposed and developed. The main function of the DEH_Narrator APP is for group touring and let the group leader be able to (i) share her/his downloaded text and multimedia contents of POIs to all of the touring group members; and (ii) control the playout of these shared text and multimedia contents in the handheld devices of all of the touring group's members synchronously and real timely. The main functions of the MEC server are (1) to authenticate the valid group and group members; (2) being the content proxy, which caches the *k* nearest public/personal/group POIs /LOIs/AOIs/SOIs based on the group leader's current location, to speed up the text and multimedia contents' downloading to users' handheld devices; (3) allowing the group leader to be able to control the text and multimedia content's synchronous and real time playout in all of the group members' handheld devices. The aforementioned functional scenario in fact belongs to the real time MSN, which cannot be achieved even if Device-to-Device (D2D) communication is adopted. This work has proved that the real time MSN can be achieved through the help of the MEC paradigm and architecture. The results of the experiments have demonstrated that the proposed scheme and system, *i.e.*, an exemplary real time MSN, have better performance, *i.e.*, low-latency response time because of adopting the MEC paradigm and architecture. This advantage still remains when the MEC server and the remote cloud server are in different countries. Thus, users can enjoy the proposed group touring service with the better QoS, which is in terms of the data transmission time, and QOE, which is in terms of the response time from selecting a POI to displaying the selected POI's text and multimedia contents to all of the group members' handheld devices, using the DEH_Narrator APP. For the future work, it can extend group members from the 1-hop away to the *k*-hop away to enlarge the sharing and control.

REFERENCES

1. ETSI GS MEC 010-1 V1.1.1. Mobile Edge Computing (MEC); Mobile Edge Management; Part 1: System, host and platform management, 2017.
2. ETSI GS MEC 003 V1.1.1. Mobile Edge Computing (MEC); Framework and Reference Architecture, 2016.
3. N. Abbas, Y. Zhang, A. Taherkordi, and T. Skeie, "Mobile edge computing: A survey," *IEEE Internet of Things Journal*, Vol. 5, 2018, pp. 450-465.
4. Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, "A survey on mobile edge computing: The communication perspective," *IEEE Communications Surveys & Tutorials*, Vol 19, 2017, pp. 2322-2358.
5. C. M. Huang and Y. A. Guo, "A touring and navigation service platform for mobile digital culture heritage (M-DCH)," in *Proceedings of the 15th International Symposium on Pervasive Systems*, *Algorithms and Networks*, 2018, pp. 185-192.
6. C. M. Huang and Y. A. Guo, "The demodulating and encoding heritage (DEH) platform for mobile digital culture heritage (M-DCH)," *Journal of Internet Technology*, Vol. 21, 2020, pp. 765-781.

7. A. Kountouris and E. Sakkopoulos, "Survey on intelligent personalized mobile tour guides and a use case walking tour app," in *Proceedings of the 30th International Conference on Tools with Artificial Intelligence*, 2018, pp. 663-666.
8. S. Jang, J. Kim, and A. Nasridinov, "Flexible POI recommendation based on user situation," in *Proceedings of International Conference on Internet of Things and IEEE Green Computing and Communications and IEEE Cyber*, *Physical and Social Computing and IEEE Smart Data*, 2019, pp. 1257-1260.
9. M. Zhou, D. Chen, and T. Yi, "The research on construction of college student online tour guide platform base on wisdom tourism", in *Proceedings of the 30th Chinese Control and Decision Conference*, 2018, pp. 3051-3054.
10. M. Kargar and Z. Lin, "A socially motivating and environmentally friendly tour recommendation framework for tourist groups," *Expert Systems with Applications*, Vol. 180, 2021, doi.org/10.1016/j.eswa.2021.115083.
11. H. Zhou, H. Wang, X. Li and V. C. M. Leung, "A survey on mobile data offloading technologies," *IEEE Access*, Vol. 6, 2018, pp. 5101-5111.
12. R. Liang, Y. Zhong, and Q. Xia, "Energy-saved data transfer model for mobile devices in cloudlet computing environment," in *Proceedings of the 3rd International Conference on Cloud Computing and Big Data Analysis*, 2018, pp. 271-274.
13. W. Fan, J. Han, L. Yao, F. Wu, and Y. Liu, "Latency-energy optimization for joint WiFi and cellular offloading in mobile edge computing networks," *Computer Network*, Vol. 281, 2020, pp. 1-11.
14. P. Yang, N. Zhang, S. Zhang, L. Yu, J. Zhang, and X. Shen, "Content popularity prediction towards location-aware mobile edge caching," *IEEE Transactions on Multimedia*, Vol. 21, 2019, pp. 915-929.
15. J. Xu, L. Chen, and P. Zhou, "Joint service caching and task offloading for mobile edge computing in dense networks," in *Proceedings of IEEE International Conference on Computer Communications*, 2018, pp. 207-125.
16. G. Lee, H. Ko, S. Pack, V. Pacifici, and G. Dán, "Fog-assisted aggregated synchronization scheme for mobile cloud storage applications," *IEEE Access*, Vol. 7, 2019, pp. 56852-56863.
17. M. Alghamdi, A. Cherif, and A. Imine, "EdgeDoc: An edge-based distributed collaborative editing system," *Pervasive and Mobile Computing*, Vol. 70, 2021, pp. 1-20.
18. I. Darmawan, A. Rahmatulloh, and R. Gunawan, "Real-time screen sharing using web socket for presenting without projector," in *Proceedings of the 7th International Conference on Information and Communication Technology*, 2019, pp 1-6.
19. Y. Gu, G. Yu, and X. N. Yu, "An efficient method for *k* nearest neighbor searching in obstructed spatial databases," *Journal of Information Science and Engineering*, Vol. 30, 2014, pp. 1569-1583.
20. Ettus Research, "USRP B210," https://www.ettus.com/all-products/ub210-kit/.
21. Software Radio Systems, "srsLTE," https://www.srslte.com/.

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