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Recommended Paper

Study and Implementation of Dynamic Network Composition in Heterogeneous Network Environments

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The development of wireless technologies, cellular networks, WiFi, and Bluetooth has created heterogeneous network environments. In these environments, users can access anything at anytime, anywhere using these wireless technologies; however, in order to make full use of such wireless networks, users need to discover whether or not wireless networks exist in their vicinity and select the most appropriate one. Then, users have to obtain and input parameter settings for the wireless networks to begin communication. In this paper, we propose a network composition framework that enables automatic connections to a wireless network suitable for the user's context with minimal interaction. Based on this framework, we introduce network composition procedures which realize network discovery, network selection, configuration information notification, and device configuration with the support of a cellular network connection. We implement the proposed framework and procedures in a real environment comprised of cellular phones and laptop PCs. We examine implemented functions and their performance using this experimental implementation and present several attractive examples of actual use.

1. Introduction

With the advance of wireless technologies, the use of wireless devices, such as cellular phones, WiMAX, WiFi, and Bluetooth, has become widespread. Some mobile terminals have multiple wireless devices, for example, cellular phones with a WiFi interface and laptop PCs with WiFi and Bluetooth interfaces. Moreover, in overlapping coverage areas, users can connect to multiple wireless networks using available wireless interfaces. Thus, heterogeneous network environments have been created as shown in **Fig. 1**. In such environments, users can access anything at anytime, anywhere.

However, to make the best use of heterogeneous network environments, users need to be able to perform a number of operations. We show an example of these operations in the situation where a user wants to access the Internet at a cafe. In this case, the user has a laptop PC with a WiFi interface and a cellular phone.

- Step 1

When the user sits down in a cafe, the sign on the table indicates the existence of a WiFi service. The sign may include configuration information for the WiFi service such as SSID and WEP key.

- Step 2

The user decides how to access the Internet, i.e., through the discovered WiFi network or a cellular network. When the user wants to access a broadband network, the user selects the WiFi network.

- Step 3

The user manually inputs the obtained configuration information into the laptop PC.

- Step 4

When user authentication is required to access the Internet through the WiFi network, the user also inputs his/her credit card number and PIN code. Having reached this stage, the user is now able to access the Internet.

Through the above example, we consider that the required operations are as follows: first, the user has to discover what wireless networks are available from the user's location. As wireless networks are essentially invisible unlinked wired networks, to find them, the user either needs help from service providers as shown above in Step 1, or must scan for wireless networks if this operation is possible. Then, from the multiple wireless networks that are discovered, the user needs to select the most suitable candidate. For example, some users may want a broadband connection to receive high quality streaming video as shown in Step 2. Other users may want an inexpensive connection because they use the network only for e-mail. Enterprise users often want secure connections. After making the selection, the user has to obtain configuration information

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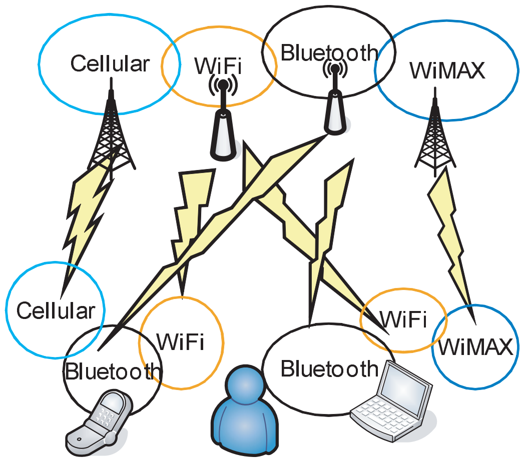

Fig. 1 A heterogeneous network environment.

for the selected wireless network and set up the configuration on the wireless device. For example, configuration information for WiFi networks is SSID, WEP key, encryption mode, and so on. When user authentication is required, the user also inputs authentication information such as his/her credit card number, or the user ID and password obtained from the service provider in advance. These operations are not easy for users who lack the necessary technical skills. Moreover, in heterogeneous network environments, these operations become more complicated.

In this paper, we aim to establish a connection to wireless access networks without the need to perform time-consuming operations in heterogeneous network environments. Our goal is the dynamic and automatic provision of wireless networks suitable for the user's context, such as location and preferences. To realize this goal, we focus on a network composition concept where the target is the composition of multiple networks that provide plug and play capability [1),2)]. In this concept, multiple networks realize network integration, control sharing, and network interworking with minimal interaction.

Based on this network composition concept, this paper proposes a network composition framework to connect to a wireless network with the assistance of an already connected wireless network. Instead of the user's operations, a pre-connected wireless network helps in the process of discovery, selection and automatic configuration of the target wireless network. As a candidate for the pre-connected wireless network, a cellular network is suitable because it has a large coverage area, a user authentication platform and secure transport capability. In accordance with the proposed framework, this paper introduces dynamic network composition procedures with the support of a cellular network. We implement the proposed framework and procedures in a real environment comprising cellular phones and laptop PCs. Using this implementation, we examine our method and show several attractive examples of practical use.

The rest of this paper is organized as follows. In Section 2, we describe related work. In Section 3, we introduce a network composition framework and its related procedures. Section 4 explains an implementation of the framework using cellular networks, and Section 5 presents a performance evaluation and considers several cases of actual use. Finally, Section 6 concludes this paper.

2. Related Work

For automatic or efficient configuration of network devices, many proposals have been studied [3)–5)]. Some of these proposals have been implemented in network devices as commercial products.

Universal Plug and Play (UPnP) [3)] has been proposed for seamless and automatic configuration of network devices in a home network. UPnP is able to carry out discovery, addressing, and name resolution for network devices. Network devices that support UPnP can work autonomously without the need for operations by connecting LAN or Wireless LAN. WLAN Access Point Device [4)] in the UPnP specification provides configuration and querying 802.11 access point (AP) parameters.

The Internet Engineering Task Force (IETF) Zeroconf WG [5)] has proposed a protocol that allows all entities, including PCs, peripheral devices, and applications on these devices to join networks without any configuration. Major functions of Zeroconf are addressing, name resolution, and service discovery without any management servers.

Though the above-described methods realize automatic or efficient configuration of network devices, they require direct connection to the target network before operations. However, when there is no connection, to establish the wireless connection, user terminals need to perform a number of operations as shown in Section 1. This paper proposes a new framework assisted by pre-connected cellular networks to facilitate automatic configuration.

In our proposed framework, the user's location is used for the selection of a suitable wireless network. While GPS measurement is an effective and common method to obtain location in outdoor environments, it cannot provide accurate location information in indoor environments. Thus, there are many research activities which aim to obtain location without GPS measurement.

LifeTag [6] proposed a WiFi-based location detection method for location logging applications. It detects a device's location from received WiFi beacon signals, and works indoors and outdoors without GPS. This method is used in PlaceEngine [7], which provides a service that estimates a location via WiFi signals. However, such WiFi-based location detection methods cannot be applied to user terminals that do not include a WiFi device.

ContextPhone [8] has been developed as a context-aware mobile application and obtains the user's location as the user's context by GPS and other methods such as 3GPP GSM cell ID-based measurement. From the cell IDs of cellular networks, as proposed in Ref. 9), the user's location can be recognized by using a database with relationships between cell IDs and locations. In addition to such cell ID-based measurement, some cellular networks support assisted GPS [10] (A-GPS), in which cellular networks send assistance information for GPS measurement and facilitate location calculation. By A-GPS, cellular phones obtain their location more accurately and quickly than stand-alone GPS measurement, even when they receive weak GPS signals, for example, in indoor environments. In our paper, the proposed framework is implemented in cellular phones with A-GPS so that the user's location can be obtained in both outdoor and indoor environments.

WiFi Alliance introduced WiFi Protected Setup (WPS) [11] to ease the task of setting up wireless local area networks. WPS provides two easy-to-use methods to configure a wireless network: Push-Button Configuration and PIN code. In these methods, wireless devices are configured to connect to a wireless network by pushing buttons on both APs and client devices or by entering a PIN code. However, to perform WPS, the user needs either physical access to push the button or a device which has a connection to the wireless network in advance to register the client device. Thus, the focus of WPS is mainly home networking.

IEEE 802.11u [12] assists the advertising and connecting to remote services and provides information to stations about external networks prior to association. Although this protocol achieves interworking with external networks through IEEE 802.11 APs, security and authentication of information depend on the AP's security and authentication. This paper proposes a way of providing configuration information to wireless networks in a secure and authenticated way.

IEEE 802.21 [13] is developing a standard to enable seamless handover and interoperability between different network types, namely, Media Independent Handover (MIH). This standard provides information to allow handing over to and from cellular, WiFi, Bluetooth, and 802.11 networks through different handover mechanisms. The goal of IEEE 802.21 shares some part of ours; however, the main distinction is that while IEEE 802.21 supports the provision of information for seamless handover, an actual handover action is outside its scope. In our proposed framework, we aim to not only provide information for suitable wireless networks, but also offer a practical configuration procedure to connect the target wireless networks.

3. Dynamic Network Composition Framework and Procedures

3.1 Network Composition Concept

In order to archive its goal, this paper leverages a network composition concept, under which multiple networks are able to realize network integration, control sharing, and network interworking with minimal interaction [1]. Ambient Network Project [14] also uses this concept aiming to provide an optimal network environment by adopting the user's context [15].

3GPP [16] discusses the feasibility of network composition for future technologies in all IP-based networks. It explores the feasibility of a uniform procedure for the integration of, and interworking with, a large variety of heterogeneous network types [2]. It focuses on ad hoc networks, Personal Area Networks (PANs), and moving networks, but also includes access systems. The goal is to avoid the need for defining a new procedure for integration or interworking with each newly emerging network type and to explore the feasibility of formulating a network composition procedure that minimizes human intervention.

Based on the network composition concept, this paper introduces a framework and practical procedures to realize the concept in heterogeneous network environments.

3.2 Network Composition Framework

By applying the network composition concept, we propose a network composition framework to connect to a target wireless access network with the support of pre-connected wireless access networks. Based on the considerations in Section 1, the network composition framework needs to provide the following functions.

(1) Network discovery
This function discovers wireless networks suitable for the user's context. The user's context includes a list of wireless devices, location, and the user's preferences, such as desired QoS and the fee that the user can afford to pay.

(2) Network selection
In heterogeneous network environments, more than one candidate can often be discovered. Among the wireless network candidates detected in the network discovery process, this function selects the most suitable one.

(3) Configuration information notification
This function collects configuration information on the selected wireless network and notifies the user terminals. Configuration information includes not only the parameters for the network devices, but also authentication information for the wireless access network. Authentication information includes the identification and password to access the wireless network.

(4) Device configuration
This function sets up the target wireless device using the obtained configuration information. This function should be executed in an automatic manner.

In this network composition framework, the pre-connected wireless network supports these functions to realize the above functions with minimal interaction. **Figure 2** shows the network composition framework.

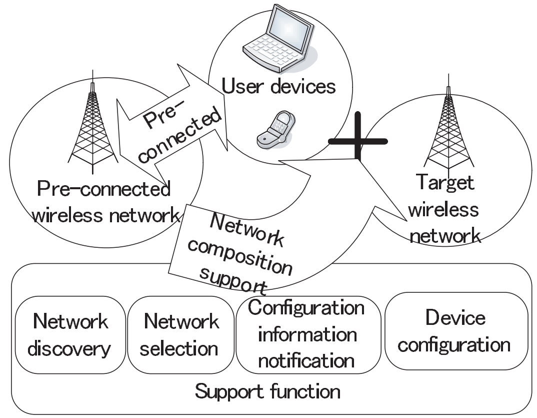

Fig. 2 Network composition framework.

3.3 Network Composition Procedures with Cellular Network Support

In this section, we introduce the network composition procedures that enable the network composition framework shown in Section 3.2 to be realized. First, we show the requirement for pre-connected wireless networks that support the network composition framework.

(1) Continuous connectivity
To realize the network composition framework, the supporting wireless network requires continuous (or semi-continuous) connectivity.

(2) Authentication platform
A network composition framework should be provided only for authenticated users. In heterogeneous network environments, however, there may be malicious wireless networks. Thus, the supporting networks require an adequate authentication platform.

(3) Secure transport capability
When malicious users can listen in to the transmission of configuration information, they may be able to access the target wireless network. Thus, configuration information must be conveyed securely.

Cellular networks have a wide coverage area and user authentication platform, such as SIM card-based authentication. Moreover, as cellular networks are capable of secure transport, they are regarded as the most suitable candidate meeting the above requirements. In addition, recent cellular phones are often equipped

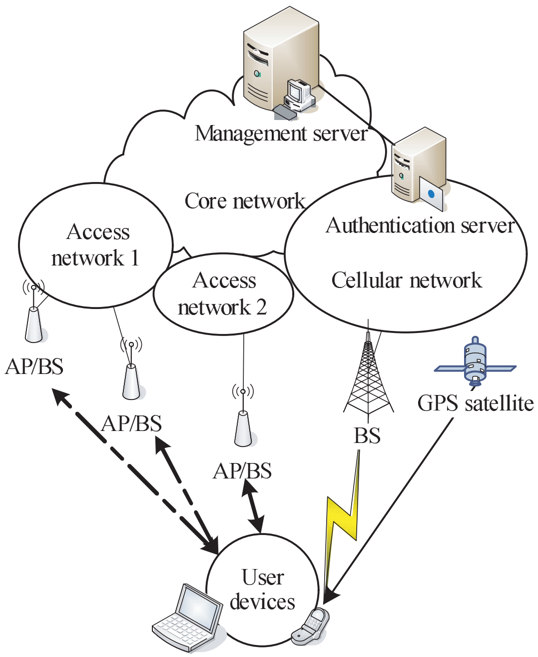

Fig. 3 Example of a heterogeneous network environment.

with GPS location services. Location measurement is particularly useful for recognition of the user's context. This paper realizes a network composition framework that leverages the functionalities of cellular networks.

Figure 3 shows an example of the heterogeneous network environment assumed in this paper. The user has wireless devices including a cellular phone. The cellular phone and the other devices are connected by several methods such as Bluetooth. Using the cellular phone, the user terminals can connect to the cellular network that supports the network composition framework. To realize this framework, a management server that manages information for network composition in its database is introduced on the core networks or cellular networks. In cellular networks, there is an authentication server, such as AAA, which manages user account information. Examples of target wireless networks are WiFi, Bluetooth, and so on.

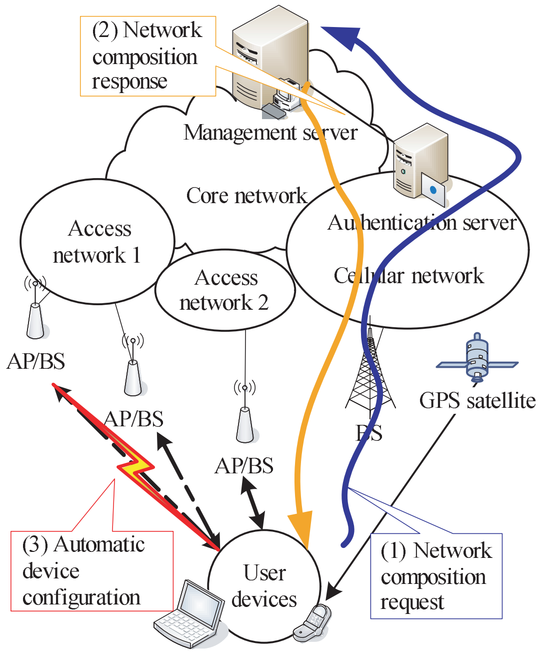

Fig. 4 Network composition procedures.

Here we introduce the procedures for realizing the network composition framework supported by a cellular network. We assume that the users do not know about the wireless networks in advance. We aim to execute the procedures with minimal interaction. The procedures consist of the following three steps. **Figure 4** shows the procedures.

(1) Network composition request

According to a request trigger, the user terminal sends a request message to the management server through a cellular network. In some cases, the cellular phone itself sends the message, while in other cases, another device sends the message via the cellular phone. The request message includes a list of the wireless devices, the location obtained by the cellular phone, and the user's preferences such as desired QoS or the fee that the user can afford to pay. The message also contains authentication information for cellular networks. Example request triggers are user movement recognized by location measurement and communication requests from applications.

(2) Network composition response

When a management server receives a request message from the user terminal, it executes the discovery, selection processes, and configuration information notification in relation to the target wireless networks. In the discovery and selection, the management server accesses a database that manages information on wireless networks. After discovery of the candidate wireless networks, the most suitable candidate for the user's context is selected. Then, the management server composes a reply message that includes configuration information on the selected wireless network, and transmits it to the user terminal through the cellular network.

(3) Automatic device configuration

Upon receiving a reply message, the user terminal sets up the obtained configuration information to wireless devices in an automatic way. Then, the user terminal connects to the selected wireless network.

In these procedures, the roles of the cellular phone are to transmit the request message and receive a reply message. In addition, the cellular phone handles the user's profile to express the user's context such as location and user preferences. Location information is obtained by means of a GPS installed in the cellular phone and is used for the request trigger. The user's preference for desired wireless networks is specified by the user in advance. The cellular phone is not restricted to preparing only one profile, but can prepare multiple profiles. For example, each profile corresponds to one application. By having multiple profiles, target wireless networks can be selected flexibly.

The cellular network supports the network composition framework, ensures secure transport between the cellular phone and the management server, and acts as the user authentication platform. This user authentication platform determines access control to the management server.

The management server has a database that manages information about the wireless networks. The managed information consists of the type, location, and configuration of wireless networks. Based on this database, the management server executes discovery, selection, and configuration information notification of the target wireless network.

4. Implementation

In accordance with the network composition framework and procedures shown in Section 3, we conduct an implementation in a practical environment as an experimental testbed.

4.1 Implementation Platform

The implementation platform is shown in **Fig. 5**. In this platform, the network composition framework is implemented with the following user terminals: a cellular phone with a Bluetooth interface, a cellular phone with a WiFi interface, and a laptop PC with Bluetooth and WiFi interfaces. A laptop PC is connected to a cellular phone via Bluetooth connection. Specifications of user terminals are shown in **Table 1**, **Table 2** and **Table 3**, respectively. The network composition framework is implemented as BREW [17] applications in the cellular phone and as

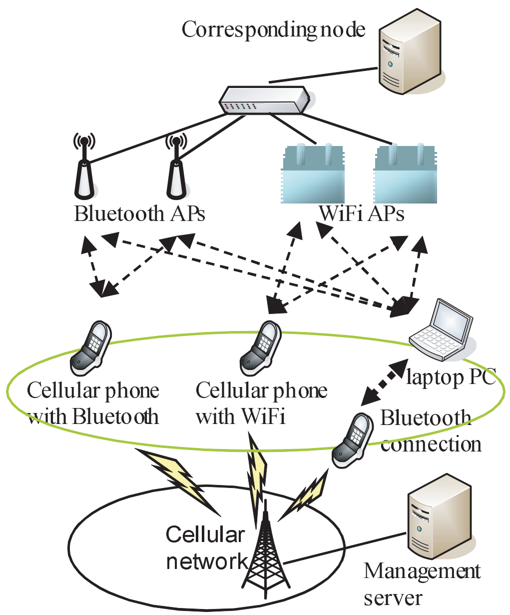

Fig. 5 Implementation platform.

Table 1 Specification of cellular phone with Bluetooth.

Terminal	Toshiba W44T
Wireless I/F 1	CDMA 2000 EV-DO Rev.0
Wireless I/F 2	Bluetooth
CPU	ARM9E
Program platform	BREW 3.1

Table 2 Specification of cellular phone with WiFi.

Terminal	Sanyo E02SA
Wireless I/F 1	CDMA 2000 1x EV-DO Rev.0
Wireless I/F 2	IEEE 802.11b/g
CPU	ARM9E
Program platform	BREW 3.1

Table 3 Specifications of laptop PC.

Terminal	Panasonic Let's note R5
Wireless I/F 1	IEEE 802.11b/g
Wireless I/F 2	Bluetooth
CPU	Intel Core Solo U1300 (1.06 GHz)
Program platform	Windows XP Service Pack 2

Windows applications on the laptop PC. In this implementation, cellular phones obtain their location by using an A-GPS [10] measurement method.

A management server, which is a desktop PC with Windows XP, can be accessed through a cellular network connection from user terminals. WiFi APs and Bluetooth APs serve as the target wireless access networks. Through these wireless networks, the user communicates with corresponding nodes such as application servers.

4.2 Implementation Functions in User Terminals

To enable the network composition procedures shown in Section 3.3, the following functions are implemented in a cellular phone and a laptop PC.

- Message handling function

The user terminals are implemented to handle a request message and a reply message for the request and response procedures. In these messages, information is described in XML format. These messages are transported between a cellular phone and a management server using a TCP connection. When the laptop PC sends a request message to the cellular phone through the Bluetooth Serial Port Profile (SPP) connection, the cellular phone adds information on location and user authentication to the message.

- Dynamic device configuration function

This function realizes an automatic device configuration procedure. The cellular phone uses BREW APIs for configuration of Bluetooth and WiFi devices. The laptop PC uses Windows XP Wireless LAN API [18] for WiFi interface configuration and BlueSoleil [19] API for Bluetooth configuration. BlueSoleil is software that enables configuration of Bluetooth devices and communication with the target Bluetooth APs.

- Trigger function

A trigger function is implemented to enable the request procedure in the network composition framework. Implemented request triggers are as follows: periodic execution, mobility detection by distance moved from previous execution, disconnection detection of currently connected wireless networks and application requests. In this implementation, these request triggers can be used alone or in combination. When request trigger occurs, this function initiates a request procedure.

- Profile configuration function

This function edits the user's profile contained in a request message. Although the other functions are executed in an automatic way, this function is controlled by manual interaction with the user. In this implementation, the user's preferences are the desired bandwidth of wireless networks and the fee that the user can afford to pay for network access services.

- GUI function

To confirm the operation of the implemented functions, the GUI function is implemented. **Figures 6** and **7** show screen images of the GUI function on a cellular phone and a laptop PC, respectively. These screen images illustrate the map of the user's location and neighboring APs with their coverage areas. Figure 6 shows the situation where the user moves rightward on the map. In the leftmost image, the user is not connected with any AP due to being outside its coverage area. The user gets connected with an AP in the center imaage, and then in the rightmost image, the user is moved within the coverage areas

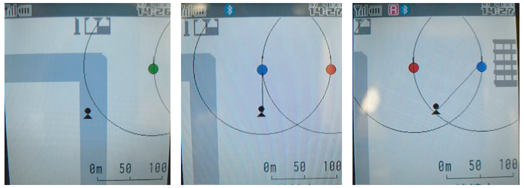

Fig. 6 Screen images of the GUI function on a cellular phone.

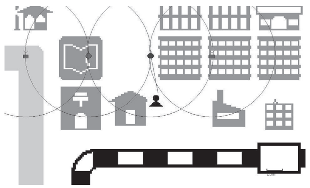

Fig. 7 A screen image of the GUI function on a laptop PC.

of two APs and switches to the AP on the right. In this scenario, the user's preference indicates that the user wants broadband communication and the right AP provides a higher speed connection than the left AP. Therefore, the right AP is selected to meet the user's preference. Figure 7 also depicts the connection status when a laptop PC is used. In our implementation, this series of connections is automatically performed with no user interaction.

4.3 Implementation Functions in a Management Server

To realize the response procedure of the network composition framework shown in Section 3.3, the management server constructs a database that manages information for the wireless networks. In our implementation, MySQL [20] is used to construct the database, which registers information on the wireless networks such as location, coverage area and configuration information in advance. In this implementation, a list of configuration parameters consists of SSID, WEP key and encryption mode for WiFi APs and Bluetooth device address and Bluetooth PIN code for Bluetooth APs.

As a response function, the management server selects the target wireless network as follows.

- Step 1

When the server receives a request message, the server selects candidates that correspond to the wireless devices described in the request message.

- Step 2

The server narrows down the candidates selected in Step 1 to the new candidates whose coverage area includes the user's location.

- Step 3

From the candidates selected in Step 2, new candidates are selected that satisfy the user's preferences. When there are multiple candidates, the server selects the most suitable one.

After selection, the server replies to the user terminal with information on the selected wireless network.

In our implementation, the management server provides the information of only the most suitable wireless network in order to minimize user operation. However, if the management server sends the information of a few candidates of suitable wireless networks, the user can select the most suitable one from the list of candidates. Although this alternative approach requires a few more steps of user operation, it provides users more flexible selection of the target wireless networks. Moreover, the alternative approach has other benefits when the user's location is not accurate enough. In this case, the management server sends information of a few candidates of target wireless networks, whose cover area may include the user's location. Then, from the candidates, the user selects the target wireless network, which is available in the user's location.

When the management server provides the information on the target wireless networks, the user terminal should be authenticated by cellular operators, for example, using SIM-based authentication. This is because the information of the target wireless networks should be provided only for the authenticated users. After provision of the information, handling the information in the user terminal depends on the operator's policy. In our implementation, the user terminal removes the information after a certain period from the connection closing. If this period is set long enough, the user terminal can access the target wireless networks by using the locally cached information even if it goes outside the range of cellular networks.

5. Performance Evaluation and Discussion

We examine the proposed network composition framework and procedures on the implemented testbed. We present the results of a performance evaluation, and consider examples of actual use.

5.1 Performance Evaluation

We show the time required to complete each network composition procedure. For the experiment, we used the implementation platform shown in Fig. 5. The target wireless devices are Bluetooth on a cellular phone, WiFi on a cellular phone, and WiFi and Bluetooth on a laptop PC. **Figure 8** shows the results for each target wireless device. The results are averaged over 20 trials.

From this figure, we confirm that the time for the device configuration procedure constitutes the major part of the time required to complete the network composition procedures. Moreover, the time for the device configuration procedure differs depending on the target wireless device and the user terminal.

The amount of time for the device configuration procedure depends on two major factors: specification-based behaviors of wireless devices and APIs. The device configuration procedure of Bluetooth devices is broken down into device discovery, connection establishment, and other processes. The amount of time for each process is shown in **Table 4**. In our implementation, the time required for the device discovery process is about 5 seconds on both a cellular phone and a laptop PC, which is the majority of the total time of the device configuration procedure. The device discovery process retrieves the Bluetooth device addresses in its vicinity and makes their radio frequency synchronized. The device discovery process is indispensable in the Bluetooth specification so it cannot be omitted. However, as the period of the device discovery process depends on the implementation stack, the time for device discovery can be reduced if a Bluetooth API supports tuning of that period.

On the other hand, for a WiFi connection, the device configuration procedure consists of scan, association and other processes. **Table 5** shows the breakdown of the time for the device configuration procedure. From this result, we can see that a cellular phone requires almost double the total time for device configuration compared to a laptop PC. This is because the BREW API used in this platform needs a longer time to probe the target WiFi AP in the scan process. In the WiFi specification, the scan process can be omitted when information of the target AP is already known. However, the WiFi APIs in our implementation require the scan process before the association process. Thus, if APIs support the omission of the scan process, the total time for the device configuration procedure can be reduced.

Focusing on the same wireless devices, a laptop PC finishes device configuration more quickly than a cellular phone. This result can be attributed, at least in part,

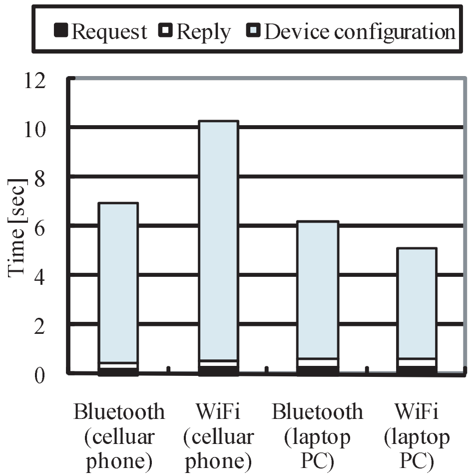

Fig. 8 Time required to complete the network composition procedures.

Table 4 Breakdown of time for the device configuration procedure (Bluetooth).

	Device discovery (sec)	Connection establishment (sec)	Others (sec)	Total (sec)
Cellular phone	5.25	0.89	0.32	6.46
Laptop PC	5.13	0.30	0.15	5.58

Table 5 Breakdown of time for the device configuration procedure (WiFi).

	Scan (sec)	Association (sec)	Others (sec)	Total (sec)
Cellular phone	8.91	0.45	0.35	9.71
Laptop PC	3.89	0.29	0.25	4.43

to differences in the processing speed between a cellular phone and a laptop PC.

On the other hand, the time required for the network composition request and response procedures is short regardless of the implementation platform and the target wireless device. In particular, though a laptop PC requires message transmission via the Bluetooth connection between the PC and the cellular phone, this transmission overhead is negligible when compared with the procedures in a cellular phone.

In this experiment, when the user manually performs operations to establish a connection with the target wireless network on the same platform, the time for device configuration also includes the time required for the device configuration procedure shown in Fig. 8. However, A-GPS location measurement is required to complete our proposed procedures. In our experiment, A-GPS requires about 10 seconds to obtain the user's location in both cellular phones shown in Table 1 and Table 2. Thus, the total time required for the proposed procedure is about 20 seconds. Nevertheless, in many cases, the user takes a considerable amount of time, if done manually, for the processes of network discovery, network selection and configuration information acquisition. Thus, we are able to confirm that the network composition procedures are capable of making a connection to the target wireless network with minimal interaction.

Next, we present some qualitative considerations for the discovery and selection of wireless networks. In our framework, the management server discovers and selects the target wireless network based on the user's context such as the user's location and preferences contained in a request message. On the other hand, by using local measurement, such as broadcast beacons from wireless networks, the user terminals can discover the target wireless networks on their own. However, the user still needs to select the most suitable network if there are multiple candidates. In addition, in some cases, APs do not advertise their existence for security reasons, which makes it impossible for the user terminals to discover the wireless networks. Our framework can realize discovery and selection of the target wireless networks in such environments.

Moreover, discovery and selection without local measurement have another advantage. By not using local measurement, the wireless devices can be turned off until our framework selects the devices, which is more efficient from the perspective of battery consumption. If battery consumption is not a critical issue, by using the radio conditions obtained by local measurement, the accuracy of discovery and selection will further improve. Therefore, combined with local measurement, our framework can discover and select the most suitable wireless networks by considering both radio conditions and network circumstances, for example, the number of users joining the wireless networks or the network loads.

5.2 Practical Examples and Considerations

We present two cases of actual use and demonstrate the extensibility of our framework.

(1) WiFi access at a cafe (dynamic and automatic configuration)

We present the case where the user wants to access the Internet from a cafe. The user has a laptop PC with a WiFi interface and a cellular phone. As shown in Section 1, when our framework is not used, the user is required to perform several operations and interactions to access the Internet. In our framework, the operation is as follows.

- Step 1

When the user sits down, our framework begins the request procedure triggered by location measurement or application request. Then, the laptop PC sends a request message to the management server via the cellular phone. The request message includes a list of the wireless devices, that is, WiFi in the laptop PC and the cellular phone, location, and the user's preferences.

- Step 2

The management server on the core network selects a WiFi network at the cafe as the target network. This is because the WiFi network is in the vicinity of the user's location and the user has described in advance his/her preference for a broadband connection. Then, the user's laptop PC is notified of the configuration information for the WiFi network.

- Step 3

According to the device configuration procedure, the WiFi interface of the laptop PC is set up by setting parameters and user authentication information to access the Internet. Then, the user accesses the Internet.

By means of these steps, the user's interaction is at most running the application for a request trigger for the network composition procedures. In addition, to satisfy the user's preferences, the user needs to prepare a profile in advance. With regard to service providers, the WiFi provider needs to register information about the WiFi such as parameter settings, location, and user authentication information in advance. Then, the user can achieve WiFi access with minimal interaction.

(2) WiFi access in the office (security and centralized management)

In an office WLAN, for security reasons, WiFi APs do not broadcast the SSIDs in many cases. Wireless terminals used by office workers are set up by administrators in advance to access the office WLAN. As shown in Section 5.1, the user can access non-broadcasting APs by using our framework. Moreover, as configuration information is managed by a management server, administrators can manage and operate wireless devices in a centralized manner. For example, when administrators want to change the configuration of the office WLAN, they only have to register new configuration information to a management server. Then, the wireless devices of the office workers reflect the configuration changes by using the network composition framework.

As shown in the above cases, our framework makes more useful and attractive wireless access services available to users in heterogeneous network environments. Moreover, our framework makes possible new services such as discovery of non-broadcasting wireless networks and centralized management of wireless access networks by using the support of cellular networks.

6. Conclusion

This paper proposed a network composition framework that enables full use to be made of heterogeneous network environments. This framework realizes dynamic and automatic configuration of a wireless devices with minimal interaction. Supported by cellular networks, this framework provides four functions, i.e., discovery, selection, configuration notification, and device configuration of the target wireless network that is suitable for the user's context. We introduced and implemented network composition procedures to execute our framework in a real environment. We performed a performance evaluation using the implementation and presented examples of practical use employing our framework. Then, we showed that our framework and procedures have extensibility and thereby make more useful and attractive applications and services available to users.

References

1) Kappler, C., Mendes, P., Prehofer, C., Poyhonen, P. and Zhou, D.: A Framework for Self-organized Network Composition, *Proc. WAC 2004*, IFIP TC6 WG6.6, pp.139–151 (2004).
2) 3GPP: Network Composition Feasibility Study (2007). TR 22.980, Version 8.1.0.
3) UPNP forum. http://www.upnp.org
4) UPNP forum. http://www.upnp.org/standardizeddcps/wlanap.asp
5) IETF Zero Configuration Networking (Zeroconf) WG Charter. http://www.ietf.org/html.charters/OLD/zeroconf-charter.html
6) Rekimoto, J., Miyaki, T. and Ishizawa, T.: LifeTag: WiFi-based Continuous Location Logging for Life Pattern analysis, *Proc. LOCA 2007*, pp.35–49 (2007).
7) PlaceEngine. http://www.placeengine.com/en
8) Raento, M., Oulasvirta, A., Petit, R. and Toivonen, H.: ContextPhone: A prototyping platform for context-aware mobile applications, *IEEE Pervasive Computing*, Vol.4, No.2, pp.51–59 (2005).
9) Mika, K.L., Raento, M. and Toivonen, H.: Adaptive On-Device Location Recognition, *Proc. 2nd International Conference on Pervasive Computing*, Springer Verlag, pp.287–304 (2004).
10) Djuknic, G.M. and Richton, R.E.: Geolocation and Assisted GPS, *Computer*, Vol.34, No.2, pp.123–125 (2001).
11) WiFi Alliance: WiFi Protected Setup. http://www.wi-fi.org/wifi-protected-setup
12) IEEE 802.11u. http://www.ieee802.org/11/Reports/tgu_update.htm
13) IEEE: Draft IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services (2003).
14) Ambient Network Project. http://www.ambient networks.org
15) Niebert, N., Schieder, A., Abramowitz, H., Malmgren, G., Sachs, J., Hom, U., Prehofer, C. and Karl, H.: Ambient Networks: An Architecture for Communication Networks beyond 3G, *IEEE Wireless Communications*, Vol.11, No.2, pp.14–22 (2004).
16) 3GPP. http://www.3gpp.org
17) BREW. http://brew.qualcomm.com/brew/en
18) Wireless LAN API for Windows XP Service Pack 2. http://msdn2.microsoft.com/en-us/library/bb204766.aspx
19) BlueSoleil. http://www.bluesoleil.com
20) MySQL. http://www.mysql.com

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Editor's Recommendation

This paper proposes a new networking framework that enables automatic connections to a wireless network best suited for the user's context. The proposed framework is also implemented in a real environment comprising cellular, Wi-Fi and Bluetooth. The evaluated results show improvement of the usability of a diversified network environment. Since the paper will greatly contribute to advancing the networking technologies in the future, I hereby recommend this paper to be published in this journal.

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