Wireless Internet over Heterogeneous Wireless Networks

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***Abstract* - One of the two keywords for the next generation wireless communications is seamless. Being involved in the essential e-Japan Plan promoted by the Japanese Government, MIRAI (Multimedia Integrated network by Radio Access Innovation) project is responsible for the research and development on the seamless integration of various wireless access systems for the practical use by the year 2005. A heterogeneous network architecture including a common tool, a common platform, and a common access is proposed in this paper. Concretely, software-defined-radio technologies are used to develop a multi-service user terminal to be used for access to different wireless networks. The common platform for various wireless networks is based on a wireless supporting IPv6 network. A basic access network, separated from other wireless access networks, is used as a means for wireless system discovery, signaling and paging. A proof-concept experimental demonstration system will be available in March 2002.**

I. INTRODUCTION

As the second generation mobile communication services have been explosively expanded worldwide since the late 1980s, a number of wireless communication systems such as IEEE 802.11a/b wireless LAN, Bluetooth, IMT-2000, fixed wireless access (FWA) and so on are getting into our life providing us more and more convenient ways to access to the Internet as well as to communicate with others. Looking at the spectrum for frequencies from several tens of megahertz to several tens of gigahertz, we find there are tens of (digital) communication systems. These ubiquitous systems are independently designed, implemented and operated (see Table 1) to meet different requirements on mobility, data rate, service type, etc. Some, even if not all of these systems may simultaneously provide services at a specific geographic location and thus a heterogeneous wireless environment is provided for users in the overlaid service area. Seamless integration of heterogeneous wireless systems will bring a revolution to wireless industrial world involving vendors, service/ application/context providers, policy makers, and users.

As the service of IMT-2000 begins in Japan, the researchers in both academia and industry are expressing a growing interest in the new generation wireless communication networks. Japanese government issued the so called e-Japan Strategy in early 2001, including an explicit target for wireless communications: to realize an IPv6-based high-speed wireless Internet access environment and a seamless mobile communication service. The essential e-Japan Plan to achieve this target requires to develop the fourth generation mobile communication system that will support a data rate as high as 100Mbps in a vehicular environment by the year 2010 and the key technologies on seamless integration of various wireless access systems for practical use in 2005. The MIRAI (Japanese for *futur*e, and an acronym of 'Multimedia Integrated network by Radio Access Innovation') at the Communications Research Laboratory is one of the Japanese national projects involved in the e-Japan Plan for seamless integration of heterogeneous wireless systems.

Table 1 Various wireless access systems especially in Japan.

Frequency \ Mobility	Static	Pedestrian	Vehicle
<1GHz			2G cellular 2-way pager, MCA
1 to 3GHz	WLAN(802.11b), Bluetooth, WPAN, VSAT	PHS, DECT	2G/3G cellular, LEO
3 to 20GHz	WLAN (802.11a). BRAN, HiSWANa	BRAN, HiSWANa	4G cellular, ITS
Up to 60GHz	FWA, mm-wave WLAN, HAPS, HiSWANb	HAPS, HiSWANb	ITS, HAPS

BRAN: Broadband Radio Access Network
DECT: Digital Enhanced Cordless Telecommunications
HAPS: High Altitude Platform Station
HiSWAN: High-Speed Wireless Access Network
ITS: Intelligent Transportation System
LEO: Low Earth Orbit
MCA: Multi Channel Access
mm-wave: millimeter wave
PHS: Personal Handy-phone System
WLAN: Wireless LAN
WPAN: Wireless Personal Area Network
VSAT: Very Small Aperture Terminal

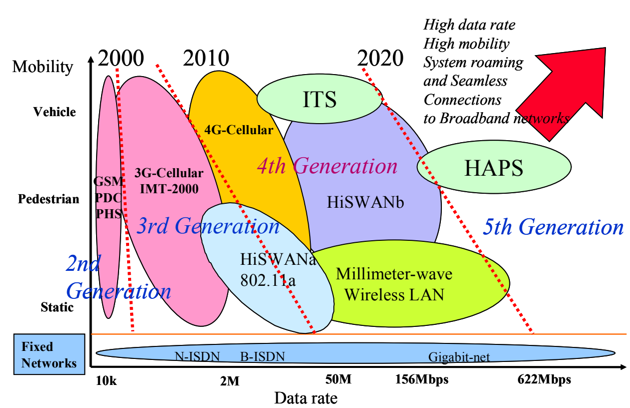

Fig. 1 A definition of generation for wireless networks.

Although the terms of "broadband" and "seamless" are raised as two keywords for the next generation wireless networks, it is still unclear what the next generation wireless network is. Figure 1 shows our understanding on the definition of the generations. It has no doubt on the definition of the second and third generation systems/networks. However, the fourth generation wireless networks should include not only the new generation cellular system but other new broadband wireless access systems such as ITS, HiSWAN, high-speed wireless LAN, HAPS as well. That is, the fourth generation wireless network should be a heterogeneous network that supports multiple broadband wireless access technologies and global roaming across the systems constructed by individual access technologies. Table 2 gives a definition of heterogeneous network.

Table 2 Definition of heterogeneous network

Network with / in	Same wireless access technology	Different wireless access technologies
Same administrative domain (company)	Homogeneous	Heterogeneous (Limited services Easy implementation)
Different administrative domains (companies)	Heterogeneous (Limited services Complicated implementation.)	Heterogeneous (General services Most complicated implementation)

Work on software-defined radios (SDR) has shown that wireless physical layers can be created dynamically by introducing code into programmable radios with tunable front-ends. It provides a *common tool* for users to access to a heterogeneous network supported by different wireless access technologies. On the network side, a *common platform* is required for integrating different wireless access systems into a heterogeneous network. The worldwide Internet provides such a common platform and the IPv6 technologies are potential candidates for network construction. Theoretically, with a SDR-based air-interface- reconfigurable user terminal and an all IP (v6) based heterogeneous network, a service can be delivered via the wireless access network that is the most efficient for that service.

As shown in Table 1, different wireless access systems are distributed in spectrum. It takes time to find out an available and preferable wireless access system(s) at the place that a user moves in even with a reconfigurable SDR terminal. Technical difficulty would be also considered in supporting the heterogeneous paging, vertical handoff, etc. We propose a basic access network that provides a *common access* function for all the wireless access systems being used for service delivery in a heterogeneous network to support heterogeneous paging, location update, wireless system discovery, vertical handoff, and so on. The basic access network may have a cellular configuration with a low data-rate but reliable communication channel. Each base station will have a much wider service area than other wireless access systems do.

With a goal to design a flexible and open architecture suitable for a variety of different wireless access technologies, for applications with different QoS demands and different protocols, the MIRAI project focuses on research and development of the common tool, the common platform and the common access. The corresponding solution is based on a SDR-based multi-service user terminal, an IPv6-based wireless supporting common core network, and a basic access network. This paper describes the MIRAI architecture and is organized as follows. First we introduce the concept of a heterogeneous network. Then, we present related work in the field of micro-mobility, and QoS mechanisms over the Internet. In Sec. VI we present the main concepts of our architecture. We present the detailed MIRAI architecture in Sec. V.

II. Models of Heterogeneous Network

There are several architectures using multiple different radio access networks (RANs). The basic models are illustrated in Fig. 2 by two RANs, network A and network B. The main distinction between these models is the layer on which the RAN communicates. Many derivates of these models are possible (see for example [13, 14]).

A. Tunneled network - In this model, a user has a service agreement with operators of several RANs independently. Based on some policy, the optimal network for the requested service is selected. The hybrid core tunnels the traffic across the Internet and the selected access network to the mobile host. Connectivity between networks is based on relatively high network layers of the Internet (i.e. transport or session layer), increasing service latency. This system requires no modification to existing access networks. Moreover, they all have their own infrastructure, e.g., signaling, handover, and billing. This makes it very difficult for existing network systems to cooperate efficiently.

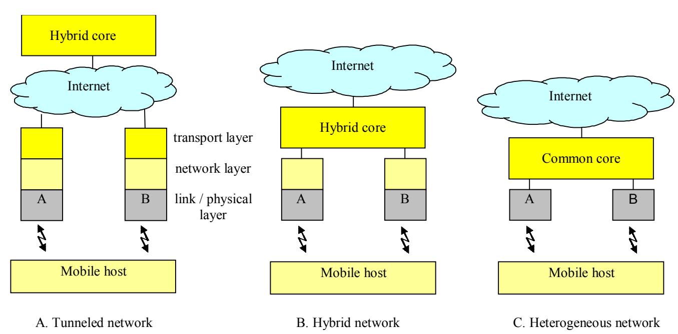

Fig. 2 Architecture models.

B. Hybrid network - In this model we have a hybrid core that interfaces directly between the RANs and the Internet. In this model the RANs implement the network layer and below. Advantages are that in the model there will be less duplicate functions, and that it is able to offer advanced services at the network or data link layer (e.g. it can provide a better handover between the RANs).

C. Heterogeneous network - In this model there is a common core network (CCN) that deals with all network functionality and operates as a single network. Different

RANs handle only those functions specifically related to a distinct radio access technology. In general the wireless access radio incorporates the physical and data link layers only. Communication between RANs belonging to the CCN is based on lower network layers (link layer or network layer). This reduces the overhead, and improves performance. A major challenge of this model is that the different RANs should converge, which requires a standardization effort and business commitment to support it.

Notice our differentiation between hybrid and heterogeneous. Often, the various kinds of architectures are all referred to as hybrid [13]. We prefer to call them *heterogeneous* to stress the fact that there can be multiple networks *simultaneousl*y, all working together. Hybrid networks describe the more traditional view of having multiple networks of which one can be chosen to use.

III. RELATED WORK

Future wireless network infrastructures will have to support a wide variety of users, applications, and access needs. High-speed access can be achieved by using small cell sizes. As base station density increases, however, so will handoff rates. Currently, related work mainly is associated with routing and handoff aspects for wireless networks. The Mobile IP protocol [8] supports mobility transparently above the IP level and it allows the nodes to change their location. Mobile IP is generally seen as a *macro mobility* solution, it is less well suited for micro mobility management, in which a mobile host moves within a sub network. A typical example of micro mobility is a handoff amongst neighbor wireless transceivers, each of which is covering only a very small geographical area. There have been quite a few proposals to support micro mobility (e.g. Cellular IP [3], HAWAII [10]). The differences among all these schemes are related to the mechanisms used to route the packets within a local (home or foreign) domain.

Related work on QoS over Internet is mainly based on Integrated Services [2] and Differentiated Services [1]. Recently, there are some initiatives that specifically relate to heterogeneous networks, but this research just started [13]. Other related research is mainly focusing on hybrid network architectures, or support for macro mobility [4][7]. Given ATM is able to support QoS, there has been strong interest in developing wireless ATM technologies (e.g. [6]).

Current work merely provides solutions to roaming mobile hosts by supporting protocols for mobility. Heterogeneous networks might be used, but more in the traditional sense of selecting one or the other. This is different from our view of heterogeneous networks, in which mobile hosts can communicate over one or more RANs simultaneously.

IV. CONCEPTS

The major challenge for the future generation wireless Internet is that the architecture will have to be very flexible and open, capable of supporting various types of networks, terminals and applications.

A. System requirements

A fundamental goal is to make the heterogeneous network transparent to the user. In addition, a goal is to design the system architecture such that it is independent of the wireless access technology. These considerations lead to the following requirements.

- Multi-service User Terminal (MUT) for access to different RANs

Having multiple wireless air-interface modules (may be implemented either by multi-mode air-interfaces or by a software-defined-radio (SDR) based reconfigurable air- interface), an MUT is capable of using one (or more) specific air-interface for the access to one (or more) available RAN.

- Wireless system discovery

The necessary condition for an MUT at a specific geographic location to use the RAN that meets the user's physical capability as well as utilization policy is to discover how many RANs are available around the place. This is essential though might become a difficult and time-consuming process. Generally, three discovery methods could be considered, distributed (searched by the MUT itself), centralized (announced by the network), and the combination of the both.

- Wireless system selection

An important motivation of a heterogeneous network is that it is possible for an MUT to select the most appropriate one(s) from a number of available RANs. The decision of the wireless system selection could be based on both the user's utilization policy (e.g., price, data rate, battery life, service grade, etc.) and the current traffic status of RANs (e.g., available bandwidth, congestion status, etc.). The result is that each service is delivered via the network, which is the most efficient to support this service.

- Mobility management

QoS guaranteed seamless handover within the same RAN (horizontal) and among different RANs (vertical) and corresponding technologies should be provided.

- Location update and paging

RAN independent, user transparent, secured, low signaling load, integrated controlling and managing, roaming supported location update technologies should be provided. Heterogeneous paging for an MUT should be supported by using the location update technologies.

- Simple, efficient, scalable, low cost.

All the requirements are closely related to each other. These requirements are of particular importance in the future pico-cellular networks in which access point offers tens to hundreds of megabits per second. It is not affordable to have many complex access points.

- Energy efficient.

We expect that wireless IP communicators will be switched on, ready for service, constantly reachable by the Internet. This implies that mechanisms for services like maintaining location information and wireless system discovery should be energy-efficient (and bandwidth efficient as well). Cellular systems employ the notion of passive connectivity to reduce the power consumption of idle mobile hosts.

- Secure

  Mobile systems are open to a number of security problems that do not exist in their stationary counterparts. Mobile hosts must update their location while moving. These location messages make impersonation possible unless properly secured. In systems and applications where seamless handover is of primary importance, session keys used by the mobile hosts must be promptly available at the new base station (in the same RAN or in a different RAN) during handoff.

- QoS support.

  End-to-end QoS mechanisms should be available. Since the RANs provide services that are specialized for some service, QoS aspects in heterogeneous networks are of prominent importance. End-to-end QoS implies that interoperation with local QoS mechanisms should be possible, but also that lower layer protocols (link and physical layer) should be aware of the traffic characteristics and so be able to meet the different requirements of QoS.

- Personal mobility

  Personal mobility in heterogeneous network is more important than that in a homogeneous one. A user with a personal ID should be supported for access to different RANs.

It should be noted that some of these requirements are closely related to each other. Solving the research challenge for one requirement may solve others. In our architecture we try as much as possible to build upon existing protocols to minimize our required effort, and to be compatible with existing protocols and applications.

B. Basic entities

Our solution to these requirements is based on three major entities:

- *Common Core Network (CCN)*. It can be a managed IPv6 network providing the common platform through which all MUTs communicate with correspondent nodes residing in the Internet. In principal all access points of the RANs are connected to this network. The network provides QoS guaranteed routing and seamless handovers among the RANs. In this way a natural integration of the various heterogeneous networks is achieved. The main functional entity of the CCN is the Resource Manager, which coordinates the traffic distribution, and selects the RAN. It has a common database for managing users' profiles with entries like authentication, location, preferred access system, billing, policy, users' terminal capabilities, etc.
- *Basic Access Network (BAN)*. It provides a common control/signaling channel for access of all MUTs to the common platform. The network is basically used to provide location update and paging and help the wireless system discovery and vertical handoff for all other wireless systems. Consisting of base stations and basic access components (terminals), the BAN will have a broad coverage area, preferably larger than the RANs it supports, and a reliable communication means for signaling transmission, while the high data rate is not necessary.
- *Multi-service User Terminal*. The MUT is equipped with a multi-radio system. Any terminal has the Basic Access Component (BAC) to communicate with the BAN. Apart from this radio system, an MUT is equipped with one or more radio subsystems to access the CCN. These subsystems are essentially (or preferably) based on SDR technologies, which allow the MUT to adapt its radio hardware to the wireless infrastructure available and required.

C. The network model

The MIRAI architecture provides communication between mobile hosts and correspondent nodes residing in the Internet. Figure 3 gives a conceptual overview of the architecture. The universal component in our architecture is the *base station*, which serves as the wireless access point and interfaces with the CCN. CCNs are connected to the Internet via *gateway router*s. A CCN provides services for several RANs. In general the RANs will overlap, and a mobile host can have access to several RANs at one location. The area covered by these wireless networks can be quite large.

Mobile IPv6 is the envisioned protocol for the connecting the CCNs and providing global (macro) mobility management. In a CCN managed area where fast handovers between base stations maybe belonging to different RANs with high-speed wireless access requires local (micro) mobility management. Mobile hosts attached to a base station use the IP address of the gateway as their Mobile IP care-of address. Inside the CCN, mobile hosts are identified by their home address. Base stations are connected to (or integrated with) a regular IP forwarding engine. These engines are connected in some network topology that allows packets to be transmitted between the base stations and the gateway.

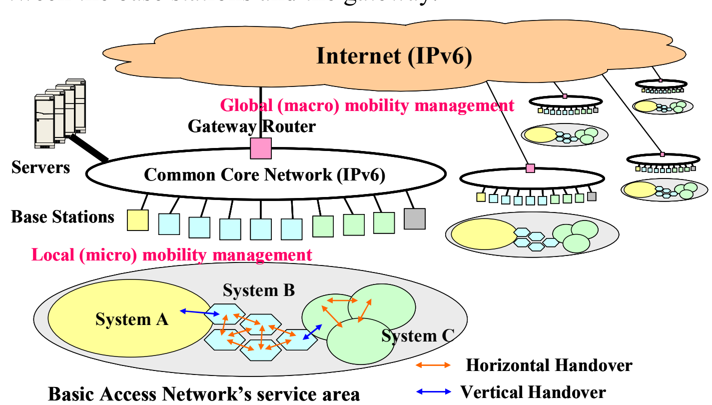

Fig. 3 MIRAI network architecture concept.

Note that, although in our concept the base station is equal to a wireless access point, there is no need to dogmatically stay on this. It is quite well possible that some wireless access providers use their own network of interconnected access points, and share one base station to connect to the core network. An important concept in our architecture is simplicity, thereby enabling low-cost implementation of the network.

The concept of CCN and separate BAN offers providers of wireless services the possibility to setup an infrastructure with little investments. New providers can easily connect to the core network, provided that they use the correct interface. They do not need to have their own infrastructure ready before they can start their business, but instead use the infrastructure provided by the core and BAN. All they have to do is to develop their wireless service, and concentrate on the wireless access only. The infrastructure that is generally needed to setup a whole new service is already provided by the architecture. This includes both technical issues (like interconnection network between base stations, routing, handoff, providing internet access) as well as business issues (like billing, and managing consumer profiles). The components they have to build are the base stations, and the access mechanism for the terminal. In general the access mechanism can be a software module suitable to be used in an SDR.

A consumer may have a contract with the CCN provider, and buy various services (provided by a RAN) from it. If the consumer has a contract that enables him to use multiple services, then the system and the user is able to select the most appropriate service. Access networks may also be combined to increase the available capacity. Different access networks might also be used for uplink and downlink traffic. This can be advantageous for user applications like web browsing and e-mail, which in many cases are asymmetrical in nature causing more downlink than uplink bandwidth. The result is that each service is delivered via the network that is most efficient (in many perspectives) to support the service. In effect, the consumer is unaware of the wireless technologies used to provide the service.

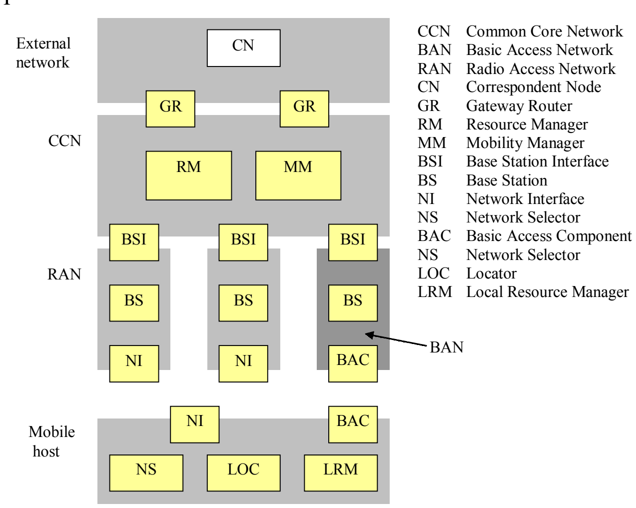

Fig. 4 Heterogeneous system architecture

V. MIRAI ARCHITECTURE

In this section we will introduce the functional entities of our architecture and the protocols used.

A. Overview

The architecture as depicted in Fig. 4 consists of four major building blocks: mobile hosts, RANs, CCN, and external network (or the Internet). Within the external network is the *Correspondent Node* (CN). One or more *Gateway Routers* (GR) connects the external network to the CCN. At the external network Mobile IPv6 is assumed. The Gateway Router plays an active role in this as, when tunneled packets arrive at the gateway destined for a mobile host, the gateway detunnels the packets and forwards them toward a base station. Two important functional entities within the CCN are the *Resource Manager* (RM) and the *Mobility Manager* (MM). They are primarily responsible for traffic distribution and mobility related issues.

The CCN supports the communication to the base stations, and thus to the RANs. The *Base Station Interface* (BSI) is primarily used to provide a uniform access mechanism for base stations to the CCN. The BSI can be a component of a base station. The *Base Station* (BS) deals with the normal link layer issues of wireless access and collects status information of the wireless network it supports. It uses the *Network Interface* (NI) to access the network.

A primary component of a mobile host is the *Basic Access Component* (BAC) to communicate with the BAN. Besides this interface, it also has a Network Interface. However, in contrast to the NI of the base station, this interface is in general based on SDR technologies to enable it to use multiple RANs. A *Network Selector* (NS) communicates with the Resource Manager to tune the radio for the RAN to use. A *Network Selection Control* protocol is used to enable the proper selection of the access network. The *Locator* (LOC) provides the RM with location information of the mobile host. The *Local Resource Manager* (LRM) deals with the local resources of the terminal, and interacts with the resource Manager at the CCN.

B. Functional entities of common core network

The main goal of our architecture is to integrate different access technologies into a common architecture. By having this, the system is used efficiently and the mobile user receives the services it requested. To achieve this goal, the main tasks to be fulfilled by the architecture are resource management to co-ordinate traffic distribution in the system and mobility management to support roaming mobile hosts.

The *Resource Manager* (RM) is thus responsible for resource allocation and admission control to support the traffic distribution in the CCN. It selects the RAN, which can provide the requested service of a mobile host in the most efficient way. In essence, it combines multiple wireless access systems, and exploits their specific strength to provide services in a spectrum efficient way [12]. Another task of the RM is to interact with the IP QoS architectures (such as Intserv or Diffserv) that might be used in the external network. This merely is a mapping between the QoS parameters of both worlds. We envision using some basic classes in the core network (e.g. best-effort, real-time, adaptive). This mechanism enables the wireless link to support IP packets with varying IP QoS parameters properly. The functional entity is realized in the network layer.

The RM is able to provide the selection by using certain criteria. These criteria originate from various sources: the mobile host (i.e. the Local Resource Manager), the mobile user, applications, and base stations. Specific inputs are:

- QoS requirements of sessions
- User preferences like cost and preferred RAN
- Terminal capabilities like supported access networks, protocols, and available resources
- Status (i.e. available resources) of the CCN and the RANs.
- Location of the mobile host.

The RM also should incorporate the costs involved in changing the access network (like the costs involved for reconfiguration of the software radio). This management task, however, is by far not trivial, especially not with mobiles that roam quickly through the region.

The *Mobility Manager* (MM) deals with all mobility related issues. It keeps track of the location of the mobiles, and determines which access networks are available to the mobile host at a certain location. The RM uses this information. The other main task of the MM is to provide handoffs, both local within the CCN as for the external network (based on Mobile IP). In providing this handoff, it needs to interact with the RM. The MM is realized at the network layer, and operates in the CCN. If the mobile host moves within the core network, the mobility is transparent to the network layer, and the system tries to maintain IP flows and IP QoS parameters. In the case of inter-core network mobility, the reservations are re-created due to which packets may be transmitted as best-effort traffic.

C. Functional entities of basic access network

In our architecture we use two distinct networks: the BAN for common signaling related traffic, and the CCN for the data traffic and signaling traffic related to individual RANs. The major functional entities can be considered as follows.

- The BAN is mainly used for supporting *heterogeneous paging*. In a mobile environment it is very important to be energy efficient since a terminal relies on its batteries to operate. We expect that the wireless IP communicators will be on-line continuously (i.e., “always on”), although not be actively communicating most of the time. In essence, mobile hosts will be in an idle state, but passively connected to the network infrastructure. It is then extremely inefficient to have to scan all RANs, and wait for a paging message. Moreover, since the wireless networks are optimized for some special services, it is very likely that they are not efficient for paging messages. A wireless network that is optimized for this kind of traffic is more efficient.
- The BAN can provide *wireless system discovery*. The BAN delivers the common access; every mobile host is capable of using this BAN. The network provides the terminal with information about the currently available wireless networks, so that the terminal is not forced to scan all possible variants.
- The BAN is used as the *signaling network* especially to enable vertical handoffs. Such a dedicated network can provide this service efficiently and securely.
- The BAN can provide the infrastructure to allow mobile hosts to determine their *location*. This information can on its turn be used by the BAN to provide the mobile the information about the available services in its region. Location management is further important for roaming and paging.
- The BAN is used as the medium for most signaling and control messages. This *simplifies* the design of a new wireless access service, since the signaling is being performed by another entity (the basic access component).
- Since we have a heterogeneous architecture in which multiple RANs can be used (semi) simultaneously, we need to have some *network access synchronization mechanism* so that a terminal knows when to tune the SDR to another access network. The BAN can provide such a service straightforwardly.
- Finally, the BAN can also be used as *a wireless access service* when a user uses a BAC standalone. It is, however, primarily suitable to provide some very low bandwidth messaging services like short message.

Since the BAN is mainly used for small messages, the speed is of less importance; the total capacity, however, must be sufficient for a large number of mobile hosts.

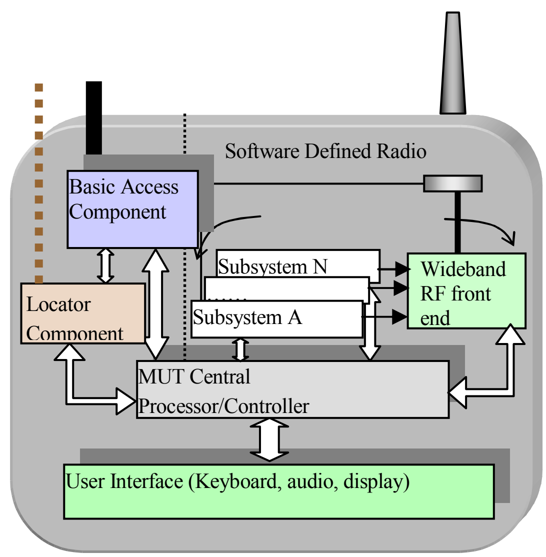

Fig.5 An image of the mobile host.

D. Functional entities of mobile host

The mobile host includes all standard transport protocols and wireless specific control services. The control messages are transparently sent between the core network and mobile hosts’ functional entities.

As shown in Fig. 5, the mobile host will contain a BAC with a locator and an SDR-based *Network Interface* (NI). The BAC is used as the primary component to communicate with the BAN and has the embedded positioning capability offered by the locator (e.g., a GPS receiver). The BAC will send out the location update data for paging (coarse update) when the mobile host moves across the paging boundary, and for system discovery (fine update) when the mobile host initializes a call or requires a vertical handoff. The *Network Selector* (NS) is the entity that is able to select the required access network. It communicates with the RM residing at the CCN via BAN to determine what network should be used and when they are supposed to be operational.

There will be one or more subsystems for accessing (communicating with) the subscribed service systems or RANs. These are indicated as Subsystem A, …, Subsystem N. When an NI is implemented with software radio technologies, it is not likely to be possible to use more than one access network at the same time (except for the transitional duration required by the vertical handoff). The RM at the CCN makes the traffic distribution based on the user preferences, the resources of the common core network including the RANs, and on the local resources of the terminal. The *Local Resource Manager* (LRM) deals with the local resources of the terminal, and interacts with the Resource Manager at the CCN. Applications should be able to use the infrastructure and specify its traffic and QoS requirements. A *QoS API* is used by the applications to specify their needs, and establish a session. If they do not use this API, best-effort mechanisms will be used for their session.

All the radio access subsystems (including the BAC) will be equipped with all necessary components to independently operate with the corresponding air interfaces. The inbound (outbound) data will be delivered to (received from) the user equipment Central Processor (CP). The Central Processor (hosting an embedded OS with TCP/IP stack) will coordinate all the operations within the mobile host. For example, it will handle the user interface, monitor channel, configure and switch between service subsystems, etc.

VI. CONCLUSION

The presented architecture shows a novel approach to enable the efficient use of available RANs. The basic concept is that each service is delivered via the network that is most efficient to support the service. The result is that the mobile user receives the requested service at the lowest cost, and that the scarce radio resources are used efficiently. The architecture solves many of the basic problems involved with wireless Internet over heterogeneous networks.

Currently, a proof-concept experimental demonstration system based on the MIRAI architecture is being developed at the Communications Research Laboratory and will be available by the end of the Japanese Fiscal Year of 2001 (March 2002). PHS and 802.11b WLAN will be used as two different wireless access technologies in the system. The MUT is currently implemented by integrating two individual PCMCIA modules of PHS and WLAN to meet the schedule and will be replaced by the software-radio-defined implementation by the end of 2002. The experimental BAN having the basic functional entities described in 5.3 is designed in the 400 MHz band to support the common signaling of the integrated RANs. An adaptive modulation based physical layer is designed to support a fixed symbol rate of 21ksymbol/s in the reverse link and a dynamic-TDMA based MAC (medium access control) protocol is designed for the implementation. In the design of the CCN, the concept of region network is proposed for each CCN. There is a signaling home agent (SHA) designed in each region network for the management of location updates, paging, micro-mobility, and minimum authentication. Modified Cellular IPv6 will be implemented in the region network. A Region Registrar is designed and implemented in the external IPv6 network. A modified Mobile IPv6 will be implemented for the handoffs between two CCNs. A related indoor/outdoor test field providing a physical handover environment is also being developed in the Yokosuka Research Park area.

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