Multi-Link Ad-Hoc Communication System based on Mobile Agents

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Abstract

Recently, long-range wireless networks such as cellular networks, and short-range wireless communication devices such as IrDA, Wireless LAN(IEEE802.11), HomeRF, and Bluetooth become popular. Wireless communication is inherently unstable, so there is a demand to utilize multiple wireless connections. In this paper, we first propose the concept of ad-hoc communication which is the short-range wireless communication between the information devices that happen to meet each other. We clarify the characteristics of ad-hoc communication and discuss the difficulties of on-demand communications. Secondly, we propose a mobile agent system for supporting multi-link ad-hoc communication by the full use of both long and short-range network devices. We implement the mobile agent system named MAGNET and we also develop communication several prototype systems which implement ad-hoc on-demand communication. These systems exemplify the usefulness of the framework.

1. Introduction

Long range wireless devices such as cellular phones and PHSs are getting popular these days. Portable cellular phone enables person-to-person communication at any time and any place. However, these communications are almost performed via conventional voice-only interface. These old-interface cannot be extended to fit variety of user requirements. In Japan, we have several cellular phone data services. Most popular one of them is called **i-mode** that enables cellular phone to be a compact web terminal. By using such devices, one can communicate with servers, but one cannot directly communicate with the other users. It is also expensive to use cellular phone network to make a big traffic such as software downloads.

On the other hand, several short-range wireless devices such as IrDA, Wireless LAN (IEEE802.11), HomeRF[10], and Bluetooth[11] are commonly used in these days. These devices are cheap and small. Some of them are combined with cellular phone devices as some kind of information devices. In such case, it might be possible to support person-to-person communication using such devices. By using both of short-range wireless device and long-range cellular network, portable information device can take an important role in person-to-person communications.

In this paper, we introduce the concept of ad-hoc communication that is the communications between the information devices that are eventually meet each other. By utilizing different characteristics of wireless devices, ad-hoc communication can be more rich and flexible. We clarify the characteristics of ad-hoc communication and discuss the difficulties of on-demand communications.

To overcome these problems, we propose a mobile agent framework for supporting multi-link wireless ad-hoc communication. We have been implementing the mobile agent system named MAGNET for ad-hoc networks [1]. By using MAGNET as a core framework, we implement several prototype systems. These systems exemplify the usefulness of the framework.

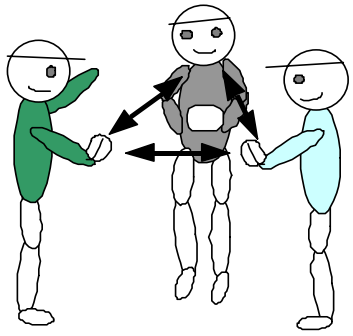

Figure 1: Ad-hoc communication using information terminals

2. Concept of Ad-Hoc Communication

In this section, we propose the concept of ad-hoc communication. It is a simple concept of human communication between peoples and systems. It happens on-demand and without preparations.

2.1 Characteristics

When persons chance to meet each other (in usual situation, it may happen on the road, in the meeting place, in the classroom, etc.), they start to have a conversation over them. We call this kind of person-to-person communication as "ad-hoc communication" that happen without any preparations. In another case, when one stands in front of the information kiosk, which is placed in station or shopping center to offer information for travel tours, sight-seeing spots, shopping etc., one want to use the info-terminal to obtain these information. We also call this kind of communication between person and system as ad-hoc communication. It also happens without any preparations.

Ad-hoc network [2] is a network that is formed on-demand to communicate between mobile hosts. This concept differs from our concept of ad-hoc communication because that ad-hoc network only considers communication between mobile hosts and do not consider the contents of the network traffics, but our ad-hoc communication considers communication between peoples and consider the exchanged information between peoples.

In the near future, most of all people will keep their information terminals like wristwatches today. Considering this situation, communications over peoples can be regard as communications over information terminals. By this foresight, we extend the concept of ad-hoc communication into the communication between personal information terminals and kiosk terminals.

Typical situation of ad-hoc communication is shown in Figure 1. To realize the ad-hoc communication using information terminals, we should consider following characteristics of the ad-hoc communication.

- Existence of several communication protocols
- Dynamic change of participants
- Situation dependent communication

On the ad-hoc communication, person wants to communicate in different protocols. For example, in the meeting, there might be chairperson to control the conversation and one can talk after the permission. In the auditorium, a speaker or panelists are talk in one-way, and after the lecture, Q&A time will start. In these situations, participants of the communication may change dynamically.

2.2 Difficulties for Supporting Ad-Hoc Communications

Considering the characteristics of ad-hoc communication, it is not feasible to use current network communication technologies to develop a system that support ad-hoc communication. In the following, we describe the reasons why it is difficult to support ad-hoc communication.

To use different kind of communication protocols, they might be prepared in all of information terminals. Number of protocols for ad-hoc communications may be large and increasing. Therefore, it is almost impossible to prepare all protocols installed in small-memory information terminals before they start to communicate.

Dynamic change of participants cannot overcome by the method of fixed network maintenance. There are several ad-hoc network protocols [2, 3], but they cannot handle the discovery of other nodes because they consider TCP/IP networks. We have already implement an ad-hoc network system using infrared communication [4]. This system can adopt the dynamic change and can discovery all participants.

Ad-hoc communication may happen any place. However, the place that the ad-hoc communication is held is very important information for supporting ad-hoc communication. Current technology for ad-hoc network cannot solve the location dependant communication, because they do not have any device to detect its location.

3. Difference in Wireless Networks

In this section, we discuss about the difference in current and future wireless network technologies to use them for ad-hoc communications. We need to understand each characteristic of them and utilize full of them.

3.1 Differences in cost and range

In Table 1., we show the speed, connection-range and cost of wireless network devices. Communication cost of

Table 1: Speed, range and cost of wireless media

Media	Speed	Range	Hard Cost	Comm. Cost
IMT-2000	144k--2M	Not yet	High	High
Cell-Phone (PDC Japan)	9.6k—28.8k	99% in Japan	High	High
PHS	64k—128k	City side	High	Medium
IEEE802.11	1M—11M	50m-2km	Medium	Free
HomeRF2.0	0.8M-10M	50-100m	Low	Free
Bluetooth	1M—2M	10-100m	Low	Free
IrDA (1.1)	9.6k—4M	1m	Low	Free

short-range device such as infrared and Bluetooth are free but long-range cellular network are high In Japan, cellular packet network costs about 0.3cent for each 128bytes packet (in Aug. 2000). If someone wants to receive 1Mbytes-sized software, it might be 8192 packets and it costs over 24dollars and takes 18min(in 9.6kbps). It is said that this cost may not drastically change in near future even IMT-2000 becomes available. This means that these cellular packet networks cannot be used for software distribution nor music downloads. That is, cellular packet networks should be used for small-sized text-based information in practice.

Connection ranges also differ in each device. Cellular packet can be used almost any place in Japan (99% of populations are covered) without considering the other side of connection. Wireless LAN (IEEE802.11), HomeRF and Bluetooth are restricted in 100m-range. IrDA is more restricted and it can only communicate within 1m devices.

3.2 Utilization of the characteristics

We should fully utilize the characteristics of these communication devices for supporting ad-hoc communication.

3.2.1 User's intention and location awareness

Infrared is restricted by its range, but it can be used as a contextual sensor of user's intention. If infrared can find its neighbor device, it might means that the user wants to communicate with the neighbor device. To understand the user's intention, the information device should have some kind of knowledge and intelligence. Infrared device can also be used for location aware device if there are Ir-beacon devices.

3.2.2 On-demand software deployment

On-demand software deployment is one of the requirements for the information terminals for the ad-hoc communication, we will describe in the next section. For the software deployment, cellular packet network is not suitable as we explain in above. Short-range wireless device such as Bluetooth and Wireless LAN are appropriate choice for this kind of communications because of its cost and speed.

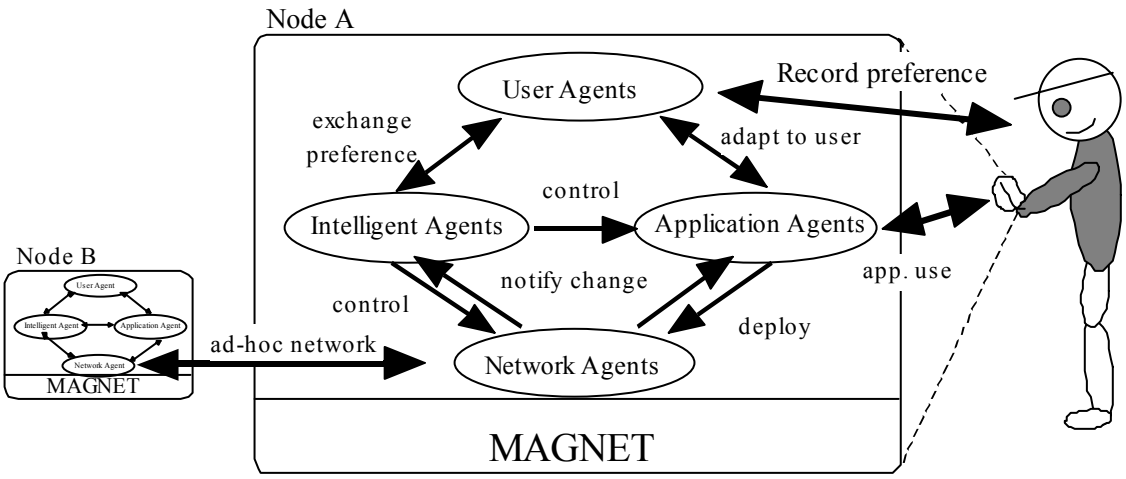

Figure 2: Design of Mobile Agent System for Ad-Hoc Communication Support

3.2.3 Global connection

Cellular packet network can be used any place and any time. Occasionally, ad-hoc communications do not finish at one place in short time. For example, participants of the communication want to continue the communication after the meeting. In this time, global connectivity of cellular packet network can be used to continue the communication.

4. Mobile Agent System for Supporting Multi-Link Ad-Hoc Communication

In this section, we present the requirements for the system to support ad-hoc communications. Then, we propose a mobile agent based system to satisfy the requirements.

4.1 Requirements for Ad-Hoc Communication System

From the characteristics of ad-hoc communication and wireless devices, we decide the requirements to utilize them and overcome the problems.

1. **Select the appropriate network device.**
   As we denote in last section, wireless devices have its own characteristics. The system should select appropriate network devices.
2. **Recognize the current surroundings.**
   The system is required to understand the context for effectively supporting ad-hoc communication [5].
3. **Construct an ad-hoc network.**
   To perform a basic communication, it is required to construct a network with the other systems that surrounds the system.
4. **Deploy software dynamically.**
   As the ad-hoc communication may happen without any preparation, it is impossible to prepare the all required ad-hoc communication software and protocols to all systems in advance. So, to perform an ad-hoc communication, it is required to deploy the suitable software to the other systems.
5. **Keep the preference of the user.**
   User may move from one system to the other system under the mobile environment. At that time, user wants to use the new system with user's preference.

Each of these requirements has many problems to be solved. Additionally, these requirements are depending on each other. For example, to recognize the surrounding devices(2), the system needs to detect surrounding devices by some network device(1). To construct a context-matched ad-hoc network(3), suitable network protocol stacks should be deployed to the other devices(4) like active networks [6,7]. To keep the user preference(5), communication software(4) should have some functionality to do it. So, these requirements cannot be solved without considering the dependency.

4.2 Mobile Agent System for Multi-Link Ad-Hoc Communication

To solve the complicated dependency, we employ the mobile agent framework. Mobile agent [8] is a software object that can move over the network itself. By using mobile agents, dynamic deployment(4) can be easily solved. Additionally, to construct ad-hoc network(3), we have already proposed and implemented framework based on mobile agents [1]. If a mobile agent keeps one's preference(5), it can move over the information devices used by the user, ant it may ease the operation of the new devices for the first-time user.

Recognition of the surroundings(2) can be also treated by intelligent agents. Therefore, we adopt mobile agents for supporting ad-hoc communications.

The agent system is composed from several layers of mobile agents. Figure 2 shows the design of our mobile agent system. The reason why we choose this design is that by separating each agent in these roles, mobility of agents may works well.

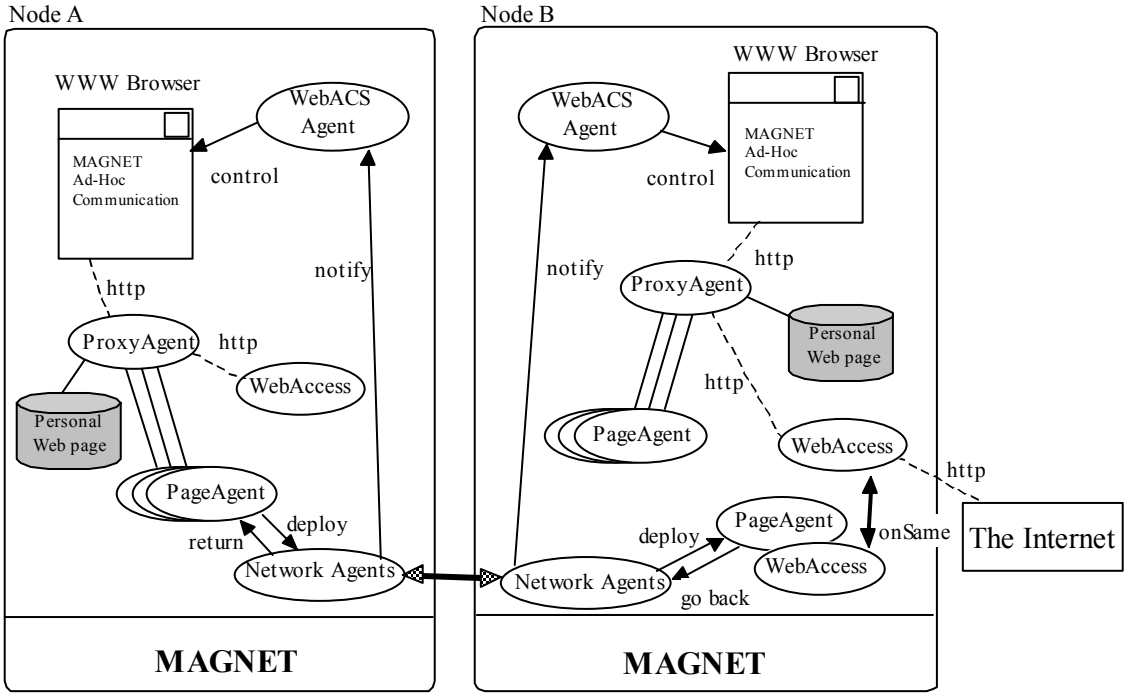

Figure 3: Agent Configuration of WebACS

The lowest layer is the network layer. Some of agents in this layer manage network devices such as IrDA, Bluetooth, and cellular phone networks. The other agents are protocol agents and router agents. These agents co-operate with each other to construct ad-hoc network over the mobile devices. The link manager agent of IrDA or other location services are always trying to recognize the surrounding situation. If the context change is detected, these agents notify the change to the intelligent agents.

Second layer is the mobile application layer. When a mobile device meets the other device, mobile application (mobile agent) will move to the new device to communicate. Applications are also invoked by contextual change. When user meets kiosk terminal,

Third layer is the intelligent layer. The agents in this layer will notice the change of environment, and select the appropriate network device and protocol or suitable application for ad-hoc communication.

Top layer is the user layer. The agents in this layer will record the preference of the user and exchange the information between intelligent agents and application agents.

5. Sample Scenario

In this section, we show a sample usage of our proposal system. When user A meets user B as a first time, usually, they start an oral communication. Because they have information terminals, they use their terminals to exchange information about themselves. Their terminals both have short-range wireless communication device and cellular network.

Using short-range wireless network, user A sends his video name-card which contain special video for introducing himself to user B. User B also sends his web-based self introduction pages to user A. The information terminal of user A starts to match web pages of user B with the information of user A. Matched information such as same kind of hobby, interest or common friends are shown to the display of terminals and help the conversation between them.

After the matching, they found their hobby is almost same and it is playing board games. Therefore, user A propose user B to play an Othello game. However, user B does not have the Othello game agent. Then, user A starts his Othello agent and sends to user B and they can start the game. After a while, user B finds out that he do not have enough time to finish the game, so they change the mode of the game (agent) into cellular mode. By using cellular mode, they can continue to play the game via cellular packet network at any time and any place. Cellular mode utilizes small-packet communications.

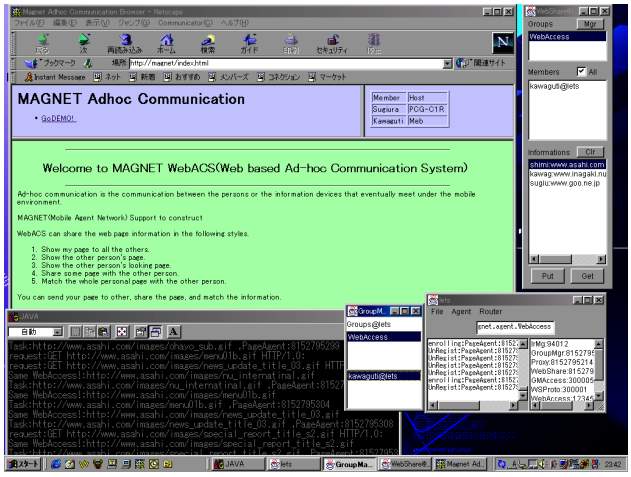

Figure 4: Running Display of WebACS

6. Prototype Systems

We have been implementing a mobile agent framework named MAGNET [1] to enable the ad-hoc communication using Java JDK1.2 (and later). Based on the framework, we develop a prototype of ad-hoc on-demand communication system by implementing four layer of agents described above.

6.1 Web based Ad-Hoc Communication System

We implement a prototype web-access system for supporting ad-hoc communication based on our framework. The system is named “WebACS: Web based Ad-hoc Communication System”. By using this system, when several user gather at the same place, each information device of each user can construct an ad-hoc network, and exchange their information over the network. If any one of the users has a web page for himself in his information device, he can publish his web page over the ad-hoc network using this system. The other users can share the user's web page on their device.

This system has following features.

- Publish the web page (can be a web server).
- Display the other participant's web page.
- Share the web page on all gathered devices.
- Show the web page that is looked at by the other user.
- Match the personal information on the web page with others.
- Share the HTTP connection to the Internet.

These all features are implemented on the mobile agent system, MAGNET with Java. The system is mainly in the layer of mobile application. Therefore, if some participant has no agent for WebACS, these agents are automatically deployed to the participant's device using ad-hoc network. The main web page sharing system is not built on TCP/IP, so if one device has a connection to the Internet, this system can perform a proxy WWW system over the ad-hoc network.

6.1.1 Behaviors of WebACS

Figure 3 shows an agent configuration of WebACS. In the following, we explain how the agents work in the mobile agent system to implement Web sharing. Inter-agent communication is supported by agent replication mechanism. Please see [1] to understand precisely.

1. Network agents recognize the connection link between Node A and B and notify it to WebACS agent (Intelligent Agent).
2. WebACS control the WWW browser to connect with Node B.
3. HTTP request from the WWW browser on Node A is sent to ProxyAgent, and then transferred to a PageAgent.
4. The PageAgent is deployed to Node B using Network Agent (original is still staying Node A).
5. The copied PageAgent create a WebAccess agent on Node B.
6. There is another WebAccess agent in Node B. It's method “onSame” is called from new WebAccess agent created by the copied PageAgent. Because WebAccess agent is a protocol agent.
7. The WebAccess agent accesses the ProxyAgent, gets personal pages, and gives the information to the copied PageAgent.
8. The copied PageAgent return to Node A.
9. The original PageAgent receive the result from the copied PageAgent (onSame).
10. The original PageAgent send the web page info to the ProxyAgent and the page is shown on the web browser.

By sharing the connection with the Internet of Node B, Node A can obtain the web page from the Internet.

Figure 4 shows a working display of WebACS system. Left side of the figure is a web browser. This browser currently shows local network information and title page. Rightmost window is the WebACS agent. WebACS agent displays the information of group list, member list, and URL information. Using this agent, one

can send current page to the other participants ("Put" button), or one can obtain the other participants looking page ("Get" button). Rightmost lower window is the MAGNET agent manager.

Current configuration of WebACS is composed from Network Agents, Application Agents (ProxyAgent, PageAgent and WebAccess), and Intelligent Agent (WebACS Agent). We have not yet implemented the User Agent. However, our experience from this prototype shows that using our framework for supporting ad-hoc communication is powerful and sophisticated way. It is also easy to develop an application for ad-hoc communication because of the encapsulation of network protocols (by agent replication) and composition of small sized agents (by agent hierarchy). Therefore, this prototype exemplifies the usefulness of our framework.

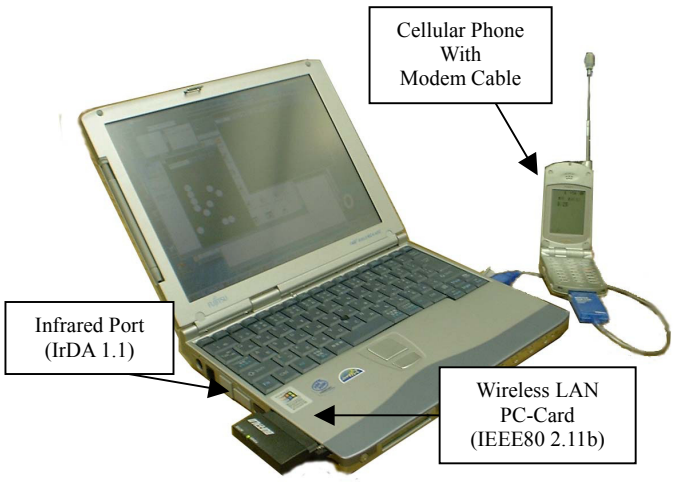

Figure 5: Notebook PC with Cellular Phone and Wireless LAN

6.2 Multi-Link Communication System

We also implement a prototype ad-hoc communication system that utilizes cellular phones. Notebook PC with IrDA and wireless LAN card is used for our system. The PC is also connected with cellular phone via modem cable (Figure 5). Software is also developed by mobile agents based on MAGNET. In the following, we explain the behavior of the system.

Before the communication, each device does not know about each other. When two notebooks are getting close, these notebooks detect each other using IrDA. Then they notice that user want to communicate each other. Therefore, they exchange their IP address and phone number. Currently, we use different identifier for each network device. After the exchange of IP address and phone number, they can apart because they can communicate with LAN card.

Figure 6: Ad-Hoc Communication System with Cellular Phone

After the encounter, an intelligent agent starts to search about what to do. If another terminal is unknown terminal, then it tries to exchange user profile. It may also start WebACS to exchange their personal web pages.

If user wants to play the Othello game, and if another terminal do not have one, Othello agent is deployed to another terminal. Then users can start to play Othello game. When these users change the communication mode into cellular mode, these terminals can move anywhere while keeping playing. Communications between terminals are being controlled under intelligent agent.

By using mobile agents, these ad-hoc communications can be implemented by easy and simple way. This exemplifies the usefulness of mobile agent framework.

7. Conclusion

In this paper, we introduce the concept of ad-hoc communication and propose the framework for supporting ad-hoc on-demand communication using short-range wireless device and long-range cellular network.

We also report the prototype implementations of web-based and cellular based ad-hoc communication system. These prototypes exemplify the usefulness of the framework. Detection and smooth handling of link breakage is important future work. Application in wearable computers [9] is a next topic in our work.

Acknowledgements

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