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P2P Networking Platform –R&D toward a Ubiquitous Communications Environment–

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Realizing a ubiquitous communications environment will require the seamless interconnection of all kinds of devices across diverse networks and the creation of many P2P applications. These devices will come to include mobile terminals, information appliances, sensors, and IC tags that must interface across ad hoc, mobile, and home networks in addition to the Internet. We are actively researching general-purpose P2P networking technologies and applications to meet these requirements.

1. Introduction

The word "ubiquitous" has been drawing much attention in recent years. It is often used in a vague sense to mean a "ubiquitous communications environment," i.e., a versatile communications environment that can interconnect a wide variety of things. In this regard, Internet access, which was traditionally limited to the computer, has expanded to Personal Digital Assistants (PDAs) and mobile terminals due to the rapid development and spread of mobile-network and Internet technologies. Indeed, a mobile Internet environment has been constructed that enables anyone to exchange mail and browse the Web from a mobile terminal. Against this background, attention will be focused on ubiquitous communications as the next-generation communications environment for launch around 2010.

Four reasons can be given for this newfound interest in ubiquitous communications. The first is the "computerization of things." For example, the computerization of mobile terminals is one technical factor behind the appearance of mobile Internet services such as i-mode. Computers featuring a Central Processing Unit (CPU) and memory have also come to be incorporated in a wide variety of "things" such as digital cameras, printers, information appliances, and general home appliances. In the future, "things" with built-in computers are expected to be given communication functions to enable them to communicate with each other in an autonomous and distributed manner. We will refer to such "things" as "devices" in this article.

The second reason is "advances in local wireless communications." To achieve an environment for inter-device communication to allow, for example, mobile terminals to be used as remote-control devices, game consoles to interact, and information appliances to communicate with each other over a home network, local and ad hoc communications environments are expected to become increasingly important in addition to wide-area communications environments such as mobile communications networks and the Internet. Progress is being made in various types of local wireless technologies including Infrared Data Association (IrDA), Bluetooth[*1], ZigBee[*2], and Ultra Wide Band (UWB) as infrastructure technologies to this end. These communication technologies are expected to be incorporated in mobile terminals and other devices.

The third reason is "advances in sensor technology." In Japan, only Radio Frequency IDentification (RFID) tags that are attached to devices as identifiers are attracting attention as a sensor technology for a ubiquitous communications environment. At present, though, the functions of these tags are limited to those that will enable RFID tags to replace bar codes. But when thinking of sensor technology in a broader sense, medical devices for measuring body temperature and blood pressure, cameras for security and traffic control, and many other types of devices can all be treated as "sensors." In fact, sensors no larger than a 100-yen coin such as the "Mote" smart sensor developed by UC Berkeley in the United States have already been commercialized. By combining these sensor technologies with wireless communications technologies, they can be expected to find widespread use in many application fields including trading, transport, disaster protection, and medical care.

The fourth reason is the "convergence of virtual space and real space." Though being a gigantic virtual space, the Internet is used for the most part by people via personal computers, mobile terminals, and other communication terminals, and extensive interaction between the Internet and real-world devices has yet to be achieved. Thus, we are expecting progress in local wireless communications technology and sensor technology as described above to stimulate R&D in diverse applications that interact with sensor nodes to collect real-world data. These might be inventory-control applications using RFID tags and traffic-control, disaster-prevention, and medical-care applications that adopt sensor technology.

To achieve a ubiquitous communications environment having these four attributes, we are focusing on Peer to Peer (P2P) scheme as a new paradigm of distributed computing. In particular, we have been researching and developing a P2P networking platform for linking diverse network environments on the application layer and providing seamless communications between devices.

In the following, we first describe the architecture and protocol of the proposed P2P networking platform. We then describe prototype software for assessing the effectiveness, and present P2P applications on the software.

2. Technical Issues in Achieving a Ubiquitous Communications Environment

Various technical issues must be addressed to achieve a ubiquitous communications environment and associated applications as described in the previous chapter. The technologies for solving these issues are discussed below.

1) Seamless Communications Technology

Diverse types of communications environments including the Internet, home networks, and sensor networks must be cross-linked and seamless communications between devices must be achieved. For example, when using a mobile terminal to control a home information appliance such as a video player/recorder, it must be possible to do so in a consistent way whether one is using i-mode from an outside location or directly using a home network when at home.

2) Autonomous Distributed Computing Technology

In a sensor network, we can envision from several hundred to several thousand distributed sensor nodes that collect data at servers autonomously and applications to perform real-time analysis and monitoring. Achieving such distributed applications requires a new computing paradigm different from the conventional client/server model. Grid computing[*3] is attracting attention as a new paradigm for autonomous distributed computing. The main purpose of this form of computing, however, is to exploit distributed CPU power, and it is not necessarily suitable to data-driven distributed applications that can be expected in a sensor network.

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*1 Bluetooth is a registered trademark of Bluetooth SIG, Inc.

*2 ZigBee is a short-range wireless-communications standard targeting home appliances using a technology similar to Bluetooth.

*3 Grid computing allows the creation of a virtual high-performance computer by connecting multiple computers over a network. A user extracts only the processing and memory capacity needed for his application from that virtual computer.

3) Resource Discovery Technology

In a local and ad hoc communications environment such as a sensor network, resource discovery technology that makes devices be able to dynamically discover neighboring devices and their attributes is important. When using a mobile terminal as a remote control at home, for example, technology is needed to enable the mobile terminal to dynamically discover neighboring devices (TV, video player/recorder, lighting, etc.) using a home network. This will also require metadata technology for describing device attribute information such as device type, manufacturer, and available services.

4) Security/Privacy Technology

In local communications environments in which a Public Key Infrastructure (PKI) does not necessarily exist, new technical issues must be addressed such as mutual authentication between devices that are connected in an ad hoc manner. Has already been pointed out by various concerned parties, there is a serious need for researching and developing technology for protecting user privacy from the traceability feature of RFID tags attached to devices.

3. Universal P2P Networking Platform

3.1 Architecture Overview

As shown in **Figure 1**, the proposed P2P networking platform consists of P2P communications protocol middleware and a middleware Application Programming Interface (API). The P2P communications protocol middleware implements the P2P protocol group (described later) required for P2P communications and operates over various transport networks. A standard API is also provided for accessing the P2P protocol stack enabling the implementation of various P2P applications on the P2P networking platform. The ability of this platform to support a variety of transport networks simplifies the implementation of various kinds of P2P applications in a ubiquitous communications environment.

3.2 P2P Communications Model

In contrast to client/server communications, the role of each node in P2P communications is not always clear. We first consider the type of P2P communications taking typical P2P application called Gnutella[*4] as an example. This application enables users to search for files kept by other users on the Internet and to exchange files as desired [1].

In a P2P distributed search application like Gnutella, P2P nodes can be classified to three types of roles. The first type of node maintains content and provides search results, the second type requests content search and downloads content, and the third type simply relays those search requests and responses. Similarly, in the case of P2P streaming, there are nodes that transmit streaming data, nodes that relay that data, and nodes that receive that data. In short, we can see that the following

*4 Gnutella is application software enabling individuals to exchange files over the Internet.

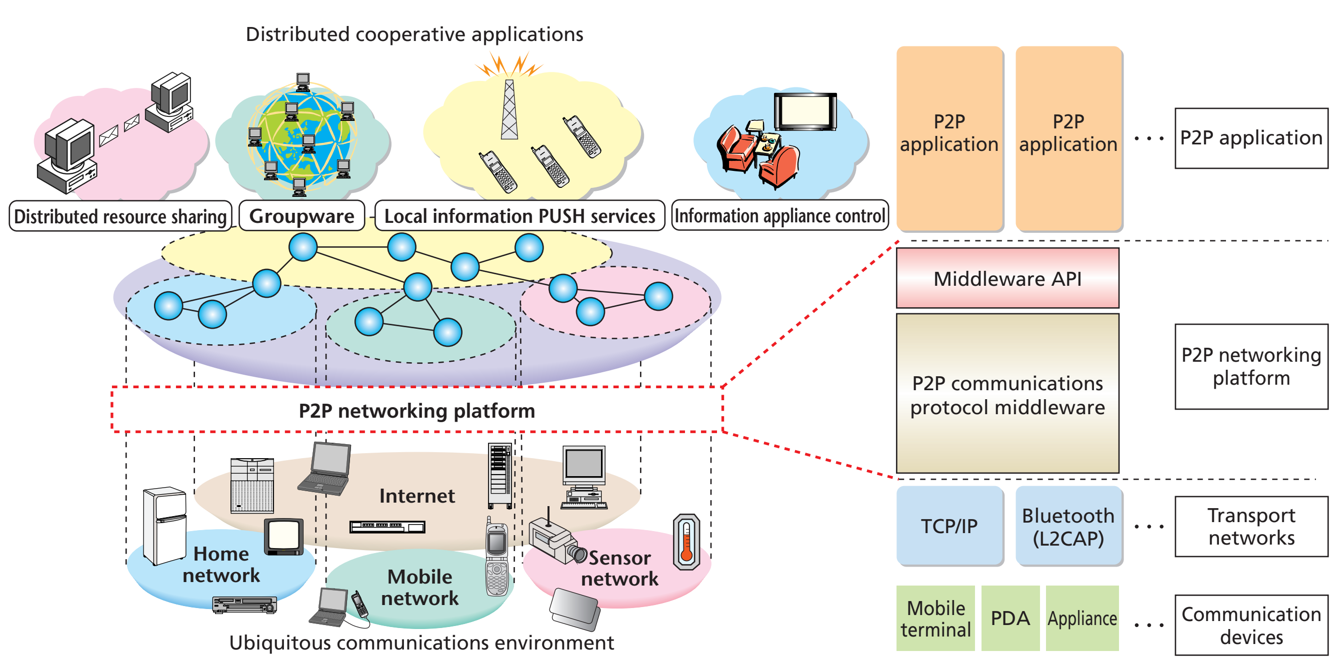

Figure 1 Outline of a P2P networking platform

three elements exist as P2P-node roles in the P2P communications model (**Figure 2**):

1) Producer Role: Provides data or services in a P2P application.
2) Consumer Role: Requests and receives data or services in a P2P application.
3) Relay Role: Relays requests for data or services and responses to those requests.

The concept of a role has been introduced into the P2P communications model in the protocol design to clarify the function of each node. In a P2P application, a P2P node can take on any one of the above three roles, and which role is does take on is decided dynamically by each P2P application. In addition, two types of P2P communication modes can be considered here: one in which the Producer Role autonomously sends data to the Consumer Role, and the other in which the Producer Role sends out data in response to a request from the Consumer Role.

1) Proactive communication mode: Data is issued autonomously (no request-for-response is made to the sending party). In a P2P network, this corresponds, for example, to a P2P node advertising the information that it holds. The sequence here consists only of the advertising message.
2) Reactive communication mode: Other parties are requested to respond and the requesting party is notified about the data in question based on that request. In a P2P distributed search application, this corresponds to a P2P node broadcasting a search request and applicable nodes returning a response. The sequence in this case consists of the request message and response message.

Basic communication types can also be defined here. These are unicast communication, broadcast communication, and multicast communication, the last of which achieves more efficient group communications. Multicast communication in a P2P network targets a subgroup of P2P nodes on the network and achieves efficient communications within that group.

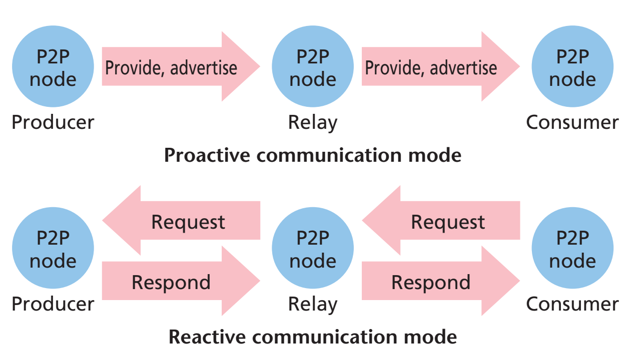

Figure 2 Roles and communication modes in the P2P communications model

3.3 P2P Routing

A P2P network is formed on the basis of neighbor relationships among P2P nodes, and P2P messages are sent and received over that network. On establishing a neighbor relationship, the P2P nodes in question notify each other of their transport addresses and node IDs, the latter of which serves as communication identifiers on the P2P network. Each node generates a mapping table for address resolution. In this way, by having each node possess a mapping table listing the transport-network addresses and node IDs of neighboring nodes and by performing address resolution between neighboring nodes, communications can be performed based on node IDs independent of any specific transport network.

Figure 3 shows the mechanism for P2P routing. To begin with, the sending node broadcasts a message searching for the receiving node (1). Next, the receiving node in question receives that message and returns a response by unicast (2). Finally, on the basis of that path information, communications commence by source routing using node IDs (3). Each P2P node in this scenario possesses a mapping table listing the node IDs and transport addresses of neighboring nodes. This path information is specified in terms of a node-ID sequence, and source routing based on node IDs is achieved by resolving node IDs and transport addresses between neighboring nodes. The P2P routing mechanism described above enables P2P communications on various transport networks.

3.4 Protocol

Based on the P2P architecture study described above, we proceeded to design protocol. **Figure 4** shows how the protocol stack takes on a 2-layer configuration. First, the P2P core protocol performs P2P routing on a variety of lower transport networks to achieve communications based on the P2P communications model. Second, the P2P system protocol group, which is situated on P2P core protocol, consists of protocols defined by the various functions required by P2P communications. Each of these protocols has functions for constructing neighboring relationships between P2P nodes, for constructing delivery trees for P2P multicasting. To run P2P applications on this platform,

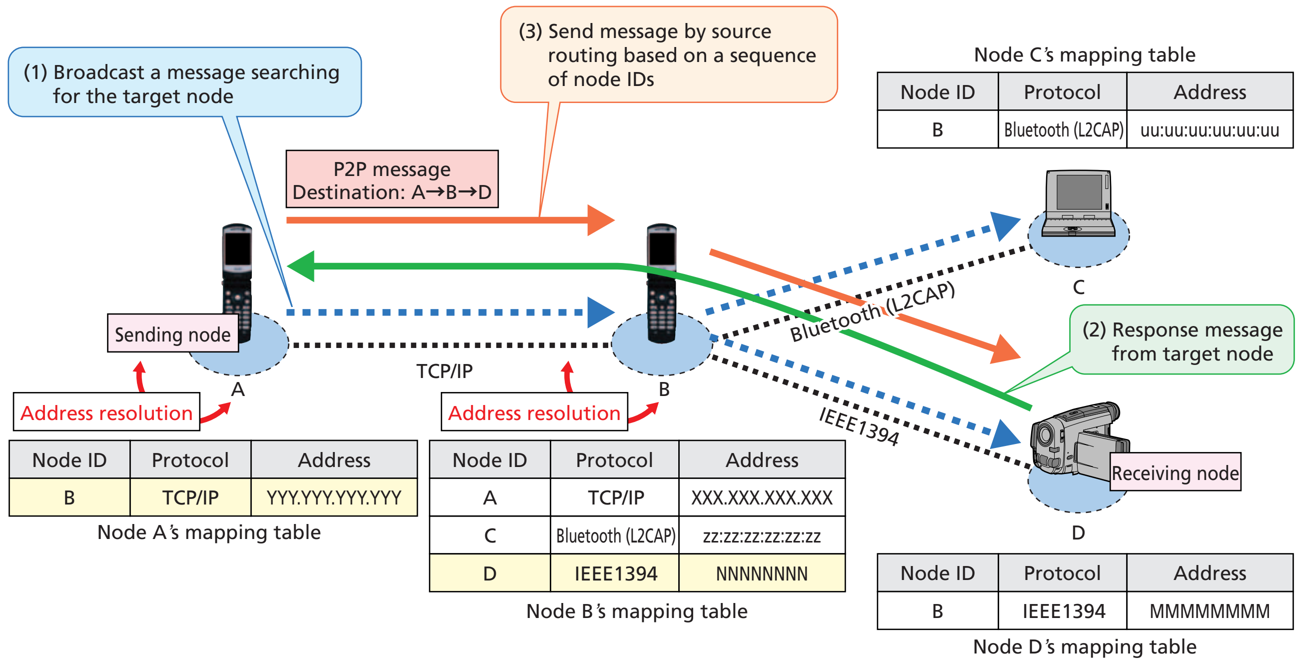

Figure 3 Source routing based on node IDs

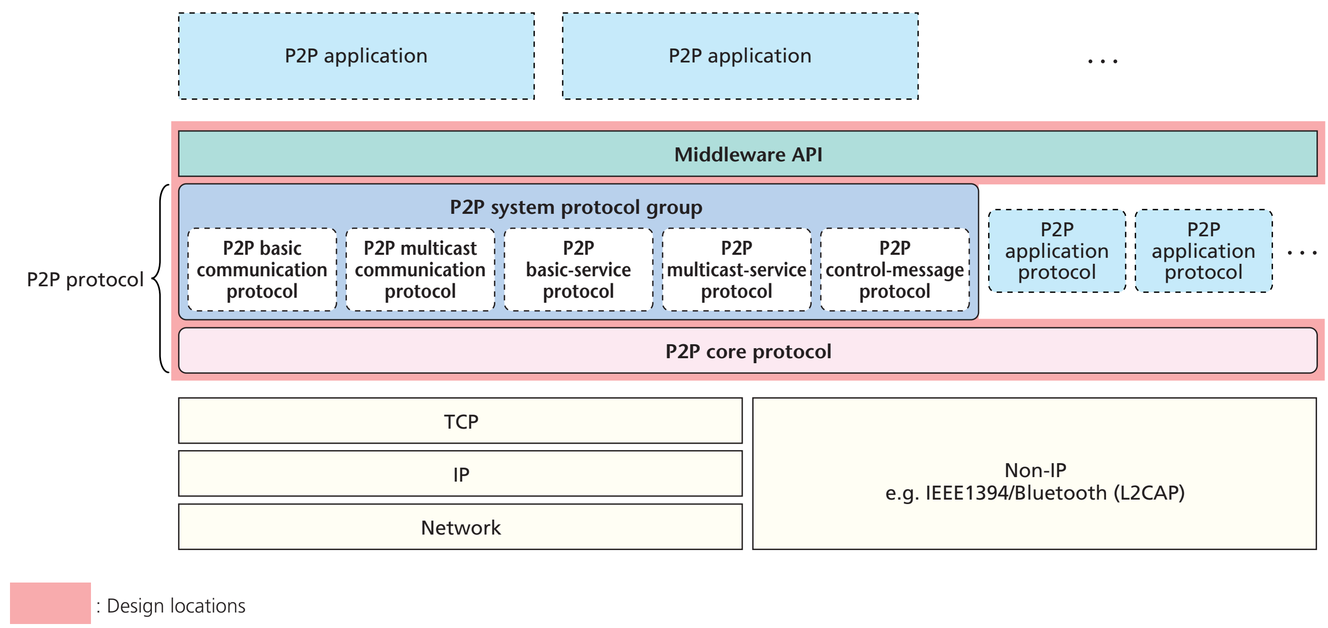

Figure 4 P2P protocol stack

P2P-application-dependent protocol must be defined on the P2P core protocol and the P2P applications must be implemented using middleware API.

3.5 Prototype Implementation

We implemented software for a universal P2P networking platform based on the proposed P2P architecture and protocol. The transport network here corresponds to Transmission Control Protocol / Internet Protocol (TCP/IP) and Logical Link Control and Adaptation layer Protocol (L2CAP)[*5]. The P2P networking platform software provides standard middleware API for P2P communications enabling application developers to implement P2P applications in a relatively easy manner.

4. P2P Applications

Various types of P2P applications are being developed on this P2P networking platform with the aim of providing new

*5 L2CAP is short-range wireless data-communication technology that serves as a Bluetooth upper layer.

P2P services for mobile terminals. The following describes two major P2P applications of this kind.

4.1 Information Appliance Application

The home network of today exists in an environment having a mixture of various communication formats (e.g., Ethernet, Institute of Electrical and Electronics Engineers (IEEE) 1394, Bluetooth, etc.). But in reality, the communication is possible only within specific closed networks even in the same household. To enable all information appliances in a home to communicate with each other even in the case of various communication environments as in a home network, we are researching and developing the seamless connection between information appliances on the application layer by P2P networking. Here, we connect information appliances using a P2P network, and apply P2P technology to the home network, and as a result, the centralized control on a home server or similar becomes unnecessary. This is advantageous since home servers require complicated settings to perform centralized control of device states, and not particularly tolerant to faults. In contrast, interconnecting information appliances by P2P networking enables each appliance to control its own state autonomously thereby improving fault tolerance.

The information appliance application shown in **Figure 5** uses a P2P network to connect information appliances in a home with an outside mobile terminal (i-mode terminal) via a home gateway. This home gateway connects the home network (IEEE1394) to the Internet and has a proxy function with respect to the information appliances in the home. The control of information appliances is achieved through use of the Audio Video/Control (AV/C) Command Set established by the IEEE1394 Trade Association. The Command Set is a standard control protocol targeting IEEE1394-compatible information appliances such as televisions and digital BS tuners. In implementing this application, a scheme is adopted to transfer AV/C Command Set messages and control information appliances via the P2P network.

This application connects an outside mobile terminal with a home gateway node via a P2P network. Here, the mobile terminal sends the broadcast message to the information appliances in the house to search which are available. A information appliance that receives that message then returns a state-notification message to the mobile terminal. The information appliances discovered can now be manipulated from the mobile terminal. If the video and tuner devices were to be discovered, for example, the user could schedule a video recording and even play back

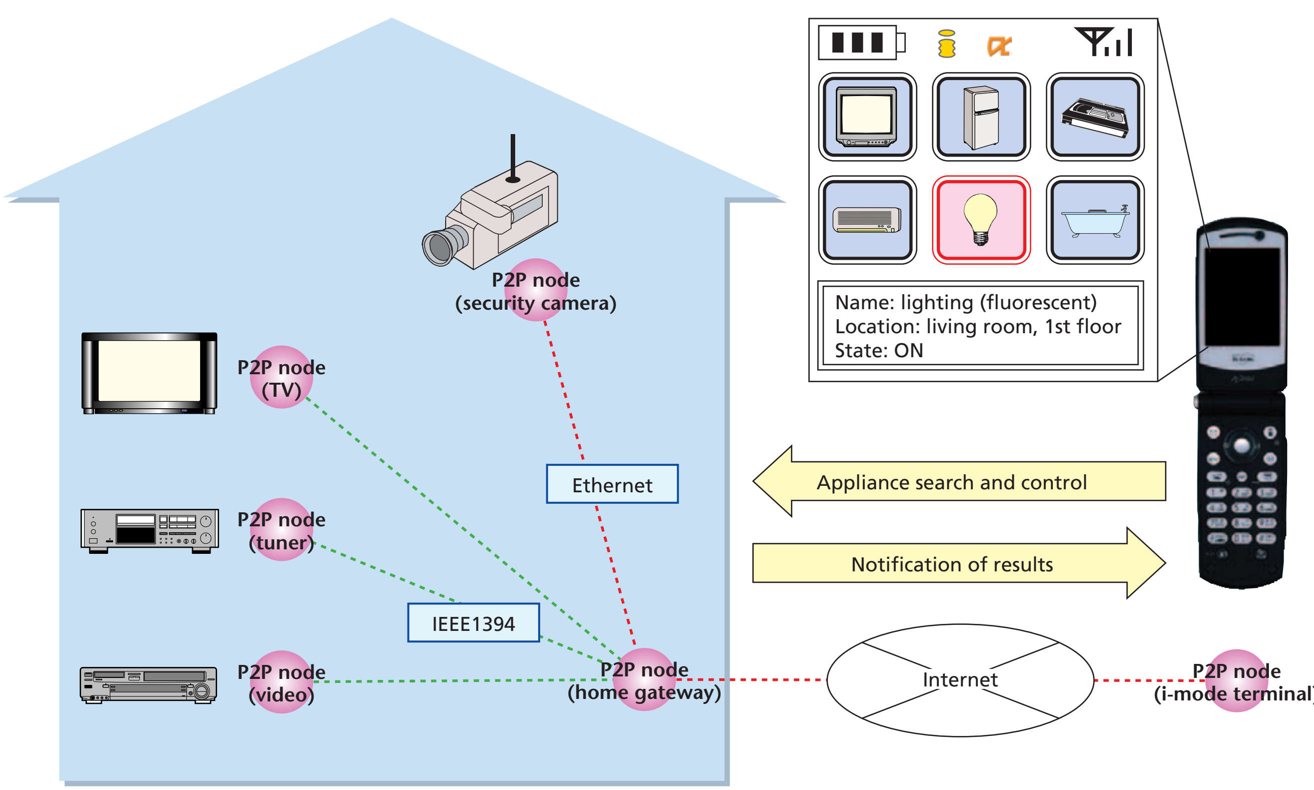

Figure 5 Information appliance application

video. Similarly, if the security camera in the house were to be discovered, the user could view the picture inside the camera. It would also be possible for an outside mobile terminal to be notified when there are any changes in the status of a information appliance within the home. For example, the mobile terminal could be notified when a visitor rings the doorbell of the house.

There are also plans to study P2P streaming applications that could stream video to a mobile terminal from a information appliance (such as a video player or camera) in a home.

4.2 Multimedia-Content Searching for Mobile Terminals

As the use of multimedia content by mobile terminals continues to spread, we can expect a growing need for services that allow users to search for and exchange photos and other content stored in their mobile terminals. With this in mind, we have developed a multimedia-content search system for mobile terminals that runs on the proposed P2P networking platform (**Figure 6**). The P2P network consists of various kinds of terminals including personal computers and mobile terminals, and users can search for and exchange multimedia content stored in these terminals. On initiating a search from a user's mobile terminal, a search-request message will be transferred between terminals on the P2P network. Any terminal that receives that message performs a self-search and returns content that matches the specified search conditions as a search result.

In typical content searching, a search is carried out based on the relevancy between keywords and text that describes content input by the user. This, however, can sometimes be difficult when searching for multimedia content such as movies and music. For this reason, we use metadata for searching in this application. Metadata consists of data that describes content attributes (content type, title, summary, etc.). The use of metadata enables the searching for multimedia content, and furthermore, the accurate description of content by metadata enables high-accuracy searches that reflect user intent. To implement such metadata searching, we first defined metadata on HyperText Markup Language (HTML) content, Java content, music content, and picture content for mobile terminals. The metadata format that we used here was Resource Description Framework (RDF), the standard metadata description format for the Semantic Web. Metadata based on RDF can do more than simply describing content attributes, but it also enables advanced processing by describing relationships between attributes. For searching term such as "a photo of Mr. Ishikawa of DoCoMo," for example, the system understands the relevancy of "Mr. Ishikawa" belongs to "DoCoMo" and execute the

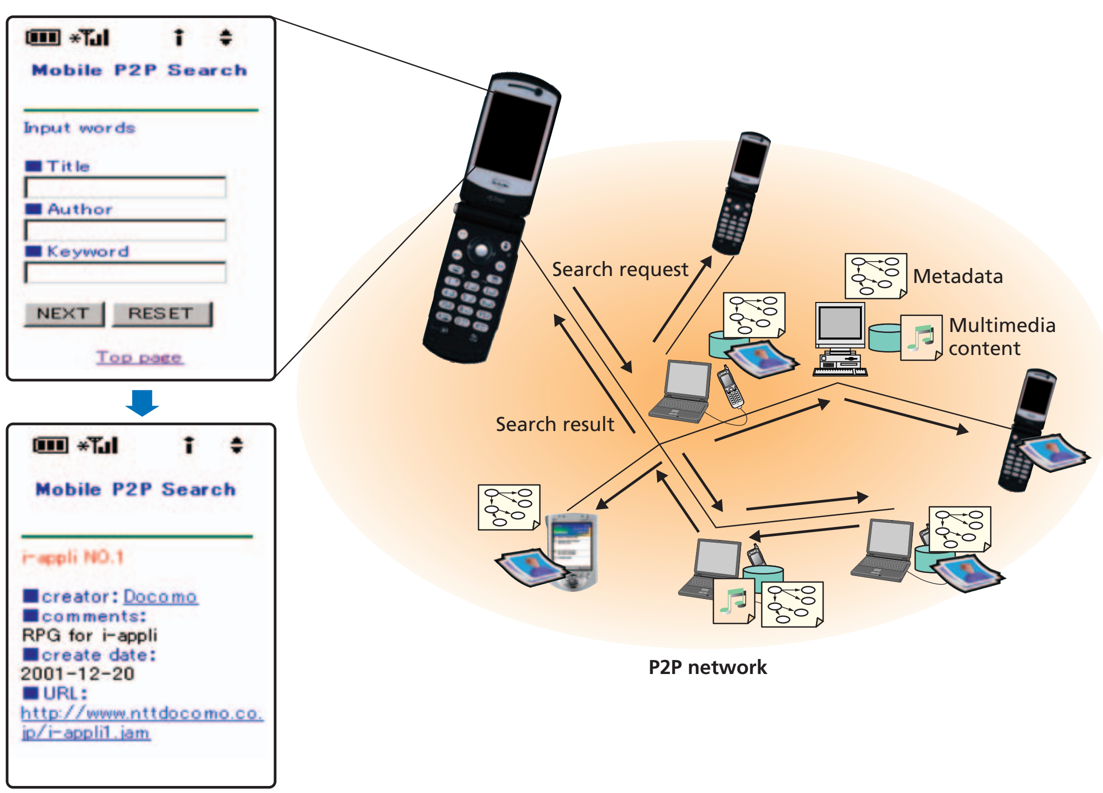

Figure 6 Multimedia-content search system using metadata

search accordingly.

Performing a search from a mobile terminal requires minimal input and interaction for a target content. To meet this requirement, we are studying the application of fuzzy logic as a scheme for returning appropriate results that reflect user intent even if the user specified vague search terms. This approach can provide the user with optimal content even for vague conditions like content size of "about 10KB" and price of "about 100 yen." In addition, we are exploring other technical possibilities from many angles including metadata search languages and database technology and an efficient search system on a P2P network for metadata searching. Our aim is to achieve a search system that integrates such technologies to provide an comfortable search environment for users.

5. Conclusion

We introduced the research and development of P2P networking platform to realize P2P services for mobile terminals.

We aim to establish base technologies of P2P network construction supporting such as the Internet, mobile networks, sensor networks, IEEE1394, and Bluetooth.

We are also studying P2P applications for mobile terminals such as information appliance control and content searching as introduced in this article as well as P2P instant messaging and sensor-network applications. We plan to continue this research with the aim of proposing and implementing attractive P2P applications for users.

References

[1] Gnutella, http://www.gnutella.com

Abbreviations

API: Application Programming Interface
AV/C: Audio Video/Control
CPU: Central Processing Unit
HTML: HyperText Markup Language
IEEE: Institute of Electrical and Electronics Engineers
IP: Internet Protocol
IrDA: Infrared Data Association
L2CAP: Logical Link Control and Adaptation layer Protocol
P2P: Peer to Peer
PDA: Personal Digital Assistant
PKI : Public Key Infrastructure
RDF: Resource Description Framework
RFID : Radio Frequency IDentification
TCP: Transmission Control Protocol
UWB: Ultra Wide Band