G-LocON: A P2P-based Communication Framework for Geo-Location Oriented Networks

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***Abstract*—This paper proposes a novel peer-to-peer communication framework to realize geographical location oriented networks called *G-LocON*. Location based services have been getting popular as typified by ridesharing and mobile games. Although these services have to construct geo-location oriented networks based on users' geographical locations, they completely rely on client/server models to communicate with neighboring terminals. G-LocON, the proposed communication framework, provides geo-location oriented device-to-device communication only with the current wireless technologies such as LTE and Wi-Fi, cooperating with global positioning system and peer-to-peer overlay networking. We introduce a location tracker, which maintains location information of user devices and helps them find the neighboring devices. After obtaining the neighbor peers list, each device can establish peer-to-peer connections to the neighbors and then directly communicate to them without relaying any server. G-LocON will thus realize a kind of mobile ad-hoc network in which devices in a focusing area can directly communicate among them. We developed the Android application to implement the G-LocON framework. The performance evaluation in the actual environment verified the usefulness of the proposed system with admissive transmission delay.**

***Index Terms*—Geo-location oriented network, Location-based service, Peer-to-peer, Overlay**

I. Introduction

In the recent decade, smartphones have been obtaining higher performance with various functions and then getting much popular as not only mobile phones but portable computing devices. Some reports forecast that the number of smartphone users in the world will reach 2.7 billion and exceed 50 percent of all mobile users in 2019 [1], [2]. One of the remarkable smartphone functions is a global positioning system (GPS). The GPS can pinpoint the geographical location of users based on received signals from four or more GPS satellites, without any data transmission from GPS receivers. Ohmae defines a generation-based evolution model for location information (LI) business [3]. The LI history started in the 1990s with digital map services, which include car navigation and digital map services on personal computers. In the applications in this generation, LI is used only personally and privately to display user's location on the map. In the 2000s, the advent of social networking service (SNS) and smartphones brought us to the next generation, LI 2.0. Users commonly provide their own LI to smartphone applications, some of which send and register the LI to the servers, and then can enjoy geo-location-based services (LBS). Ohmae estimates that we are opening the door of LI 3.0 era in which the LBS will be much improved and enhanced by Internet of Things (IoT) devices and sensors around us.

In looking toward geo-location-based applications, digital map application came first but is still much popular and useful in route search and navigation. SNS applications such as Facebook, Twitter, and Instagram, are also often installed in most user smartphones. By tagging and sharing users' locations and trajectories where they are/were or they want to visit, they can easily find useful information such as reputations and recommendations of shops and popular places. Ridesharing services such as Uber and Grab integrate LI and SNS: Digital map applications show user's position as well as available cars around the user; and social networks establish trust and accountability between passengers and drivers [4], [5]. Furthermore, augmented reality (AR) is a popular application that utilizes user's LI in recent years. Sekai Camera [6] brought a new world where, through the smartphone camera, we can see the messages and photos that are ever saved and linked to the real space with LI tags by other users. Niantic, Inc. [7] launched megahit games, Ingress and Pokémon Go, and is a leader of AR game product in the world.

Following the above LI services, inter-vehicular communication is one of promising core technologies in intelligent transportation systems (ITS) [8], [9]. In general, vehicular-related communication forms a vehicular ad hoc network (VANET) among neighboring devices by utilizing radio propagation-based direct communication [11] and infrastructure-based communication [12]. VANET thus realizes a close-range direct or multi-hop communication among vehicles and other peripherals [10].

As just described, geo-location-oriented communications have good prospects and potentials for the future. However, there are some problems and challenges in LBS. Firstly, the current location-based applications are mainly realized as server-based systems. User devices and their LI are registered and maintained in the location servers, and each device has to connect to the servers to obtain the information around the user. The computation and storage load would be thus concentrated to the servers. Secondly, although multi-hop communication has been certainly a promising technology for more than 20 years, no one knows when it becomes widespread and is installed to consumer devices. For example, the VANET system will work well after all vehicles are equipped with wireless communication, while people do not replace their cars to new ones so frequently.

In this paper, we propose *G-LocON*, a novel communication framework to realize geographical location oriented networks. G-LocON constructs a peer-to-peer (P2P) logical overlay network around each user. We implement a location tracker, which maintains the LI of user devices and helps to discover neighbor devices. The proposed framework thus provides geo-location oriented device-to-device communication. Since the system works relying only on the current technologies such as LTE, Wi-Fi, and GPS, people can obtain a future service on their smartphones right now.

The remainder of the paper is organized as follows. Section II briefly discusses previous works related to LBS and location-based P2P networks. In Section III, we explain the G-LocON framework and describe the proposed protocols as well as an implementation method. Section IV reports the results of experimental evaluations in the actual environment. Conclusions and suggestions for future work are provided in Section V.

II. Related Work

LBS is one of the recent hot topics and has attracted much attention to many researchers [13]–[21]. Popular research objectives are mainly categorized to LBS frameworks [13]–[15] and LBS applications [16], [17], [20], [21]. In the former category, authors propose new network architectures or frameworks to provide location-based services. The latter category, on the other hand, develops new application such as mobile positioning or navigation systems.

Some articles utilize P2P approach, which we also focus on in this paper, to construct logical overlay networks to discover neighbor peers [18]–[21]. Kaneko et al. propose a tree-based P2P overlay structure called LL-Net [18]. They assume a mixed environment where both fixed and mobile devices coexist, and try to form a three-layer tree structure on a traditional grid-cutting region model. LL-Net was evaluated for the content retrieval by computer simulation. Kovačević et al. also propose a hierarchical tree-based P2P overlay called Globase.KOM [19]. They focus on the world-wide spanning network, which is divided into non-overlapping rectangular zones. Simulation results show that Globase.KOM achieves full retrievability of area searches and short response time. Wang et al. develop a P2P mobile navigation system to guide visitors in a flora exposition with 3D rendering pictures [20], [21]. P2P technology is used for clustering neighboring users who have similar interests and downloading data from them. They also validate the faster transmission rates of the proposed system by computer simulation, assuming all the devices are connected by Wi-Fi.

The conventional location-based P2P systems mentioned above still have some problems. Both LL-Net and Globase.KOM rather target wide-area content retrievals and then form hierarchical tree-based overlay networks. This approach is costly to find super peers and construct hierarchical networks when focusing on a small area around each user. Moreover, all the systems mentioned above do not seem to consider real-time communication among users. In addition, they can hardly be implemented as-is in mobile network environment due to the private addressing system. We believe that a hybrid P2P system in which some servers exist for maintaining peers help to quickly look for neighbor peers.

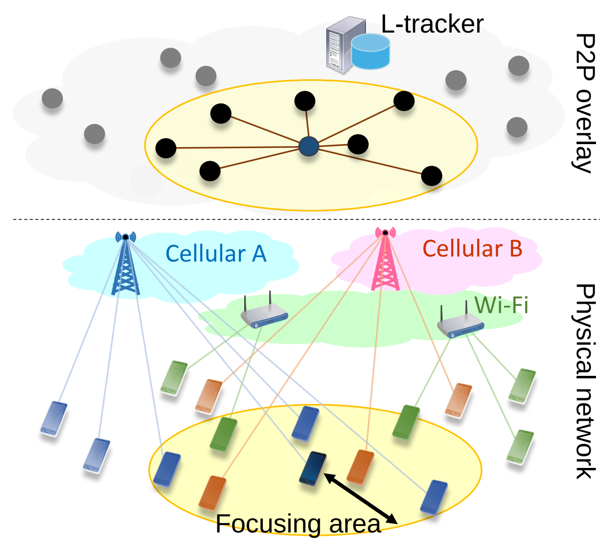

Fig. 1. G-LocON framework: forming a P2P overlay managed by L-tracker on interconnected physical networks.

III. G-LocON Communication Framework

A. Overview of G-LocON

This paper proposes a P2P-based communication framework to realize geographical location oriented networks called *G-LocON*. An outline image of the proposed system is shown in Fig. 1. In the proposed system, mobile devices i.e., peers, are assumed to connect to various networks: They connect to cellular networks, Wi-Fi, and so on. G-LocON provides a hybrid P2P network by implementing a location tracking server called *L-tracker*. The L-tracker maintains peers information that consists of peer identifiers and locations, and helps each peer to discover neighbor peers around it.

When a new peer joins to the proposed system, the peer first sends a join message with peer information and its LI to the L-tracker. The peer then requests neighbor peers information to the L-tracker, and finally establishes P2P connections to its neighbors. In the proposed system, every peer periodically registers its LI to the L-tracker by reusing the join message, obtains renewed neighbor peers information, and updates the connections to the neighbors. After the establishment of P2P connections, the peer directly communicate to its neighbors without relaying any server.

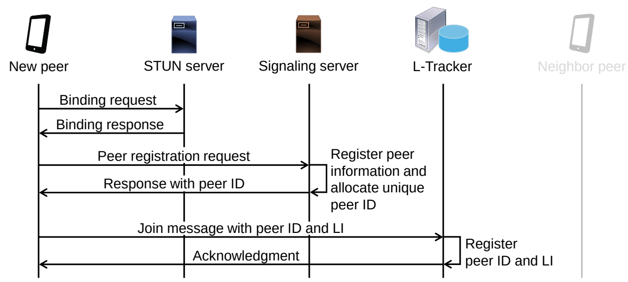

Fig. 2. Join process to G-LocON.

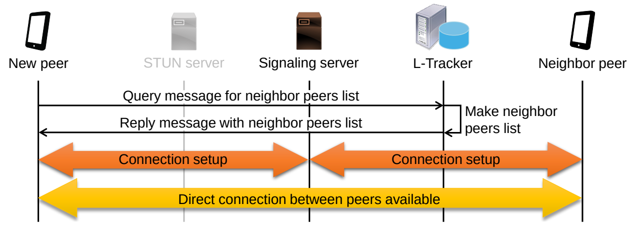

Fig. 3. P2P connection process.

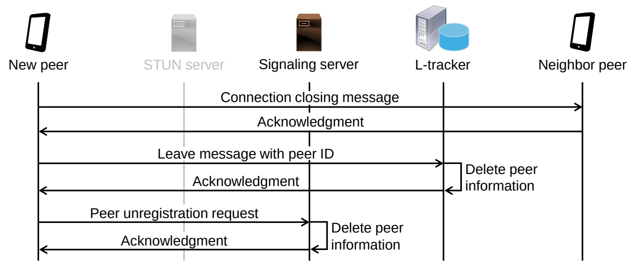

Fig. 4. Leave process from G-LocON.

B. How to form the G-LocON overlay

To establish a direct connection between two mobile devices, a peer needs to know the translated IP address and port number of the destination peer. Such information is called *address bindings* automatically allocated when a packet traverses a NAT gateway. In this paper, a STUN server [22] is deployed to resolve the bindings information. Moreover, peers also have to exchange metadata to coordinate communication. We thus introduce a signaling server to share the peers information and to coordinate connections among peers.

1) Join process to G-LocON

Fig. 2 shows the communication process when a new peer joins the G-LocON overlay network. The sequence of the join process is described as follows:

- A new peer firstly sends a binding request to the STUN server. The server replies a binding response that consists of the IP address and port number, as observed from the server's perspective.
- The new peer then sends a registration request to the signaling server. The request message contains the peer's IP address and port number resolved by the STUN server. The server allocates a unique identifier to the peer (peer ID) and registers these three data into the database. The server also sends back the peer ID to the peer as a response.
- The peer sends a join message to the L-tracker. The message includes the peer ID and LI that is obtained by the GPS module. The L-tracker then registers them into the database and replies an acknowledgment. This step will be periodically repeated for updating the LI at intervals of T_{int}.

2) Establishment of P2P connection between peers

After the join process, the peer becomes ready to establish P2P connections. Fig. 3 shows the communication process. When a peer sends a neighbor search query to the L-tracker, the area to be searched has to be clearly indicated. In this paper, we define that every search area is a circular form that is defined by a center and a radius. The center point can be the peer's location, and the radius represents the size of focusing area. The sequence of the P2P connection process is described as follows:

- The peer sends a query message to the L-tracker to discover neighbor peers. The message includes the search area information such as peer's LI and a radius. The L-tracker makes a list of neighbor peers found in the search area and then sends it back to the peer as a reply message. The peer maintains the list, which consists only of peer IDs.
- Based on the neighbor peers list, the peer sets up the P2P connection with the neighbor peers by the assistance of the signaling server. By this process, the peer obtains the IP address and port number of each neighbor peer. The server sends another signaling message to the neighbor peer to inform of the connection request from the new peer as well as its IP address and port number. Herewith, two peers can establish the P2P connection and subsequently communicate to each other at any time while the connection is alive. Each peer maintains the list of P2P connections.
- The peer closes the P2P connections if the neighbor peers that have already been connected disappear in the neighbor peers list.

If there is a particular type of NAT between two peers, the connection may not be established by the above sequence. In this case, the peers try to connect through a TURN server [23]. Moreover, the P2P connection process is executed every after the periodical repetition of sending join messages to L-tracker; the interval time is thus T_{int}.

3) Leave process from G-LocON

Fig. 4 shows the communication process when a peer leaves the G-LocON overlay network. The sequence of the leave process is described as follows:

- The peer first closes all the P2P connections with the neighbor peers by sending connection closing messages.

- The peer sends a leave message to the L-tracker. The L-tracker then deletes the relevant information from the database.
- The peer sends a peer unregistration request to the signaling server. The server then deletes the relevant information from the database.

4) Avoidance of multiple P2P connections

If two peers virtually simultaneously try to initiate P2P connections to each other, multiple connections may occasionally be established. We therefore prepare a process to avoid such multiple connections. When a peer detects a new P2P connection with a neighbor peer, the peer checks if another connection with the same peer ID exists in the list of P2P connections. If it exists, the new connection is immediately closed. Otherwise, the list is updated by adding the information of new connection.

C. Implementation

We implemented the G-LocON framework to realize geo-location based P2P overlay networks. The L-tracker was developed on NIFCLOUD, a public cloud computing service provided by Fujitsu Cloud Technologies [24]. We also used SkyWay API, a WebRTC platform provided by NTT Communications [25]. SkyWay also offers the STUN, TURN, and signaling services. The mobile software was developed on Android Studio with NIFCLOUD and SkyWay APIs. As Android smartphones, ASUS ZenFone 3 / 3 Laser / 2 Laser, LG Nexus 5 / 5X, Samsung Galaxy S6, and Sony Xperia ZL2 were used.

In the developed application, each peer obtains its LI from the GPS module every one second, and registers and updates the LI to the L-tracker every five seconds: $T_{\mathrm{int}} = 5$ [sec]. After establishing P2P connections to the neighbor peers, each peer tries to send and share the LI to the neighbors as soon as the LI is updated, i.e., every one second. Each peer will maintain the LI received from the neighbor peers.

IV. Performance Evaluation

A. Experimental settings

To evaluate the performance of G-LocON framework, we performed experiments to form a P2P overlay network by several Android smartphones in the actual environment. In the experiments, we especially focus on communication and processing delay. Here, t_l, t_s, and t_r denote the times when a peer obtains its LI from the GPS module, when the peer starts sending the LI to each neighbor peer, and when the neighbor peer receives the LI, respectively. These times were recorded in each smartphone device by using the GPS signal and its internal clock that had been adjusted beforehand by the network time protocol (NTP). $T_{\mathrm{send}} = t_r - t_s$ represents the transmission delay for a peer to send its LI to each neighbor peer. Meanwhile, $T_{\mathrm{total}} = t_r - t_l$ represents the total delay time from when a peer obtains its LI to when the LI arrives at each neighbor. In this paper, we evaluate T_{send} and T_{total}.

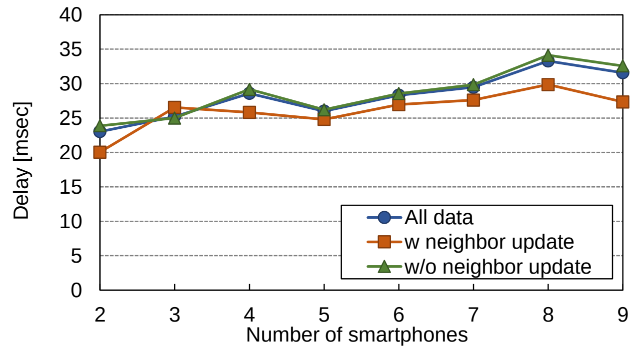

Fig. 5. Average transmission delay T_{send} (static case).

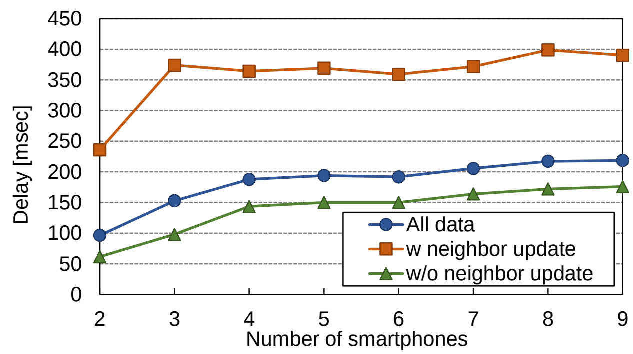

Fig. 6. Average total delay T_{total} (static case).

We assume two situations: static and dynamic cases. In the static case, two to nine smartphones were placed in the laboratory by a window, to clearly obtain the GPS signals, and connected to Wi-Fi provided by our university. The G-LocON overlay established by those devices formed a full mesh topology since all the peers were in the focusing areas of the others and thus mutually regarded as the neighbor peers. In a experimental set, each peer sends its LI to the others 300 times. We performed three sets and calculated the mean values of T_{send} and T_{total}. In the dynamic case, two to five persons randomly walked with their smartphones in a specified open-air area. The devices connected to LTE cellular networks provided by Japanese well-known mobile services, au (KDDI) and IIJ mobile (MVNO on NTT DoCoMo). The form of G-LocON overlay was not always full-mesh since some peers occasionally moved out of the focusing areas of other peers. We performed only one experimental set and calculated the mean values of T_{send} and T_{total}.

B. Results

Figs. 5 and 6 show the average transmission delay T_{send} and the average total delay T_{total} in the static case, respectively. In a similar fashion, Figs. 7 and 8 show the results in the dynamic case. In each figure, we indicate three types of delay values: the overall average delay (the blue line and circles), the average delay when peers obtain the updated neighbor peers list from the L-tracker (the red line and squares), and the

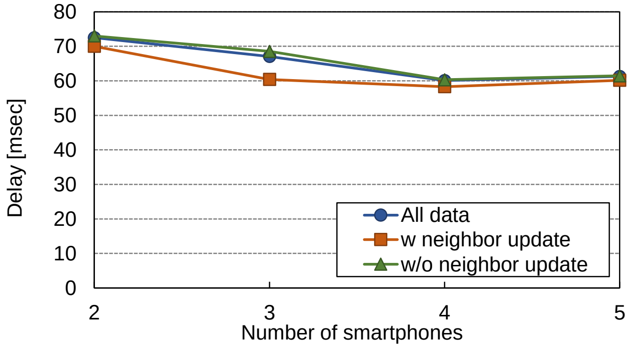

Fig. 7. Average transmission delay T_{send} (dynamic case).

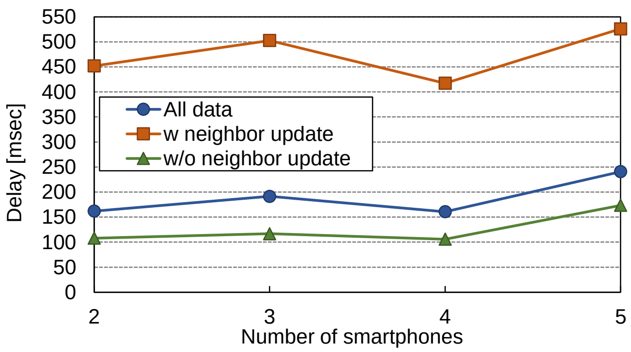

Fig. 8. Average total delay T_{total} (dynamic case).

average delay when not obtaining the updated list (the green line and triangles).

From Fig. 5, the average transmission delay T_{send} becomes gradually longer with an increase in the number of devices. This is because both transmission and processing load of each peer becomes large as the number of neighbor peers increases. On the other hand, the delay when peers receive the updated neighbor peers list (the red line) is smaller than the delay when not obtaining the list (the green line). For updating the neighbor peers, each peer connects to the L-tracker at intervals of T_{int}. Since this process is executed sequentially in our current implementation, the peer does not communicate with the neighbor peers; and consequently the processing load will be reduced. From Fig. 6, it is observed that the average total delay T_{total} becomes much larger than the transmission delay T_{send}. In particular, the red line is roughly twice as high as the blue line. The total delay represented by the red line includes the processes to obtain the neighbor peers list from the L-tracker and to establish P2P connections to the neighbors. These processes take 170 to 270 milliseconds, which are obtained as the differences between the red and green lines. From the above results, we think that the performance of G-LocON framework depends strongly on the communication to the L-tracker and the establishment of P2P connections.

Next, we turn to the dynamic case. From Fig. 7, it is observed that the average transmission delay T_{send} rises more than twice that in the static case. This is because longer network delay was added since all the smartphones connected to LTE networks. Meanwhile, it does not become worse with the number of devices. A possible reason for this phenomenon is that the conditions of cellular networks varied from hour to hour, and accordingly the available bandwidth changed. To be honest, however, further experiments and thorough measurements are needed with more smartphone devices in the dynamic case. From Fig. 8, the average total delay T_{total} has the similar characteristics to that in the static case: The total delay when the neighbor peers list was updated is much longer than that without the update. This also makes it clear that the communication to the L-tracker and the establishment of P2P connections take relatively long time comparing to direct P2P communications among peers.

In regard to this point, we carefully examined the log data when three smartphone devices had formed the G-LocON overlay in the dynamic case. What we here focus attention on is how long it takes for a peer to completely establish a P2P connection after the peer receives the neighbor peers list. From the observation, we found that there existed the cases when the time required became several seconds. The time scale of this waiting time cannot be negligible when the G-LocON framework is used for real-time application such as inter-vehicular communications. Since the delay time will probably increase with the number of peers, the protocol implementation to communicate with the L-tracker and the processing methods to establish P2P connections should be much improved.

V. Conclusions

In this paper, we proposed the G-LocON framework to realize P2P-based geo-location oriented networks. By using the proposed scheme, each mobile device can easily discover the neighbors around it and then form the G-LocON overlay network. We developed the Android application to implement the G-LocON framework by utilizing public cloud computing and WebRTC platform services. We also evaluated the performance of G-LocON framework with several smartphones in the actual environment. The results obtained from the experiments in the static and dynamic cases can be summarized as follows:

- The average transmission delay between peers, represented as T_{send}, is of the order of tens of milliseconds, and gradually increases with the number of neighbor peers.
- The average total delay from when a peer obtains its LI from the GPS module to when the LI arrives at each neighbor, represented as T_{total}, is of the order of hundreds of milliseconds, and gradually increase with the number of neighbor peers.
- When peers obtain the updated neighbor peers list from the L-tracker, the total delay becomes much longer than that without the update.
- Occasionally, several seconds are needed to initiate a P2P connection after the neighbor peers list arrives.

These results clearly indicate that the protocol implementation to communicate with the L-tracker and the processing methods to establish P2P connections should be much improved for real-time application. We will strive to introduce parallel processing among the communications to the L-tracker and neighbor peers. Moreover, as space is limited, we have concentrated on the protocol description and its performance evaluation in this paper. Our next report will unveil the real-time applications that can communicate among neighbor smartphones.

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