(1) IP² Network Architecture Overview

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Network Laboratories has started research on next-generation mobile communication networks for "Beyond IMT-2000" (3rd Generation (3G) and subsequent generations) under the name of IP-based IMT network Platform (IP²). This article presents the IP² network capabilities and the requirements for services provided by IP², and explains the technical characteristics of the IP² network architecture.

1. Introduction

As exemplified by i-mode, mobile Internet access services blossomed in the 2nd Generation (2G) mobile communication networks. To add to this, NTT DoCoMo launched a 3rd Generation (3G) mobile communication service based on the international standard, International Mobile Telecommunications-2000 (IMT-2000) in 2001 that can offer faster mobile Internet access services at speeds of up to 384kbit/s.

In the future, penetration of mobile Internet access services is likely to accelerate further in "Beyond IMT-2000" networks, and the traffic in mobile communication networks is expected to shift radically from voice to multimedia. Accordingly, "Beyond IMT-2000" networks require a network based on the Internet Protocol (IP) that can process efficiently not only multimedia traffic but also voice traffic. However, in order for mobile Internet access services to succeed in the near future, it is necessary to offer an environment in which attractive services can be used by anyone from any location. To achieve this, mobile communication networks must be able to promptly support application services provided by third parties such as service providers, and should incorporate service middleware to allow the creation of added value for such services.

Against such a backdrop, this article presents the requirements for IP² with reference to our Beyond IMT-2000 research, and explains the technical characteristics of the IP² network architecture that is designed to fulfill these requirements.

2. Main Requirements for IP²

2.1 Massive Multimedia Traffic Accommodation

The Internet Penetration in recent years has been astonishing. New business styles are gaining ground with the use of websites and e-mail in corporate activities, and we can infer that penetration of the Internet will continue to accelerate. Websites, which used to be based primarily on text and still pictures, now feature video, and an increasing number of applications are using video-on-demand. Such IP multimedia traffic is expected to increase to the same level as voice traffic within a few years, and is likely to account for most of the traffic in the near future. Moreover, it is quite conceivable that voice traffic will be handled as IP multimedia traffic at a level of quality comparable to current voice traffic. These trends also apply to mobile communications – not mentioning i-mode as an example. Against such a backdrop, IP² needs to handle massive volumes of IP multimedia traffic in an efficient and affordable manner.

2.2 Advanced Mobility Management

Signaling traffic required for mobility management accounts for a large proportion of the signaling traffic in mobile communication networks. In the ubiquitous networking era, one of the crucial challenges is to improve the efficiency of mobility management in the next-generation mobile communication networks, in which the scope of mobility management includes not only people, but also includes diverse entities such as pets and commodities.

Mobility management for mobile networks up to 3G was designed to optimize for objects moving at high speed such as automobiles, and does not adapt the mobility management to the terminal's mobility characteristics. However, signaling traffic required for mobility management is expected to be reduced by the diversification (differentiation) of mobility management systems between such entities as vending machines that move only infrequently, trains that move according to a schedule, people whose range of movement is limited to certain areas, and so forth. Such advanced mobility management systems are expected to cut mobility management costs.

Further, with consideration to the diversification of mobile terminals (managed objects) and communication styles in the future, it will be necessary not only to reduce signaling traffic, but also to manage mobility in various ways for the purpose of creating new services. Important factors to be considered include, for example, mobility management that coordinates with ad hoc networks and considers grouping in ad hoc networks.

In summary, in order to handle the increased users diversity, IP^2 is required to offer efficient and flexible diversified mobility management.

2.3 Multiple Wireless Access System Support

In recent years, a wide range of wireless access systems has emerged. To provide users with a seamless environment, it is essential that these diverse wireless access systems can be accommodated smoothly into mobile communication networks. In addition to Wideband Code Division Multiple Access (W-CDMA), a wide range of access systems are also expected to emerge in the future, including High Speed Downlink Packet Access (HSDPA), Wireless Local Area Networks (WLAN), Bluetooth*, and 4th Generation (4G) wireless access. It is hoped that there will be a framework to promptly accommodate diverse wireless access systems with minimal impact on the network.

Wireless access based on IMT-2000 supports a maximum speed of 2Mbit/s, and 4G wireless access aims to support at least 20Mbit/s. Also, in terms of wireless control, it is hoped that various Quality of Service (QoS) controls will be provided, and that uplink and downlink transmission speeds can be controlled independently of each other in a flexible manner. For example, a high-speed downlink will be required for a mobile terminal accessing the WWW, whereas a high-speed uplink will be required for a mobile terminal acting as a server.

In this manner, IP^2 is required to accommodate flexibly diverse wireless access systems, and to support uniform system control of diverse wireless access systems.

2.4 Seamless Services

As stated in 2.3, mobile communication networks must support diverse wireless access systems, and allow mobility between these diverse access systems without disruption to communications. We call this ability "network seamless", for the access system to be changed appropriately without disruption to communications as a user moves around. An example of network seamless is switching the access system from Freedom Of Mobile multimedia Access (FOMA) to wireless LAN without the communications being cut off.

Further, as stated in 2.2, in the ubiquitous networking era, users' terminals also diversify. Thus the ability to switch services from an active terminal to another terminal according to the user's environment or other factors will be demanded. We call this ability "device seamless", for a service to be switched to another user terminal when the active terminal becomes no longer suitable for the service following user movement. An example of device seamless is where a user has to leave the office in the middle of a teleconference using a fixed terminal, and the service is sustained by switching the service to a mobile terminal.

Likewise, service contents may be adapted to the environment according to changes in the terminal or changes in the user's state. We call this "contents seamless." Suppose that a user participating in a teleconference in the office needs to leave the office and catch a bus. Out of consideration to the other passengers on the bus, they may continue to use the service by having the teleconference contents converted into voice or text.

In this manner, IP^2 needs to offer seamless services that minimize seams in the environment where services are provided.

2.5 Application Service Support

In line with the penetration of mobile Internet access services, as represented by i-mode, interaction between mobile communication network operators and service providers will become more critical. Currently, many service providers merely use mobile communication networks as access networks for providing services to mobile users. However, in order for mobile Internet access services to further evolve in the future, mobile communication networks should furnish essential service components so that service providers can promptly and easily develop services. The active provision of information unique to mobile communication networks to service providers also makes it possible to add unique properties of IP^2 to the Internet services, and thus add value to the services. For example, service providers can concentrate just on the creation of content if mobile communication networks manage the subscriber information securely and enhance the billing functions. In addition, one can expect the creation of new services based on the provision of location information or other network information.

The conventional approach in the Internet is based on a

* Bluetooth: Bluetooth™ is a trademark owned by Bluetooth SIG, Inc. and licensed to NTT DoCoMo.

model in which the carrier offers nothing but forwarding capability. In order for truly rich contents to flourish, it is important to ensure collaboration between the contents and the enhanced service support functions.

In this manner, IP² needs to offer a support environment that will enhance the service provider support functions and allow the creation of high value-added services.

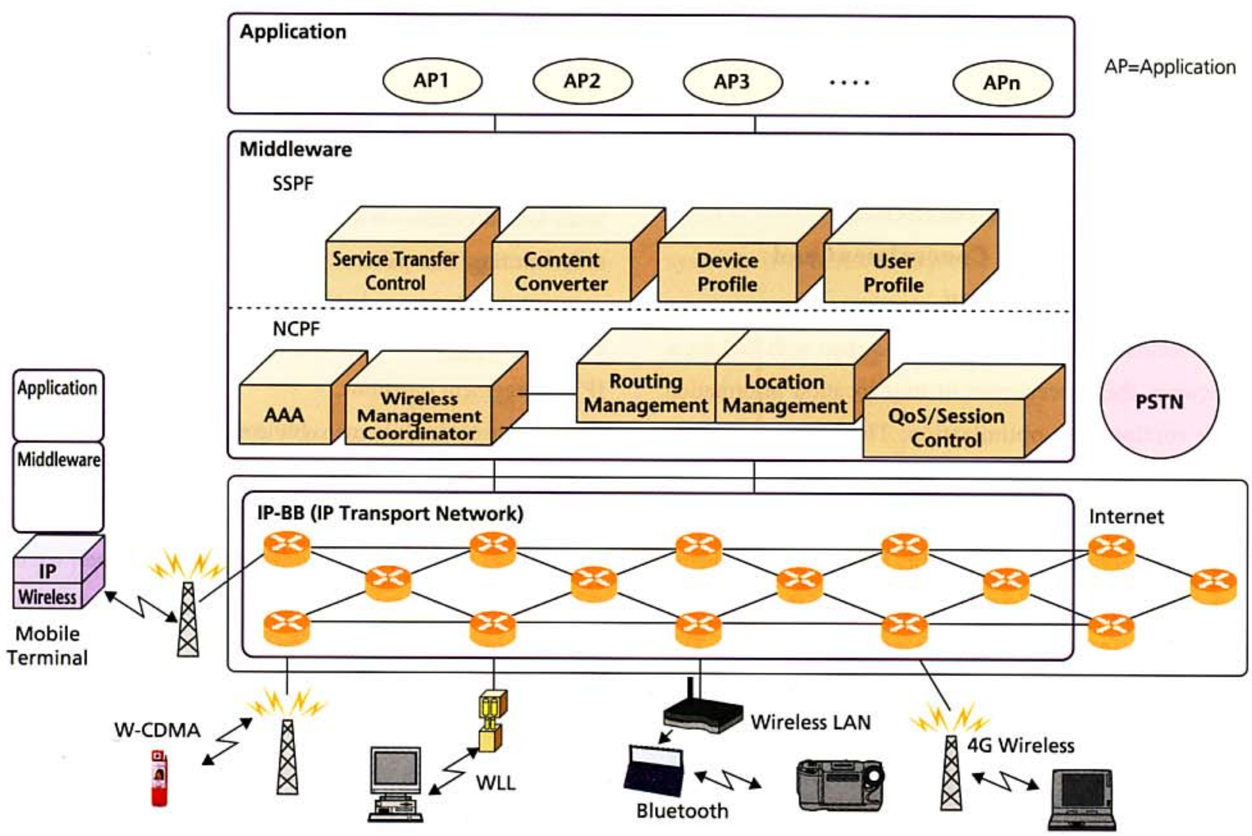
3. Architecture Overview

Figure 1 shows the logical functions arrangement of the IP² network architecture for satisfying the five main requirements mentioned in the previous chapter. The IP² network architecture consists of an IP transport network dedicated to IP packet forwarding and middleware in charge of advanced control.

We believe that the trend towards "IP over everything", that is, to carry IP packets over diverse transport technologies (e.g. Asynchronous Transfer Mode (ATM), optical routers etc.) will further evolve in the future, and that IP² transport networks should concentrate on IP packet forwarding since, as we mentioned before (refer to 2.1), IP multimedia traffic is set to increase dramatically.

Nevertheless, it is believed that the next generation operator networks must also have support functions to facilitate the creation of new services, control functions for efficient mobility control, and control functions to provide high-quality communications (refer to 2.2 and 2.4). Moreover, we believe that such control functions should evolve independently of the packet forwarding functions. Accordingly, we have proposed a model for the IP² system that separates the functions logically into transport network and middleware.

The middleware consists of two platforms: the Network Control PlatForm (NCPF) and the Service Support PlatForm (SSPF). Assuming that the transport control functions and the support functions associated with advanced services will evolve independently of each other in the future, they should be given more freedom through separation.



AAA: Authentication Authorization and Accounting
IP: Internet Protocol
IP-BB: IP BackBone
LAN: Local Area Network
NCPF: Network Control PlatForm
PSTN: Public Switched Telephone Network
QoS: Quality of Service
SSPF: Service Support PlatForm
W-CDMA: Wideband Code Division Multiple Access
WLL: Wireless Local Loop

Figure 1 IP² Network Architecture

The NCPF consists of functions required for basic mobile communications management such as mobility management, session management, QoS management, authentication/admission, and common radio resources management.

In addition, in order to maintain services in a seamless manner across diverse access systems, it is necessary to have a common mobility management function independent of the wireless systems. Accordingly, we are studying an architecture that can absorb the differences between individual access systems, and execute mobility control collectively in IP^2 for diverse access systems including 3G wireless access (W-CDMA, HSDPA), wireless LAN, Bluetooth, Wireless Local Loop (WLL) and 4G wireless access (refer to 2.3).

The SSPF consists of service functions such as content conversion and service distribution. The SSPF also has the function to provide services such as location service support that are unique to mobile communications. The aforementioned seamless services can be provided to users by using these functional elements in a collective manner (refer to 2.4).

Furthermore, these functions operate in coordination with the NCPF to generate added value to application services. Such capabilities can only be realized by incorporating intelligent functions in the network (refer to 2.5).

4. Technical Characteristics

4.1 Location Information Concealment and Optimal Path Forwarding

The first technical characteristic is concerned with striking a balance between the concealment of user location information and the the routing path optimization. This characteristic is explained below with reference to Mobile IP as an example.

Mobile IP is a mobility management scheme proposed by the Internet Engineering Task Force (IETF). When this scheme is used, problems arise with regard to concealing the user location information and optimizing the routing path [1]. The Mobile IP scheme enables communication by informing the destination the user's physical location information: that is, the IP address. In other words, if a malicious third party gets hold of this IP address, it will be a real threat to the operator and the user. This is a major drawback of the Internet, which proposes an open environment. A network that conceals the user's location information must be built out of consideration to threats from malicious third parties, as exemplified by spam mail. The concealment of the user's location information, which is also realized in 3G, is believed to constitute a vital element for the next-generation mobile communication networks as well.

Another issue is route optimization: there are many cases in which the routing paths are not optimized under Mobile IP. In the near future, anything and everything, including, but not limited to, humans and transport, might become mobile users. If this happens, massive volumes of traffic will be generated, and as a matter of course, it will be necessary to use optimal paths (as opposed to redundant paths). Mobile IP executes mobility management based on a Home Agent (HA). It is believed that efficient forwarding via optimal paths and effective mobility management can be achieved in IP^2 by implementing mobility management in the network as a whole. The method of achieving this will be described in the later sections of this special article [2].

4.2 Separation of Network Control Functions from Transport Network

The second technical characteristic relates to the separation of network control functions from the transport network. In this separation model, in order to achieve highly efficient, high performance packet forwarding, the NCPF is designed to execute intelligent functions such as diverse network control analysis and control state management, while leaving the transport network to concentrate on nothing but the execution of basic packet forwarding. The merit of this separation model is that existing services can be provided by IP^2 by just accommodating the existing transport network and controlling it collectively by the IP^2 management functions.

The current mobile management method in Mobile IP heavily depends on the IP version. This means that the transport network's mobility management functions need to be changed in the event of an upgrade of the IP version. However, we believe that mobility management should basically be independent of the transport network or the forwarding scheme, and thus that mobility management technologies and forwarding technologies should be evolved independently. Another merit of this independence is that in cases of multiple transport networks, the transport networks can be controlled collectively if mobility management is unified. Further, we think that the same approach is also applicable to network control functions other than mobility management (e.g. session control, QoS management).

The accommodation of multiple transport networks is also advantageous in that, for example, the transport network can be chosen and applied logically according to the communication quality requested. Moreover, it makes it possible to reuse existing transport network facilities, such as Asynchronous Transfer Mode (ATM) networks, in IP^2 transport networks. It also makes it easy to renew and make functional extensions to the transport networks in the event of shifting from IPv4 to IPv6. For these reasons, we advocate the separation of the network control functions and the transport network functions in IP^2, and view this separation as one of IP^2's key technical characteristics.

4.3 Mobility Management Based on Location and Routing Management

The third technical characteristic is that mobility management is realized by a combination of location management and routing management [3].

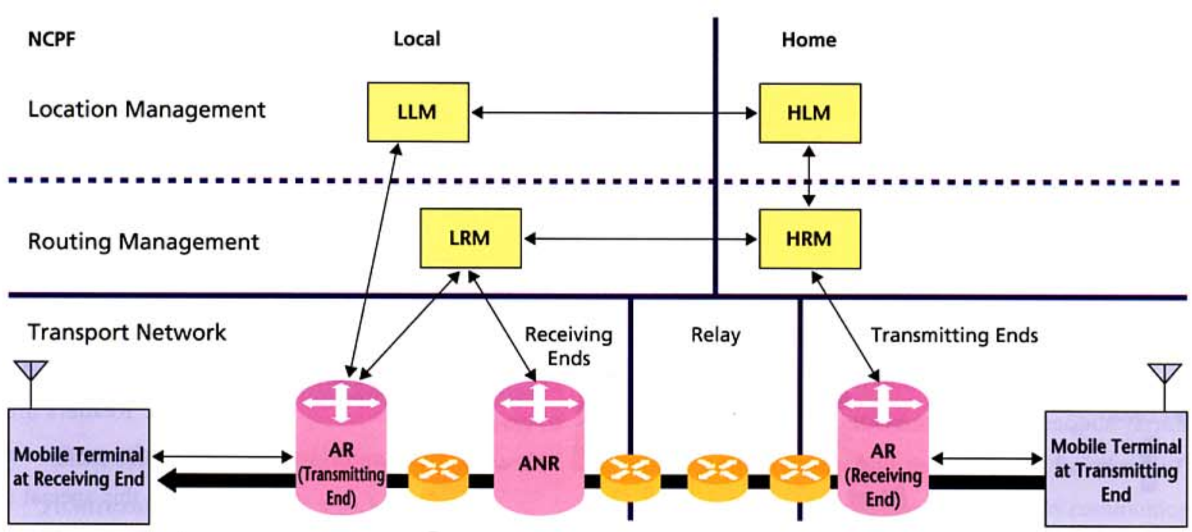
Location management keeps track of the mobile terminal's location in standby mode within the network, and activates the mobile terminal to an active communication state by alerting the terminal with the use of this location information. In contrast, routing management keeps track of the routing address of the mobile terminal when it is in the active communication mode, and sets up the combination of the routing address and the terminal identification address in the appropriate routers along the routing path in the transport network. Mobile IP is inadequate in this respect because it only executes routing management with respect to a terminal in active communication mode; that is, it doesn't perform location management.

While routing management is an essential function in mobile communications, location management is also a crucial function for IP^2, not only because it suppresses the power consumption of a terminal in standby mode, but also because it consequently limits the signal processing volume required for mobility management.

Figure 2 shows the IP^2 mobility management architecture. Location management and routing management should both be defined at two levels: local management (targeting the vicinity of the area visited by the mobile terminal at the receiving end), and global management (including the home network to which the user subscribes and the mobile terminal at the transmitting end). By defining these two levels, updates to location information and routing information can be limited to local updates in many cases, making it possible to reduce both the time and the signaling traffic consumed for updates. A comprehensive outline of mobility management research at the Network Laboratories is presented in later sections in this special article [4].

4.4 Common Radio Resources Management Interface

The fourth technical characteristic is that functions are provided to promptly accommodate a wide range of wireless access systems. It is believed that this can be realized by setting up a



ANR: ANchor Router
AR: Access Router
HLM: Home Location Management
HRM: Home Routing Management
LLM: Local Location Management
LRM: Local Routing Management
NCPF: Network Control PlatForm

Figure 2 Mobility Management Architecture

common interface independent of the wireless access systems between the Radio Resource Manager (RRM) and the network control entity (**Figure 3**).

This common interface enables the introduction of access technologies regardless of when the access system is realized in the future, and conversely, enables the accommodation of existing wireless access systems in IP^2 on a plug-in basis.

IP^2 divides RRM into a function unique to the wireless access system (individual RRM) and a function shared by the systems (common RRM). The former is directly derived from the radio resources management function mounted in each wireless access system. For example, in W-CDMA, RRM is located in the Radio Network Controller (RNC) and the mobile terminal. The latter is a functional entity newly defined in the network control layer in IP^2, which abstracts radio resources information collected from each wireless access system and manages it as common information independently of the wireless access system. Each network control entity can provide network control considering of the state of the radio resources (i.e., seamless mobility control) by making reference to the common radio resources information via the common interface with common RRM, without being aware of the differences in wireless access systems.

4.5 SSPF for Seamless and Ubiquitous Services

The fifth technical characteristic is the differentiation of the use of diverse terminals according to the user's situation and the provision of seamless services for smooth reception regardless of time and place through the SSPF, which consists of support function groups unique to mobile communications, such as location service. These function groups are required to operate in an efficient manner in coordination with the NCPF to add value to application services.

We are also working on how to realize ubiquitous services that are a step ahead of the times by improving and enhancing the functions of the SSPF, such as supporting users in real life in an environment in which extremely small terminals like wireless tags are installed all over the place.

The current Internet architecture does not take such an approach. In contrast, we believe that enhancements to the service support functions, including the combining and processing of various management information held by networks, will help create services. The methods of achieving this in concrete terms will be explained in the later sections of this special article [5].

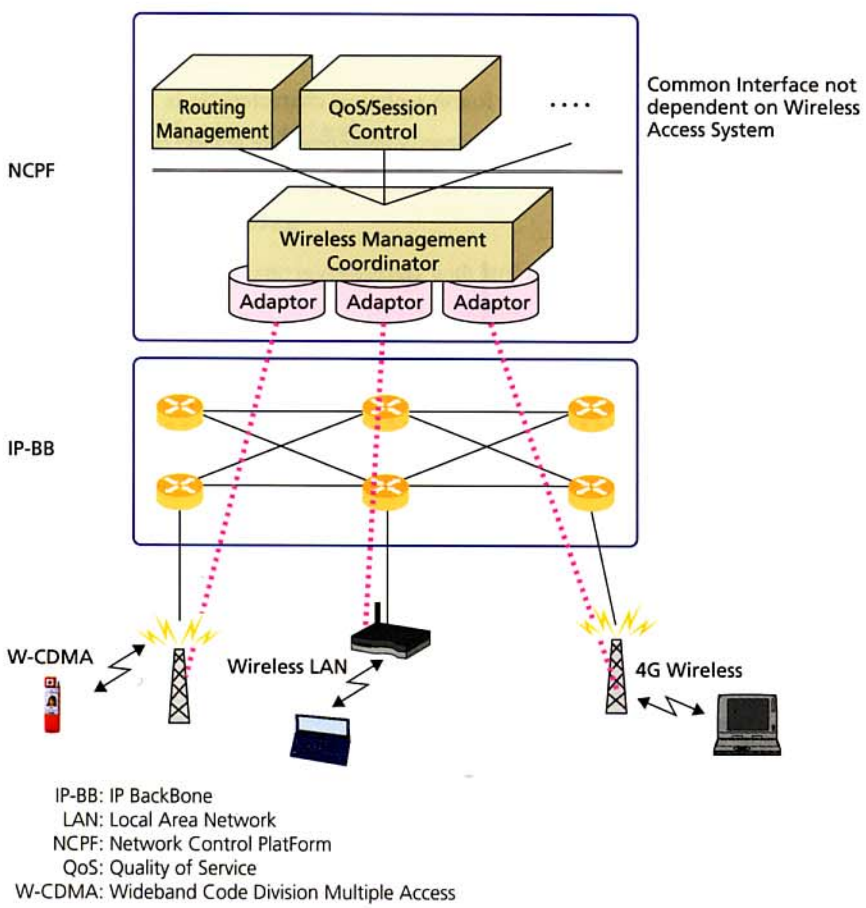


Figure 3 Common Radio Resources Management Interface

5. Conclusion

This article explained the requirements for IP^2, which is subject of the Network Laboratories' research aimed at next-generation mobile networks, the architecture overview, and the technical characteristics. Readers are encouraged to refer to the subsequent sections in this special article for further information on the technical elements. As for future studies on architecture, we intend to conduct quantitative evaluations through experiments aimed at the integration/systemization of elemental technologies, seek research partners on an international scale, and work on international standardization.

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Glossary

AAA: Authentication Authorization and Accounting
ANR: ANchor Router
AR: Access Router
ATM: Asynchronous Transfer Mode
FOMA: Freedom Of Mobile multimedia Access
HA: Home Agent
HLM: Home Location Management
HRM: Home Routing Management
HSDPA: High Speed Downlink Packet Access
IETF: Internet Engineering Task Force
IMT-2000: International Mobile Telecommunications-2000
IP: Internet Protocol
IP^2: IP-based IMT network Platform
LAN: Local Area Network
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