Design and Implementation of Mobile P2P Collaboration Framework for Spatial Data

By Jaegon Jung*

A map is one of the most useful media in disseminating spatial information. As mobile devices are becoming powerful and ubiquitous, people increasingly want spatial information to be available anywhere and anytime. Google Maps for Mobile is one of the most popular mapping applications on mobile devices delivering location aware information since mobile map services are introduced a few years ago. When it is used in Mobile Collaboration in which sharing of information is focused, sharing of location is realized by means of real-time transfer of spatial data between mobile devices. In the perspective of map based communication, the mobile maps used to share information on spatial properties can play an important role in wireless environment.

This research describes a practical approach to designing spatial data sharing framework for efficient interactions between mobile devices. There are just a few studies on the interaction of spatial data between mobile devices while researches on standards based spatial data interchange in the wired Internet has been widely conducted. General collaboration technologies applied to spatial data can provide facilities for spatial data delivery but it is hardly applicable for real world data on mobile devices because of unacceptable performance and lack of research effort addressing limitations of mobile environment.

To overcome the limitations in mobile collaboration with spatial data mentioned above, an approach based on a peer-to-peer standard protocol which initiates and maintains sessions between mobile is introduced. Peer-to-peer based approach has benefits such as improved scalability and elimination of the need for costly infrastructure by enabling direct communication among clients. Among several protocols for peer-to-peer communication on mobile devices, SIP is unique, flexible and stable enough to be used in designing new framework.

The main contribution of this work is to design new framework based on standard peer-to-peer technologies enabling spatial data transfer between mobile devices. Prototype applications for several typical scenarios are also designed and implemented to prove feasibility of the framework. This research proposed extensible components by extending basic features of SIP protocol and it means that it is compatible to SIP standard. The new framework accelerates and facilitates sharing of spatial data for real-time communication because it can be easily applied to existing SIP based voice communication systems. WKT format is used to transfer spatial data and a new formal SDP model was designed to represent it.

Typical scenarios are analyzed to extract user requirements dealing with spatial data transfer and essential components consisting of the new framework are designed based on them. The first scenario is to share

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destination and current location in navigation system and the second one is to send and receive hazardous area for emergency cases in forest fire. Spatial data types such as point, polyline and polygon need to be transferred as primitive data types to support immediate notification and display on mobile devices after updating current location or target region to meet the requirements of the above scenarios.

In implementing prototype applications, user agents on mobile devices play an important role for seamless integration of mapping modules and communication modules. Immediate notification and display is verified as an important and necessary function for a mobile client that is designed on a user agent because real-time delivery of spatial objects is assumed. The performance of lightweight mobile libraries for the user agent is good enough to be used in real world applications. Open API for the integration of existing mobile applications dealing with spatial data is also proposed to facilitate loose coupling between the proposed framework and existing mobile applications.

Finally, the results of this research show SIP based mobile collaboration system architecture can be implemented with spatial features by incorporating open standards in the design and by resolving notification services using our proposed framework for mobile devices. The framework can also be applied in many emergency cases such as criminal investigation and in fieldwork for the monitoring of land resources.

Key Words : Mobile P2P, Mobile Collaboration, Mobile GIS, Sharing Framework, SIP, Spatial Data Transfer Standard

1. Introduction

1.1 Background and Scope

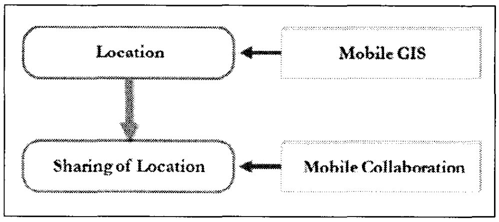
A map is one of the most useful media in disseminating spatial information. As mobile devices are becoming increasingly powerful and ubiquitous, people want spatial information to be available anywhere and anytime. The progress in the field of mobile communications and mobile devices which was achieved during the last years allowed the development of mobile map applications, addressed to the users of handheld devices[1].

With the success of Google Maps[2] and iPhone devices[3], mobile map services are introduced a few years ago and they are currently popular on several mobile devices. Google Maps for Mobile is one of the most popular mapping applications on mobile devices delivering location aware information. When location in those services is used in mobile collaboration in which sharing of information is focused, sharing of location is realized by means of real-time transfer of spatial data.

For example, network-oriented car navigation systems have become a hot topic because of the expanding car navigation and active wireless communication markets[4]. More and more navigation systems are getting integrated with wireless communication modules and this fact allows users to send messages to another buddy's navigation system as well as to browse general web sites. However, there is no way to send or receive spatial objects on the map and it is not easy to implement those functions without common sharing framework. Proprietary systems with those functions implemented by each navigation manufacturer can be useless if it is not based on international standards while standards based approaches ensure that collaborative access is independent of operating systems (meaning ubiquitous), and open to large and small institutions[5]. A standard based sharing framework is, therefore, needed for spatial data transfer capabilities of mobile applications as a location aware communication infrastructure.

To meet the needs, mobile collaboration in which sharing of information on location is realized is emphasized in this research. Basically, sharing of location does not mean just to refer server generated maps or spatial objects as they are served in general mobile GIS applications but to directly notify them from one mobile device to another one moving anywhere in real time.

Technically, almost all mobile map services are browsing server generated maps that are referred in wireless environment and user added markers can be stored into server side systems. This research focuses on technical aspects of mobile collaboration and it means that technical architecture is important to provide infrastructure in which spatial objects can be directly transferred from one mobile device to another one in peer-to-peer manner. ⟨Figure 1⟩ shows transition of interest from simple reference of location to



〈Figure 1〉 Transition of Interest to the Sharing of Location

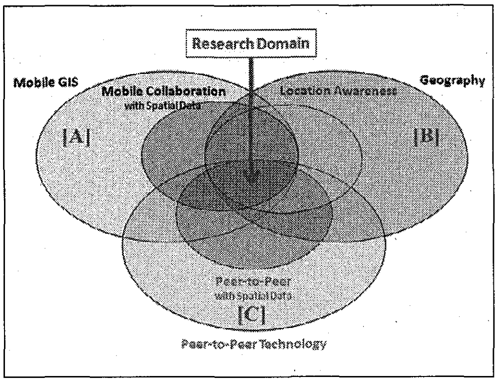
sharing of location. Users in mobile collaboration domain can share both location itself and new information generated from its context (ex. sharing of the location of adjacent restaurants).

Definitions such as Mobile GIS, Wireless GIS, Real-Time GIS and Mobile Collaboration are closely related to technical aspects of this research and there are lots of researches enough to form independent research domains. Among those terms, mobile GIS is definitely well-known to be described for current technical improvements from web GIS.

On the basis of mobile computing environment, a mobile user is often conceived as a person executing tasks anywhere and anytime, using mobile computing devices with wireless communication capabilities. Typically they require functionalities for data synchronization and on-demand collaboration with other people[6]. Mobile collaboration is useful when mobile users need autonomous, flexible and interoperable collaborative solutions, regardless of the availability of centralized resources or communication infrastructure[7]. Spatial data used in mobile GIS can also be transferred between mobile devices using collaboration technologies efficiently.

Collaboration technologies applied to spatial data between mobile devices provide facilities for spatial data delivery between mobile devices but it is hardly applicable for real world data because of the above limitations and lack of research effort on spatial data transfer in mobile collaborative environment. In overcoming this kind of lack of functionality, it is important to choose appropriate mobile technologies in designing and developing new framework for communication or sharing of spatial data because there are various kinds of devices and OS platforms which are not compatible to each other and hardly applicable for real world spatial data.

Recently, growing demand for mobile applications due to real time information needs can be requirements for spatial data sharing and peer-to-peer (P2P) technology can be applied to make collaborative communication system feasible on mobile devices[8]. Peer-to-peer technology supports the creation of sessions between two network nodes and is widely used for the session control and services on it. Mobile P2P is an extended peer-to-peer networks that can be accessed from mobile devices. They have advantages of information sharing, using less network bandwidth, saving computing power, etc. There are several peer-to-peer technologies such as JXTA[9], XMPP[10] and SIP, but they have some limitations not to support mobile devices in a simple manner. Most of current studies in peer-



〈Figure 2〉 Research Domain

to-peer technology concern about text and multimedia data such as voice and video. Only a few of them discuss on spatial data, and still very few of them study the interactions between mobile devices.

In 〈Figure 2〉, the domain of this research is defined because there are many different technologies related to this research. Basically, this research focuses on mobile collaboration applying peer-to-peer technologies to make users send or receive spatial data efficiently between mobile devices in wireless environment. Spatial data needs to be transferred in seamless manner on those peer-to-peer networks and therefore, one of spatial data transfer standards needs to be selected after comparison to make it compatible in mobile GIS domain.

Possibility of extending the basic Telephony service over Internet-based networks is important in mobile P2P because IP Telephony service became one of the most stable and widespread services for data transfer between mobile devices. Comparison of current standard based technologies and feasibility test on several selected technologies after defining requirements of new framework are important steps in designing a spatial data sharing framework.

1.2 Objectives

To overcome the limitations in mobile collaboration with spatial data mentioned in the previous section, this research proposes an approach based on a standard peer-to-peer protocol which initiates and maintains sessions between mobile devices to transfer spatial data in real time. A new framework for efficient spatial data transfer is to be designed after analyzing basic functions of appropriate technologies and typical user requirements especially on spatial data usage on mobile devices. The major objectives of this research are as follows.

- Design of essential components including mobile agents based on a standard peer-to-peer protocol for spatial data transfer to propose new system architecture.

- Feasibility test on the designed framework by implementing prototype system focusing on functionality for spatial data transfer between mobile devices.

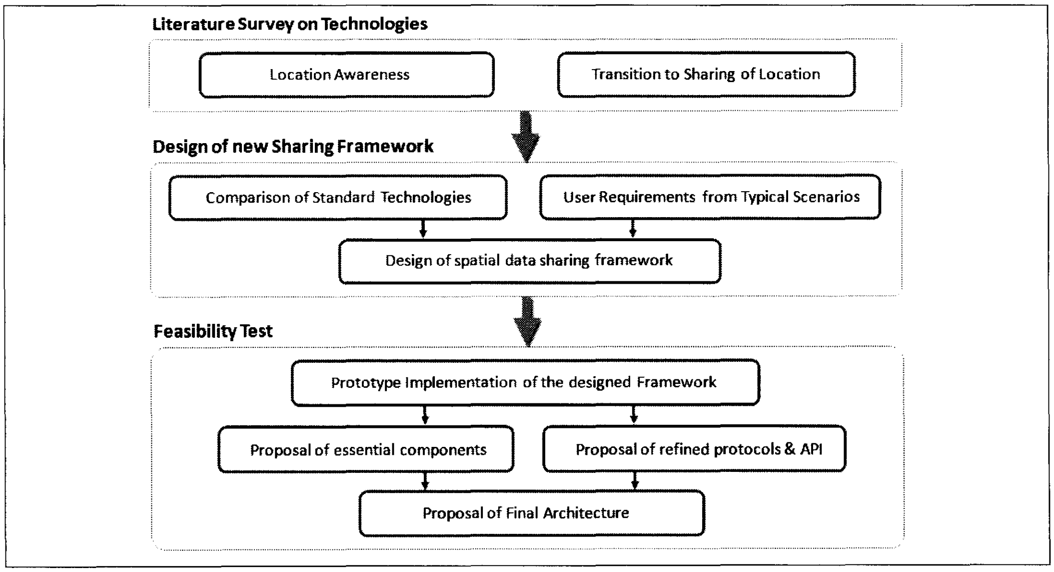
Design and implementation of the framework can be performed by considering underlying peer-to-peer protocols and display of spatial data on mobile devices. The proposal of new framework can help other developers to implement mobile applications with sharing capability for spatial data because it is designed using component technology and international standards.

1.3 Research Procedures

〈Figure 3〉 shows procedures used in this research. To propose a new architecture, it starts from literature survey and comparison of current technologies. Design of mobile agents and spatial data transfer format will be done after analyzing requirements for spatial data sharing. Typical scenarios can be considered to extract user requirements. After implementing prototype system and testing performance, essential components for our framework and efficient protocols for spatial data transfer will be proposed. Feasibility test helps to prove functionalities of the framework and to refine protocols and components for the final architecture.

1.4 Structure

This research is organized as follows. Chapter 2 introduces the concept of mobile GIS, SIP and more that is summarized from the survey of literatures on mobile map service technologies and peer-to-peer communication on mobile devices. Chapter 3 presents the design of new sharing framework. Client and server side



〈Figure 3〉 Research Procedures

architecture are proposed to define structure and interactions of its components. Typical scenarios appropriate for applications enabling spatial data transfer between mobile devices are also described. Chapter 4 deals with prototype implementation to prove feasibility of the designed framework.

Finally, Chapter 5 describes the findings of this research and presents the conclusions that can be drawn from them.

2. Literature Survey

This chapter reviews literatures on several concepts and technologies that are related to the approach of this research. Researches on mobile GIS have widely been carried out and it seems to become a new research domain. As mobile devices such as mobile phones are popular, location is treated as one of important information to improve the quality of life. Mobile collaboration directly deals with sharing of various data between mobile devices and basic communication schemes are helpful for the understanding of standard communication protocols for sharing of spatial data.

2.1 Mobile Computing with Location

Mobile computing with location is realized using handheld devices such as smart phones and mobile phones. These devices provide the capabilities of information processing through the wireless communication and GPS equipment in many cases[11]. In other words, location is used for mobile users with mobile computing equipment and technology in addition to wireless communication channel on which spatial data can be transmitted.

A map has been an important communication tool in cognitive perspective[12]. The meaning of map based communication has somewhat been changed according to the Internet and mobile technology. Ubiquitous Mapping refers to the use and creation of maps by users anywhere and at any time. It is strongly influenced by advances in information technology, such as the development of wireless systems, high-density data storage and broadband communication, which can be seen as stimulation and facilitation of dynamic and personalized mapping[13]. The mobile maps used to share information on spatial properties can also play an important role in the scheme of map communication. Mobile collaboration with spatial data technically supports this role of the mobile maps.

Map-based mobile services are cartographic presentations on small display devices intended for interactive use in mobile environments[14]. Google Maps for Mobile is a well-known service but it is not the only one on which general users can see maps on mobile devices. One of common features of the following mobile map services is that they extend web map service (or wireless Web GIS applications) to mobile devices. It means that they basically browse server generated maps and add more features on it. Wireless connection is used to browse maps on mobile devices. Several solutions on mobile phones such as Map Talk from Docomo[15] and Mobile Map Editor from Google[16] support reference of location from other buddies but, they are based on proprietary protocols to send and receive location or on transfer of URL of user created maps.

Mobile GIS is a relatively new technology, but with the availability of digital geographic datasets its application potential has increased tremendously. There is a huge amount of available geographic information that can be re-purposed for mobile GIS applications; together with the ability to filter and personalize content by reference to a user' s physical location, this will provide compelling business and research opportunities in this emerging field[17].

Basic mobile GIS architecture makes real-time operation available for some, such as field workers, maintenance operatives, etc. However, there are performance issues caused by limitations of these architectures such as narrow network bandwidth of mobile communication, multi-user real-time response, and huge spatial data transmission, fewer supporting of terminal system[18]. In order to improve response time and accuracy of searched or transferred information in mobile GIS applications, a conceptual mobile GIS model is defined, which depicts the logical architecture from the viewpoint of mobile GIS functions when designing whole mobile GIS architecture.

2.2 Mobile Collaboration with Spatial Data

A mobile user is often conceived as a person executing tasks anywhere and anytime, using mobile computing devices with wireless communication capabilities. Typically they require functionalities for data synchronization and on-demand collaboration with other people [6]. Given the uncertainty about the next collaboration scenario and its characteristics, mobile users need autonomous, flexible and interoperable collaborative solutions, regardless of the availability of centralized resources or communication infrastructure.

When two or more mobile users meet, their physical location should not be a limitation to collaborate. Recently, growing demand for mobile applications due to real time information needs can be applied to spatial data sharing and peer-to-peer technology can be applied to make collaborative messaging system feasible on mobile devices [8]. The term "peer-to-peer" refers to a class of systems and applications that employ distributed resources to perform a critical function in a decentralized manner. With the pervasive deployment of computers, P2P is increasingly receiving attention in research, product development, and investment circles. P2P application design can improve scalability and survivability in the event of central network outages.

Mobile P2P is an extended P2P networks that can be accessed from mobile devices. They have advantages of information sharing, using less network bandwidth, saving computing power, etc. There are several P2P technologies such as JXTA [9] and XMPP [10] to send and receive messages but they have some limitations not to support mobile devices in a simple manner.

JXTA is useful in implementing P2P networks. However, it is not international standard and not convenient to be implemented on mobile devices. XMPP is used to send and receive messages such as chat text and video. H.323 and SIP are international standards that are used to manage sessions between two peers in telephony domain. As a typical example to describe features of P2P, JXTA is reviewed to go over what peer-to-peer technology is. XMPP and H.323 protocols are also reviewed and see section 2.3 for SIP protocol that is assumed as a suitable protocol to design peer-to-peer computing framework for spatial data.

2.3 SIP and Peer-to-Peer Computing

To propose a new architecture based on mobile collaboration and mobile GIS, SIP protocol in IP Telephony domain is considered to provide more stable and extensible framework. It can be used to enhance the communication mechanism but is somewhat complex in implementation. Possibility of extending the basic Telephony service over Internet-based networks is important in mobile P2P because IP Telephony service became one of the most stable and widespread services for data transfer between mobile devices. There are two standards, H.323[19] and SIP[20], created by ITU for IP Telephony signaling.

SIP is an application-layer protocol that was initially specified by the IETF Multiparty Multimedia Session Control Working Group (MMUSIC WG) in 1999 and updated by the SIP WG in 2002. SIP, which is delineated in RFC 3261[21], is used for creating, modifying and terminating sessions with one or more participants, and was designed to be independent of the underlying transport protocol. As in H.323, features in SIP are also classified into three similar categories, namely local features, network-based features such as authorization and supplementary services. The main functions of this signaling protocol are: (i) location of resources/parties; (ii) invitation to service sessions; and (iii) negotiation of service parameters. For conveying information about the media content of the session SIP relies on the Session Description Protocol (SDP).

SIP is very flexible and in a short time it has the ability to adapt quickly to needs of any Service Providers to meet new customer demands. This is the main advantage and it has also been chosen as the signaling protocol for the core network in the next generation of wireless communications. SIP adopted as common signaling protocol over IP networks, allows the users to have a contract with the local Internet Service Provider (ISP) or wireless provider while having the possibility to access any service implemented on any IP-based network[22].

3. Design of Sharing Framework

Taking into account advantages and disadvantages of the available technological solutions for mobile devices and GIS, it seems feasible and economically justified to employ SIP technology for building mobile collaboration systems in peer-to-peer manner, especially for the considered scenarios. Therefore, the system architecture of sharing framework based on user requirement analysis is designed assuming that it uses SIP protocol over wireless network to make spatial data delivery feasible between mobile devices.

In this chapter, system architecture and specific components for it are described after a few scenarios are analyzed to extract user requirements for the delivery of spatial data. A mobile client for one of the scenarios is also designed as a part of newly constructed system.

3.1 Comparison of Protocols

Peer-to-peer technologies and spatial data formats explained in the previous chapter need to be compared to choose appropriate ones. As already explained, there are several messaging protocols based on peer-to-peer technologies such as XMPP, SIP and H.323. These messaging protocols can be used as a basic framework for spatial data exchange between mobile devices. Among a few properties compared, extensibility is one of the important factors for designing new framework because these protocols are to be extended to design a new framework for spatial data.

A spatial data transfer standard is also considered as a container in which spatial features such as current location or designated region are transmitted. One of the most important factors in choosing the best spatial data scheme is how lightweight and simple enough to be extended and transferred quickly in wireless environment because simple protocol is better for quick implementation that is used to verify proposed framework is feasible or not.

Peer-to-Peer Technologies (International Standards for Messaging)	Spatial Data Format (International Standards for Map)
XMPP	ESRI Shapefile (de facto)
SIP	WKT
H.323	GML

⟨Figure 4⟩ Comparison of Protocols

⟨Table 1⟩ shows a matrix to compare several features of three peer-to-peer technologies. XMPP is specialized in IM domain while SIP and H.323 protocols are mainly used in telephony domain. Features for collaboration such as text messaging are supported by all the protocols but specific features are different from each other. Peer-to-peer session control is also supported by all but XMPP and SIP are better for transmission of

〈Table 1〉 Comparison of Peer-to-Peer Technologies for Messaging

	XMPP	SIP	H.323
Specialized Domain	IM	VoIP	VoIP
Collaboration Features	Supported - Chat - Presence - File Transfer	Supported - Message - Presence	Supported - Whiteboard File Transfer
Peer-to-Peer Session Control	Supported	Supported	Limited
Mobile Support	Limited	Extensible (on several devices)	Limited
Spatial Data Support	No (Extensible)	No (Extensible)	No
Extensibility	High	Very High	Low
Heterogeneous Platform Support	No (Extensible)	No (Extensible)	No

packets over a firewall. On several mobile devices, SIP library is provided and it is extensible enough for the addition of other features. None of these protocols supports spatial data, but XMPP and SIP are able to be extended to support it. SIP is the best to be extended for additional features because SIP provides richer extensibility and better scalability. Another important feature is how easy it is to be implemented on mobile devices. It means that the selected protocol needs to be simple and straightforward.

Consequently, SIP is considered better compared to other protocols that are able to be used for peer-to-peer based messaging system. Session control and extensibility are most important features in designing a peer-to-peer framework because we need to extend basic features to spatial ones.

Typical three spatial data transfer formats are considered to be compared for the selection of an appropriate one for the framework. 〈Table 2〉 shows features of several spatial data formats. The most important thing in considering spatial data formats is how lightweight and simple because this research deals with design of sharing framework for mobile devices. WKT and GML are international standards while ESRI Shapefile is proprietary and de facto standard. Shapefile format is of binary form and therefore data size can be somewhat smaller than other text based

⟨Table 2⟩ Comparison of Spatial Data Format for SDP model

	ESRI Shapefile	WKT	GML
International Standard	No (de facto)	Yes	Yes
Format (Text/Binary)	Binary	Text	Text
Complexity	Low	Very Low	High
Spatial Reference System Support	No	No	Yes
Spatial Index	No	No	No
Extensibility	Limited	Limited	High
Data Volume	Small	Small	Big

formats. Complexity of GML format is higher than other formats and WKT is straightforward. GML supports spatial reference system and highly extensible based on XML. Data volume of GML format is, however, bigger than others.

WKT is considered as the best one in its data volume and simplicity of format. ESRI Shapefile is lightweight and somewhat widely used in GIS domain as a de facto standard but it is proprietary format and therefore, not so good for interoperable transfer format.

3.2 Typical Scenarios for Spatial Data Sharing

Wireless communication protocols and spatial data transfer formats are combined to design new spatial data sharing applications between mobile devices. New applications based on those technologies contain a user agent with spatial data sharing capabilities, and other location based services. In case SIP is used as wireless communication protocol, a user with spatial data can establish a session with any SIP proxy. The SIP message transfers spatial data to a proxy. Afterwards, the proxy can send back a response to the user. SIP is a transparent signaling protocol and the spatial data can be previously obtained by the user or map data that are already stored by mobile applications.

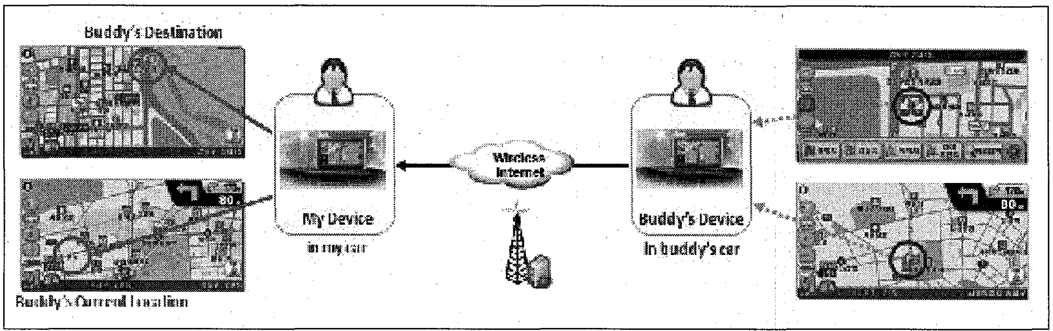
In assuming a user agent handling spatial data transfer, its features need to be defined because they are important and useful in designing the architecture of client applications. Therefore, the first step to be taken in modeling new framework based on those technologies is to extract important features and functions by analyzing typical scenarios dealing with spatial data sharing.

Mobile devices are widely used for industrial or personal use. In this paper, however, just two scenarios are considered as typical examples dealing with spatial data transfer as a collaboration method. The first is navigation system that is usually installed in a car. Users started to think that it is useful to share some information between navigation systems mainly because more and more navigation devices contain communication modules enabling wireless communication. The second is emergency cases for forest fire. People need to communicate each other in the field in emergency cases but only voice is usually used for communication. If field workers responsible to extinguish forest fire can send their location or hazardous region to other buddies directly, it will be helpful for effective information exchange in the field. Many other applications can also be assumed but the above two scenarios are typical ones because navigation system is the most popular mobile application all over the world and forest fire fighters are field workers who can make these mobile collaboration functions useful. Several interaction metaphors are described with conceptual stuffs that are commonly used in GIS applications. For example, mapping component is commonly used to describe a component which is responsible to display spatial data.

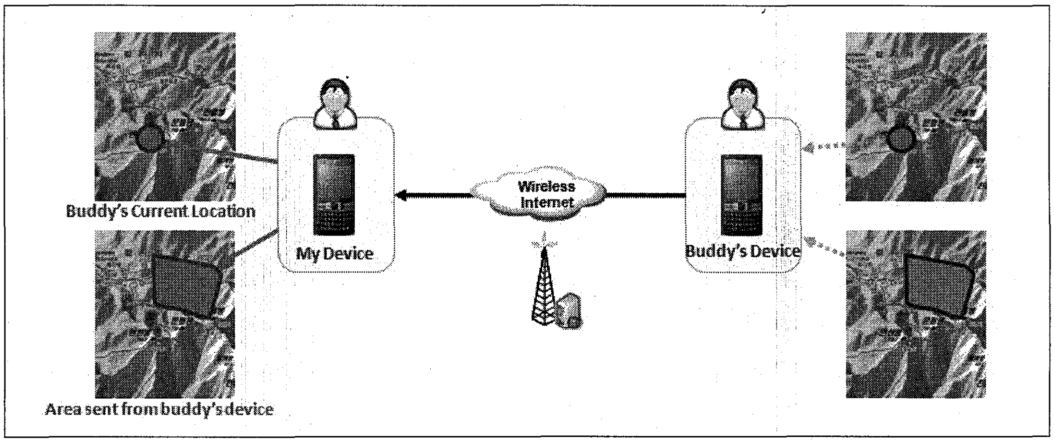
Network-oriented car navigation systems (off-board navigation systems) have become a hot topic because of the expanding car navigation and active wireless communication markets[23]. The device on which a navigation system runs can get access to wireless network in this environment. If a driver wants to connect to one of registered friends, he will just click on the selected name on the screen of the device. After connected to each other, driver A can send his location to driver B to inform current location. This location can be displayed on the screen of driver B' s device as current location of the driver A. Destination information as a point location can also be transferred to other buddies.

⟨Figure 5⟩ shows this example scenario for the transfer of buddy' s destination and current location. Current location of registered buddies needs to be displayed as different symbols. There can be many other cases for the usage of spatial data transfer between navigation systems such as exchange of location of a restaurant which is searched by one of my buddies. Driver A can designate the restaurant to inform the location where driver A and driver B meet together after the search.

Therefore, several scenarios and all the information to be exchanged have to be considered other than current location. In those cases, point, line or polygon types can be used to share spatial data each other.



〈Figure 5〉 Transfer of Buddy's Destination and Current Location



〈Figure 6〉 Transfer of Hazardous Area

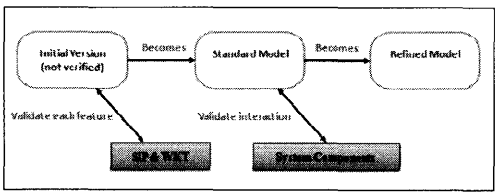
Wild fires, including forest and plant fires, are uncontrolled fires occurring in wild and rural areas which can cause significant damage to natural and human resources[24]. In many cases, however, forest fire fighters only have voice communication devices and this makes it difficult to get correct information on location. For example, there is no way for fire fighters to get exact location of hazardous area in extinguishing forest fire. If they are able to send their location and hazardous area to other people who are working together in real time, it will help them to survive and allocate resources efficiently. Notification between fire fighters in the field is needed in real time and visual representation is also useful in addition to voice communication.

〈Figure 6〉 shows an example of the transfer of current location and hazardous area to other buddies. The handheld device on which an application playing a role for the above functions runs can get access to wireless network. If a fire fighter wants to connect to one of registered buddies, he will just click on the selected name on the screen of the device. After connected to each other, fire fighter A can send his location to the selected fire fighter B to inform current location. This location can be current location of the fire fighter or lines representing dangerous sites and hazardous area.

Location data can be automatically extracted from GPS module if it is integrated to the handheld devices and it is also able to be sent to other people periodically. Spatial data types for this scenario include point, polyline and polygon while point data is mostly used to be transferred in the other scenario for navigation system.

3.3 Modeling Approach

After sample service scenarios are translated into charts, system architecture for transferring and displaying spatial data on mobile devices is created. The initial architecture is revised and the refined version which includes validated components is extracted. The diagram in ⟨Figure 7⟩ shows that the initial models involve validation of each feature against SIP and WKT standard formats. Then, the standard model is checked for spatial data transfer between system components.



⟨Figure 7⟩ Iterative modeling process

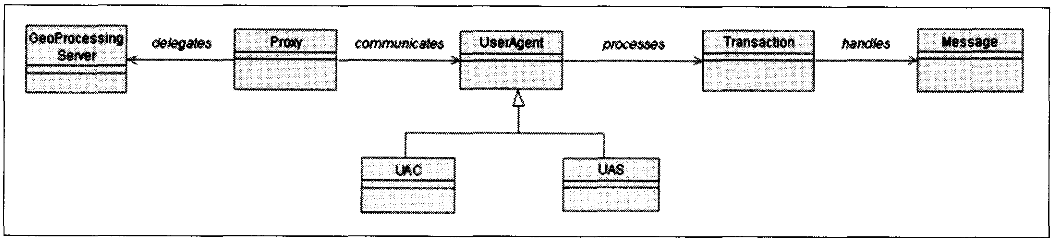
Finally, the refined model is produced.

The approach to model SIP and WKT based sharing framework begins with modeling the core signaling functionality of SIP. The basic service includes registering agents, sending a message with spatial data, notifying transferred data and displaying mapped area. The user agent and proxy are the only SIP entities that are modeled.

The relationship between the modeled entities, their interfaces, and attributes are considered parts of the structural definitions. A framework for spatial data sharing uses the SIP protocol and a part of its components for data communication represents static interactions between SIP entities. The channels connected between various block instances specify the signals or SIP messages that are sent between user agents and proxies.

The entities usually involved in a SIP session are the User Agent (UA), the Proxy Server, the Redirect Server, the Registrar Server, and the Location Server. The User Agent is located in the user device. The Proxy, Redirect and Registrar are network elements, interacting with the User and other network entities simultaneously. The Location Server helps the previous network elements to identify and locate the user.

The UA is normally placed in the user terminal and it can act as a Client (UAC) or as a Server (UAS). The UAC initiates a SIP request while the UAS contacts the user when a SIP request is received and sends back a response on behalf of the user requirements. The Proxy Server is an intermediate entity that behaves as client and



〈Figure 8〉 Structural Model using SIP

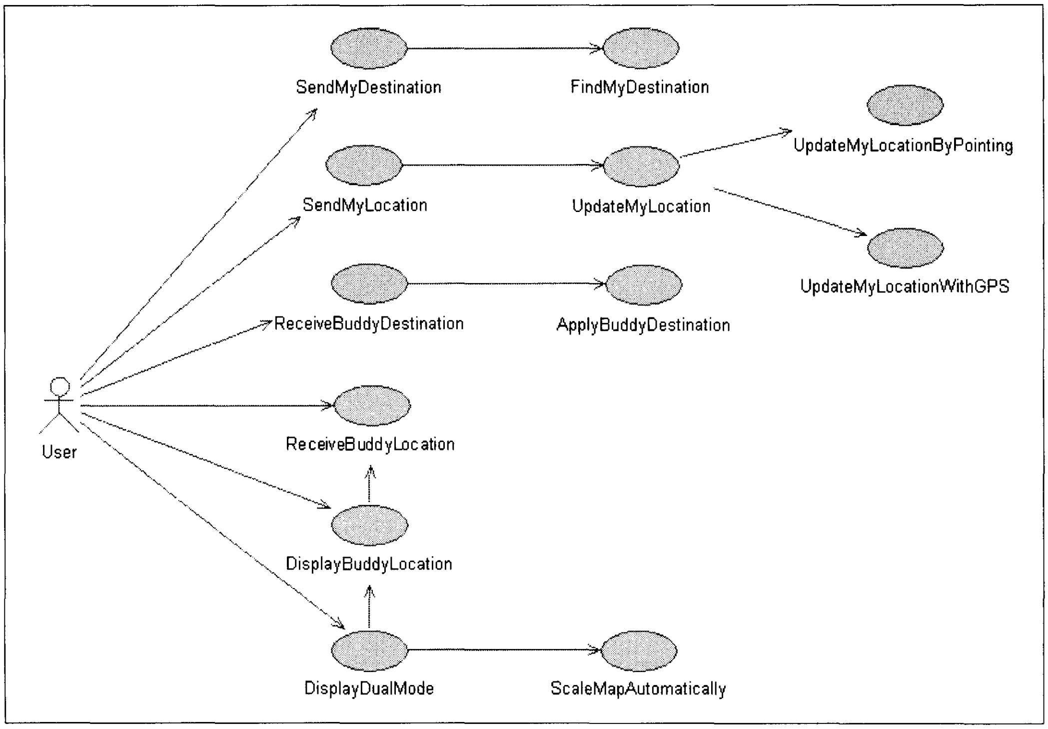
server simultaneously. It is a network element that receives the messages (requests) from the user (UA.) It can analyze and modify the request before forwarding it to other servers. The Registrar Server accepts the user registration (REGISTER message). The user information received within the SIP message at the Registrar is extracted from the SIP message and forwarded to be stored at the Location server.

〈Figure 8〉 describes basic relationship between defined objects in the structural model. A proxy and a user agent communicate each other using SIP based communication channel. If the proxy needs to process a received message containing spatial data or requests for spatial data, it delegates the job to a geo-processing server which is responsible for server side mapping and spatial operation. If the user agent receives messages, it handles them to create a response. If the messages received from other user agents requests spatial objects or display of spatial objects, the user agent controls mapping engine to manage or display them.

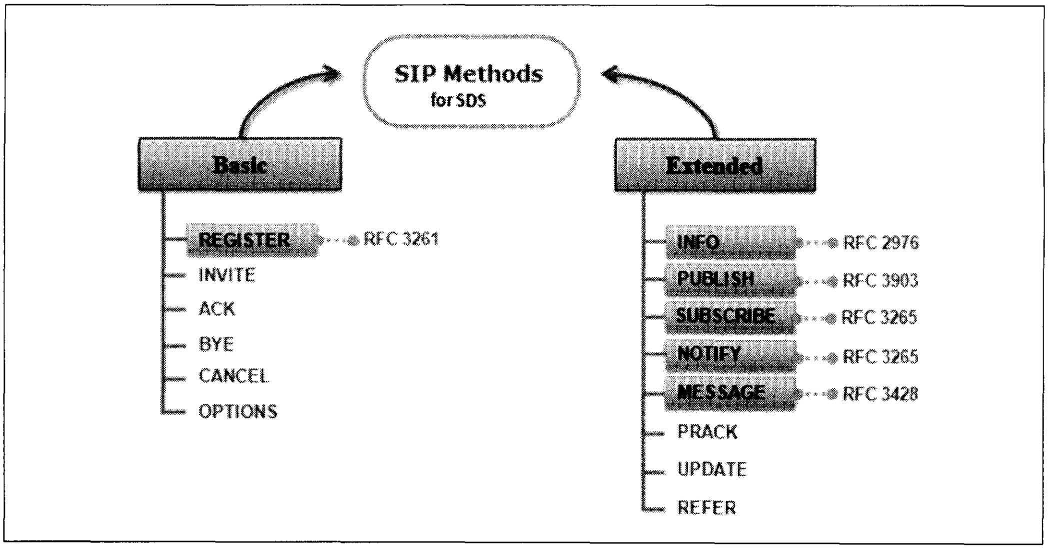
User requirements analyzed for the framework focus on the delivery of spatial data. 〈Figure 9〉 show use case diagrams for the navigation system scenario. After registering buddies on the buddy list, the user can send spatial data such as destination and current location. These spatial data received from one of registered buddies can be displayed immediately on the screen of device.

SIP message flow for spatial data transfer includes some of defined methods in standard specification because all the 14 methods are not necessary for the framework in which voice call between mobile agents is not mandatory. 〈Figure 10〉 shows which methods are considered for the framework. Only two methods, "REGISTER" and "MESSAGE", can be used to define message flow between mobile devices as the simplest example.

A client (Client #1) sends "REGISTER" method to the proxy server and it authenticates the client with the help of registrar server. After registered to the server, it updates its location to the server periodically. It can send or receive "MESSAGE" method whenever it is needed. If a client sends "MESSAGE" method to another client (Client #2), it is expected to receive "OK" method that means the message sent is transferred successfully.



〈Figure 9〉 Use Case Diagram for Navigation System



〈Figure 10〉 SIP methods considered for the framework

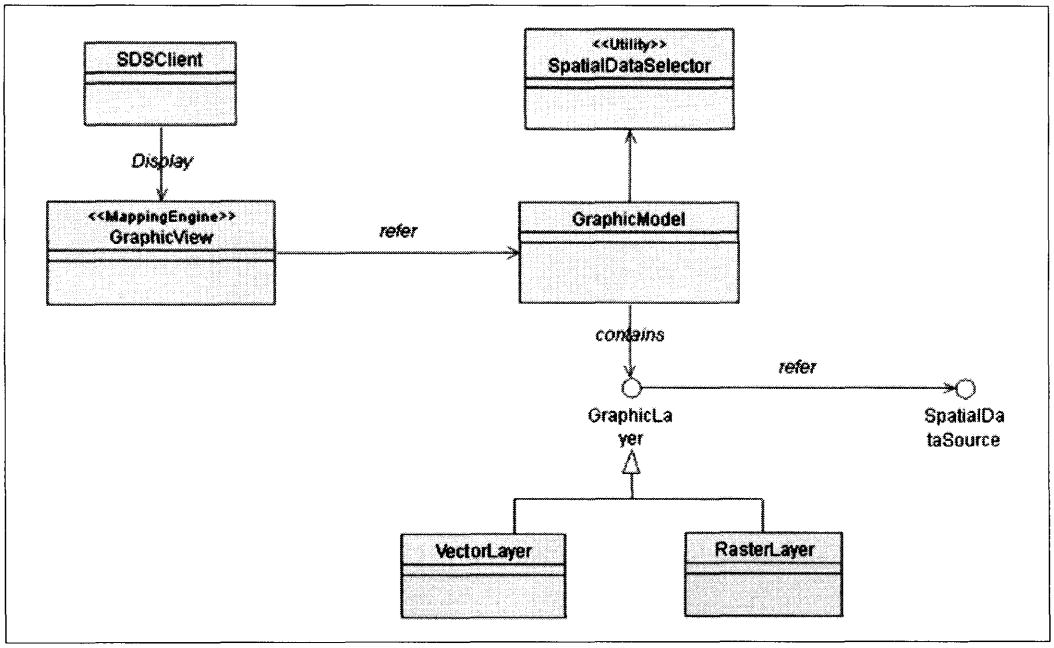
3.4 Design of Mapping Engine

To meet all of the mobile GIS mapping technologies, mapping engine for mobile devices is designed basically on a virtual machine. Newly designed mapping engine can be flexible in integrating basic user requirements for spatial data transfer based on SIP. In other words, this mapping engine can be modified to catch user input of current location by touching mobile device' s screen and immediately send it using user agent module.

⟨Figure 11⟩ depicts the visual notation for mapping components. Since a new framework is expected to allow the activation and display of layers from a buddy' s application located on remote devices, two mapping components are conceptually linked to represent spatial data. In the framework especially for navigation system, the spatial data selection is one of the most common operations of user-application interaction.

3.5 Mobile Client Architecture

The architecture is layered comprising transport layer, peer-to-peer overlay, lower-level services, and higher-level services with an add-on for device dependent presentation. The transport layer provides the basic network communication between peers. The peer-to-peer overlay on top of this layer supports basic data processing as a peer-to-peer solution. SIP processing layer is identified as a basic layer to make this system

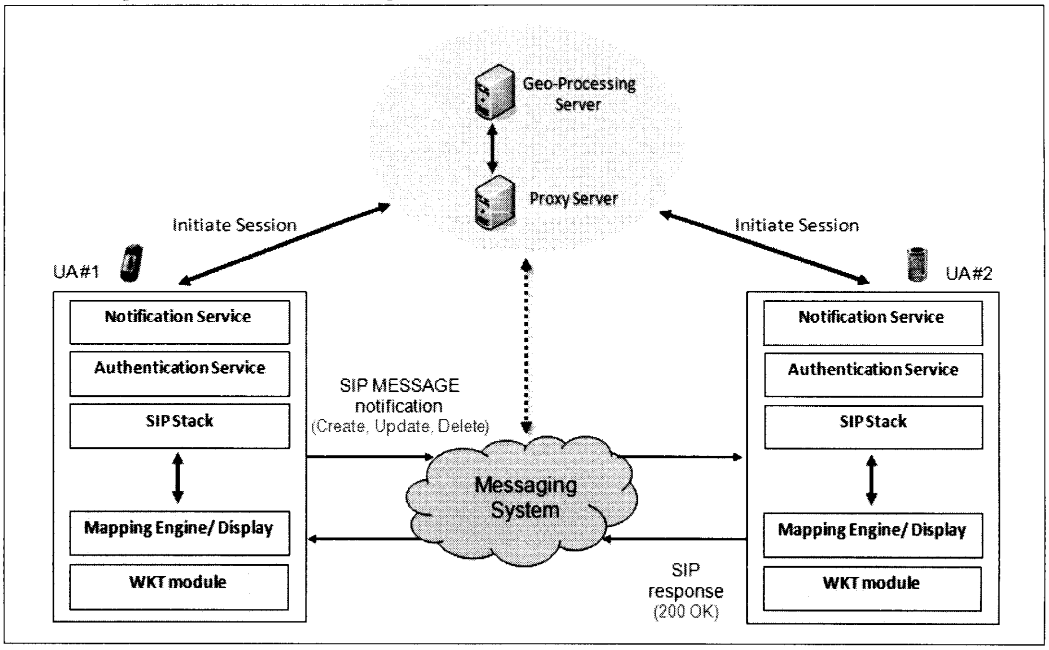


[Figure 11] Visual Notion for Mapping Components communicate each other having these lower-level distributed services in place. The job of building and deploying various collaboration tools for spatial data becomes quite straightforward because basic communication layer is provided.

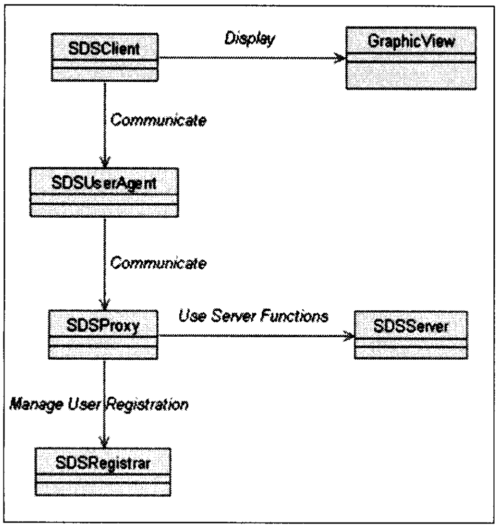
〈Figure 12〉 shows overall system architecture for mobile clients and basic components for it are described. SIP stack is a main component and other services are defined on the stack. Mapping and display module is designed to interact with SIP stack. The main reason of this architecture is to simplify the system architecture and make developers integrate with other systems easily. For example, if any developer wants to apply this architecture to existing car navigation system, he or she just needs to understand this architecture and make it compatible with the SIP stack implemented. Authentication service and notification service are basic functional services for SIP protocol.

Essential classes are designed to define roles for each classes used on mobile devices and in the server. 〈Figure 13〉 shows class diagram for SDS system and 6 main classes and relationship between those classes.

To clarify functionalities for the system architecture, it is also important to stop viewing it just as simple messaging systems. The system architecture assumes that spatial data is also included in messages transferred between clients and these features make it more complex. It means that both client applications and server system need to process spatial data as basic data structure.



〈Figure 12〉 System architecture for mobile clients



⟨Figure 13⟩ Class diagram designed for SDS system

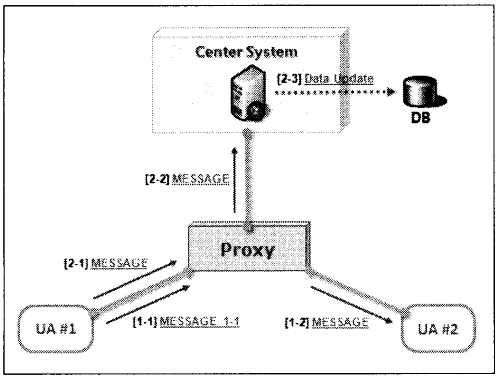
3.6 Proxy Server Configuration for Spatial Data

Proxy is responsible for handling packets from user agents. The server for the sharing framework is designed to include a proxy server and geo-processing server. Then, it can handle spatial data transferred on SIP channel because spatial data is delivered in SIP MESSAGE method. There can be, however, various configurations for the proxy server because SIP basically supports transmission of data packets to another proxy to process requests for user agents in another domain.

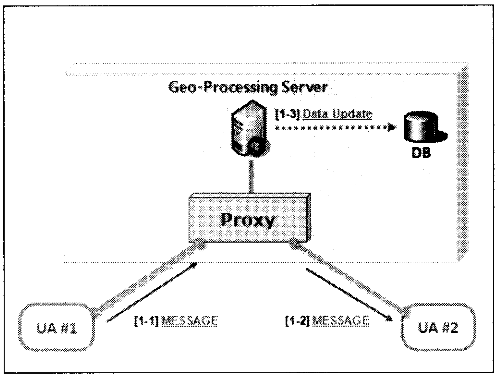
The easiest way to design a new proxy server is to treat a geo-processing server as a user agent. If a geo-processing server integrated with the proxy can send and receive data packets, they can request operation on spatial data or send updated spatial objects to save them. Message flow to update spatial data to both other user agents and center system is presented in ⟨Figure 14⟩. User Agent #1 sends a message with spatial data to User Agent #2 to update changed location. This message is transferred to User Agent #2 through the proxy server. If User Agent #1 wants to update spatial data in center system, it sends the same message to the center system which is treated as a user agent. The center system can update the received spatial data in database.

But, this way of integration is not efficient because User Agent #1 has to send the same messages twice to store or update in center system. To solve this problem, the proxy server is tightly integrated with a geo-processing server. It means that the proxy can catch messages for spatial data updating and process them automatically. Received spatial objects can be directly processed by the geo-processing server because it runs in the same process. General purpose SIP proxy server needs to be modified to meet these requirements.

Server components are designed based on this configuration and the proxy server consists of integration classes as well as basic SIP classes to handle client requests. There can be several server functions in the server to mediate client requests and process additional information to make responses with spatial data if needed. ⟨Figure 15⟩ shows server side functions defined based on SIP methods that are used in this research. User authentication uses "REGISTER"



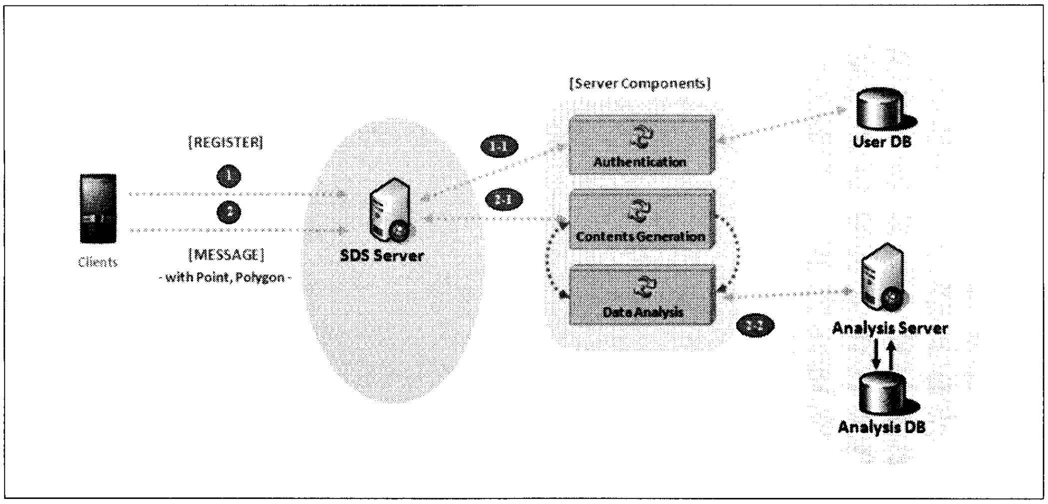
〈Figure 14〉 Integration with Center System as a User Agent



[Figure 15] Tight Integration with Geo-Processing Server

method to let server know client list connected and authenticated with id and password. Location information is also registered to find out client location in the wireless network whenever other clients want to deliver messages to it.

〈Figure 16〉 shows message flow with the server components defined. If a client register using SDS server which plays a role for the SIP proxy server, "REGISTER" message is transferred and authentication component check it with user database. If the same client tries to send spatial data such as point and polygon with additional information, the server either just transfers it to another client or tries to analyze for new spatial data using contents generation component. Analysis server is used for the spatial operation and the result will be sent back to the client in the "MESSAGE" method.



[Figure 16] Message flow with the server components

3.7 Summary

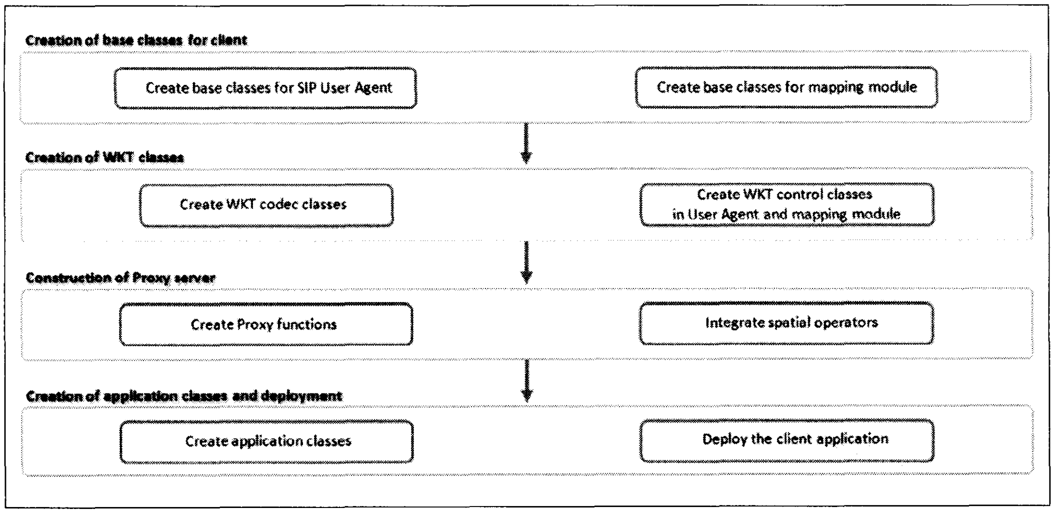
In this chapter, system architecture for the new framework is designed based on the standard SIP protocol. User requirements dealing with spatial data are analyzed to extract essential components which are important in designing a mobile client. A user agent is designed for the mobile client and it handles immediate notification and display of transferred spatial data. A proxy server configuration appropriate for geo-processing server is also designed to specify server side functions for spatial data updating and retrieving. In the next chapter, implementation process and details on a prototype system will be described.

4. Implementation of Sharing Framework

This chapter describes implementation process and the results from it. The objective of the implementation is to verify functionality of the framework designed for spatial data sharing between mobile devices for its feasibility. Implemented components in the framework can be applied to scenarios presented in the previous sections. The prototype mobile client system runs on a mobile device which is a smart phone with GPS receiver and wireless communication facilities for WiFi and 3G. This system provides transfer functions of spatial objects such as point and polygon. Third-party solutions used during the implantation of prototype applications are also listed.

4.1 Methodology for System Implementation

Client applications are basically implemented on a virtual machine called EVE[25]. There are several



〈Figure 17〉 System Implementation Process advantages using EVE VM. The first is that it is easy to port developed applications to Microsoft Windows Mobile and Linux/Java OS.

〈Figure 17〉 shows system implementation process. The classes that are needed for client and server side functionality of the new framework are created from scratch. Client classes are created for SIP User Agent and mapping module. These components provide general functions as basic libraries. Unit test for these classes are taken to prove that there is no critical error. WKT codec classes are implemented to encode and decode WKT encrypted SDP data. For example, current location needs to be encoded to WKT point data whenever a user updates current location by touching the screen of a smart phone.

Proxy server which is capable of processing user agent' s sessions is constructed and tested with the above clients. Then, this proxy server is integrated with a geo-processing server to support spatial operation. Classes for the client application are created on top of base classes to run prototype applications.

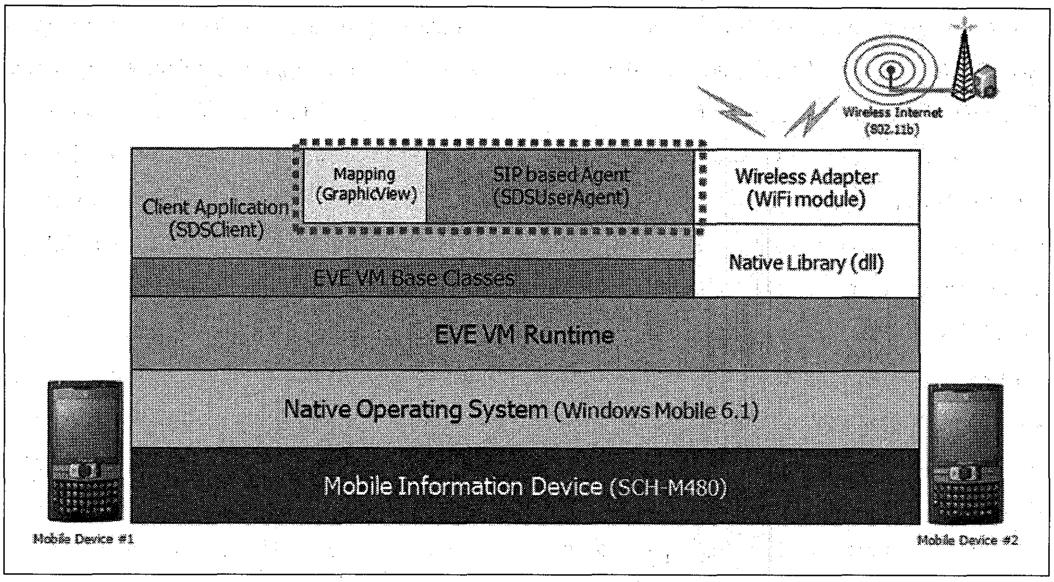
4.2 Prototype System and Implemented Components

Deployment program is used to convert those packages into EVE files and native executables for specific platforms if needed. Over 1,000 classes are created to implement basic SIP User Agent and mapping module on EVE VM. The mapping module basically supports display of spatial data and parsing of GIS file formats like ESRI Shapefile. Classes for User Agent can handle both basic SIP methods like REGISTER and extended methods such as INFO, PUBLISH, SUBSCRIBE, NOTIFY and MESSAGE.

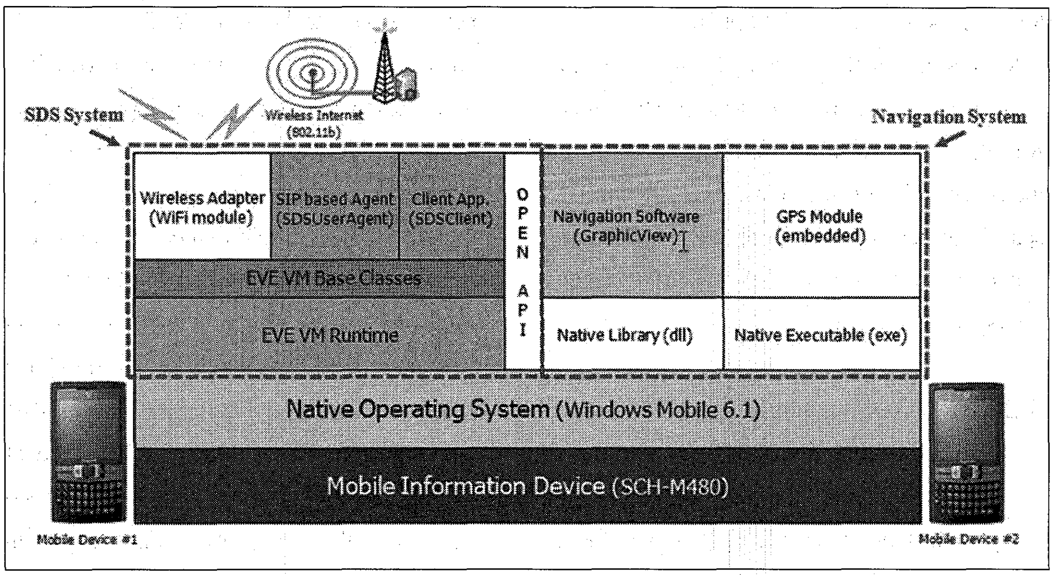
As mentioned in the previous sections, one of the important features of basic components is immediate display of spatial data after received from another user agent. For example, there is a controller to handle user input by touch screen in mapping module and it encodes the updated location by the user to data of WKT format. This data is delivered by User Agent classes after creating a new message with the created WKT data.

There are many other components on top of the base classes for User Agent and mapping module. Two mobile devices have the same profile and 〈Figure 18〉 shows the architecture of the prototype system implemented for the client application. Operating system is Windows Mobile and EVE virtual machine is running on it. Client application called SDSClient runs on the virtual machine that consists of lots of base classes. Main components for the client are SIP based agent called SDSUserAgent and mapping module called GraphicView. If a client tries to communicate with another client, it uses WiFi module that is embedded in the device.

Mapping module can be replaced with existing

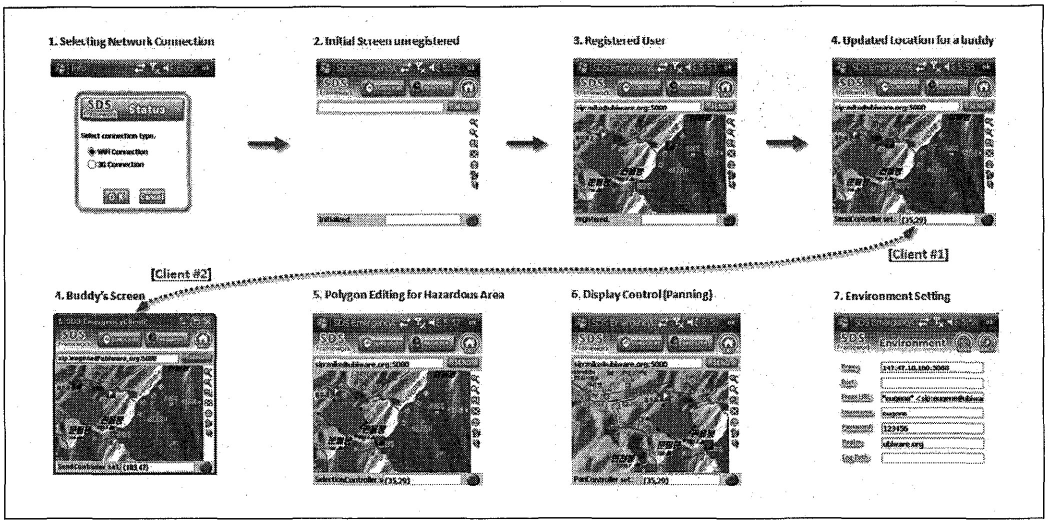


⟨Figure 18⟩ Prototype system for mobile client



⟨Figure 19⟩ System architecture with Open API for existing navigation system

applications which are able to be integrated because they already have mapping modules to display spatial data and result of spatial operation. For example, a navigation system basically has



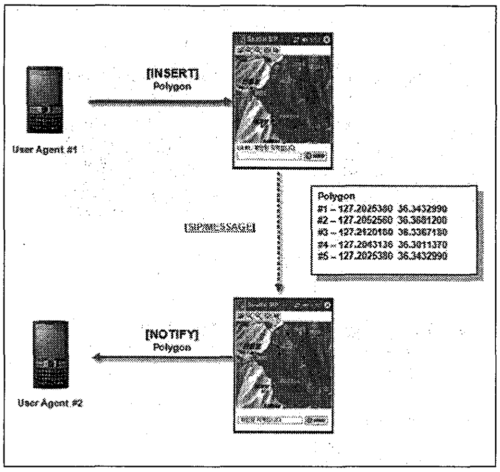
[Figure 20] Implemented Client Application for Emergency Cases in Forest Fire

mapping module and several spatial operators such as route finding. GPS processing module is also integrated with navigation system and therefore, any device connected to GPS receiver can be used to find current location.

⟨Figure 19⟩ shows adjusted system architecture to integrate with navigation system through Open API playing an important role in communication with other mobile devices. It means that existing navigation doesn' t need to implement SIP communication protocol to process standard based sharing functions. SDS client takes a role as a delegate for SIP client enabling spatial data sharing. In the system architecture, mapping module belongs to navigation system and GPS module is also integrated with it.

⟨Figure 20⟩ shows the implemented client application for emergency cases in forest fire. The screen resolution is 320x320 and this application is shown in 320x296 display area. When the application is started, the user can select one of connection types. If WiFi connection is selected, the device is connected to the nearest access point. If 3G connection is selected, the device is connected to the carrier' s broadband connection such as HSDPA. Once it is loaded, the user can make a session with the proxy server by registering. A small light in lower right corner shows current status of registration.

The input control in the upper side of the screen is used to show buddy' s URI. This information can be changed by simply clicking on it. Whenever a user clicks "send" button in the right corner of the input control, this application tries to send changed spatial data to the designated buddy. Basic environment variables can be changed using "Environment" panel. The last screenshot shows basic information on IP and



〈Figure 21〉 Editing functionality for emergency cases

port of the proxy server to which this application connects. Additional information such as "from URI" can be changed if the user wants to change the name of user agent.

The third screen capture shows registered user see current location with a base map. The user can see the location of another registered buddy. The next ones show steps to send updated hazardous area as a polygon to the buddy's mobile device. This prototype application can send point, polyline and polygon as primitive spatial data types immediately after changing current location and it shows how to share spatial data between mobile devices using SIP.

Editing functionality is important in emergency cases. If any person finds hazardous area in mountain he can send it as a polygon to another person with mobile devices. However, only selection and display of selected spatial features are important in navigation system. 〈Figure 21〉 shows spatial data transfer example for editing with text messages. Client applications need to check if the notified spatial data is to be edited or just selected. WKT encrypted spatial data is included in the body part of the method in transferring to other mobile devices.

4.3 Open API

Open API for the integration of existing mobile applications dealing with spatial data is defined to facilitate loose coupling between newly implemented client components and existing mobile applications. XML based protocol is considered to allow developers for third-party applications to easily understand what functions are defined. Navigation Software is widely used and the relationship with the new components is expected to be loose coupled. It can communicate with the new components via TCP/IP connection on the same mobile device locally. This relationship enables developers to integrate other navigation systems easily by just implementing proposed API functions for the components.

Existing navigation solutions already have mapping module and routing capability such as network analysis functions. Open API provides communication capability for the transfer of spatial data and integration is possible by using Open API client classes. Open API plays a role like a bridge between existing navigation solutions and User Agent for mobile client. Open

API client which is created for third party applications is integrated with Open API service using local network and XML-RPC protocol. Existing navigation systems can use the framework designed in this research by just calling Open API client.

4.4 Summary

In this chapter, details on the prototype system and implemented components were described. A virtual machine is used to implement a mobile client and Java language is widely used for client-side and server-side programming. A prototype application for forest fire fighters can handle spatial data transferred from other mobile devices. Immediate notification and display of the user agent running on a smart phone is feasible by integrating SIP communication modules and mapping modules. A proxy server is also implemented and it serves both session initiation and spatial data updating. Performance test for the duration time of spatial data delivery shows the prototypical mobile clients is good enough to be applied to real world data.

5. Conclusions

Increasing demands on mobile collaboration for spatial data can be met by providing a standard based framework for easy development and deployment of mobile transfer capabilities with existing mobile applications. Standard peer-to-peer technology based framework can improve scalability and survivability in the event of central network outages and these advantages makes the messaging of spatial data useful one for mobile users.

Main contribution of this research is to design new sharing framework to make essential components that are extracted from typical scenarios for spatial data transfer between mobile devices such as navigation system and emergency cases in forest fire. Feasibility test on the designed framework by implementation of mobile agents based on international standards can play an important role in map based communication and location awareness by providing common mobile sharing facilities to existing map services. SIP protocol is adopted to make newly designed framework compatible with existing systems based on international standards and WKT format is used to represent primitive spatial data types.

In the process of design, there are three notable findings that have an effect on the framework. The first is the need of definition of spatial data transfer format for SIP. There is no standard SDP model for SIP MESSAGE method and this makes a mobile GIS system incompatible with others because many different formats can be used for representation of spatial data for SIP MESSAGE method.

The second is that notification service is important for both immediate dispatch of updated spatial objects and immediate display of received ones. This means that User Agent and mapping module need to be tightly integrated for efficient operation of client applications on mobile devices. User Agent is designed to display received spatial objects immediately when it is notified that the message has a SDP data of special MIME type designed for the framework.

The third is that Proxy is responsible for spatial data updating in server side systems and it needs to be modified to integrate a geo-processing server. When a proxy server relays messages between mobile devices, it cannot store or process them because it has functions only for transmission. The proxy server is modified to be connected to a geo-processing server and it can simultaneously update spatial data that is transferred from one of User Agents without making another session with it.

By implementing designed framework on virtual machine for mobile devices, prototype system is proved to be efficient enough to be used for real world applications. Lightweight User Agent that is created for the integration of SIP module with mapping module shows that peer-to-peer communication for spatial data transfer is possible between heterogeneous mobile devices in the same manner.

The implemented system includes User Agent as one of client components for mobile device and these components communicate with server systems that are comprised of SIP proxy and a geo-processing server supporting spatial operation. The prototype application implemented for emergency cases in forest fire has functions to send and receive point, polyline and polygon data representing current location and hazardous area. Open API for the integration of existing mobile applications dealing with spatial data is also proposed to facilitate loose coupling between SDS system and existing mobile applications. Especially, existing navigation systems can be integrated using Open API and it helps those systems to extend basic navigation functions to messaging capability of spatial objects.

With all the contributions made in our work, this research shows that SIP standard protocol can be successfully combined with spatial data to construct a new spatial data sharing framework. As SIP is becoming one of the most important Internet telephony signaling protocols, methods to transfer spatial data contained in SIP will be required in many domains. The new framework meets those requirements and therefore, it accelerates and facilitates sharing of spatial data for real-time communication between mobile devices. It will help users with mobile devices to use maps as a communication tool easily and intuitively.

The framework can also be applied in many emergency cases such as criminal investigation and in fieldwork for the monitoring of land resources.

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