Ambient Network and Its Key Technologies

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Abstract:
The Ambient Networks project of European Union has carried out in-depth research on heterogeneous network convergence, where the Ambient Control Space (ACS) is proposed to support dynamic, distributed, self-managing and self-maintaining management for heterogeneous networks. With the Multi-Radio Access (MRA) architecture, the Ambient Networks take full advantage of multiple access technologies to provide all users with the "Always Best Connected" services.

Started in 2004, the Ambient Network (AN) project is a large-scale collaborative project within the EU's 6th Framework Programme. It aims at easing efficient interconnection and cooperation between future heterogeneous mobile and wireless networks with Ambient Networking technology, thus enabling the end user to enjoy easy-to-use and diversified services, regardless of the networks in use. Based on a combination of different technologies and dynamic composition of networks, the goal of the AN project is to effectively utilize existing network infrastructure and accesses, and try to avoid adding new network technologies to the growing patchwork of extensions to existing architectures.

The project has three phases. So far, this project has gone through 4 years, and two phases have been finished. Phase 1 (2004-2005) has established the overall approach and developed innovative technical concepts. Phase 2 (2006-2007) has proven their viability through implementation, integration, measurements and performance evaluation, and made related standards.

This project is divided into 8 Working Packages (WPs). WP1 concentrates on the coordination of the technology developed within the project, and evaluates the business feasibility of AN. WP2 is responsible for mobility management research. WP3 focuses on multi-access research. WP4 studies network management policies to support heterogeneous network convergence and cooperation in dynamic situations. WP5 deals with dynamic internetworking and routing architecture, with a specific focus on mechanisms that support user plane communication. WP6 focuses on enhancing the transport layer with the concept of Service-aware Adaptive Transport Overlays (SATO). WP7 studies uniform, dynamic establishment of interworking between heterogeneous networks, and introduces network composition on the control plane, enabling the same procedure for all networks, independent of network type and network technology. WP8 has the overall responsibility for the implementation, integration and verification activities in AN.

This paper focuses on two key techniques of the AN project, i.e. Ambient Control Space (ACS) and Multi-Radio Access (MRA).

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1 Ambient Control Space

The network management of the AN should be dynamic, distributed, self-managing, self-maintaining, and adaptive to the network and ambient environments. For this purpose, WP4 proposes the ACS.

The ACS is a distributed, common control space. It can not only perceive the characteristics, resources, faults and performance of underlying network continuously, but also support self-management and re-configuration of the AN. Innovatively, the ACS covers three different research fields (i.e. network environment management, network management, and policy-based system management), and suggests a solution that meets AN network management requirements. The two basic elements of the ACS architecture, illustrated in Figure 1, are functional module and interface.

The ACS consists of several functional modules, such as Multi-Radio Resource Management (MRRM), traffic engineering and Mobility Management (MM). These modules cooperate with each other to realize the overall control functionality.

The ACS architecture includes Ambient Service Interface (ASI), Ambient Resource Interface (ARI), and Ambient Network Interface (ANI). The ASI not only allows higher-layer applications and services to make requests to establish,

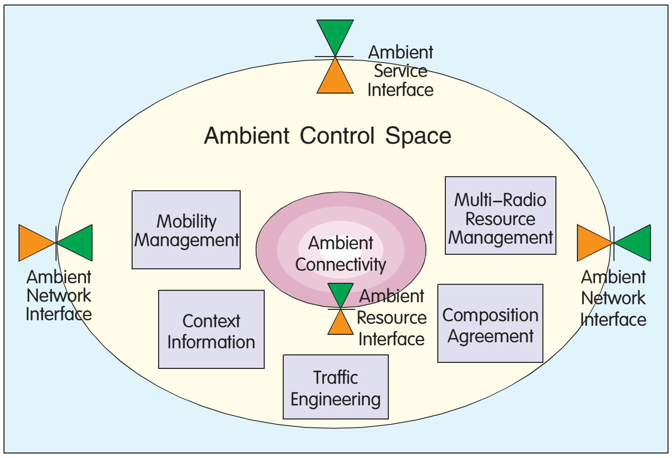

Figure 1. Ambient control space architecture.

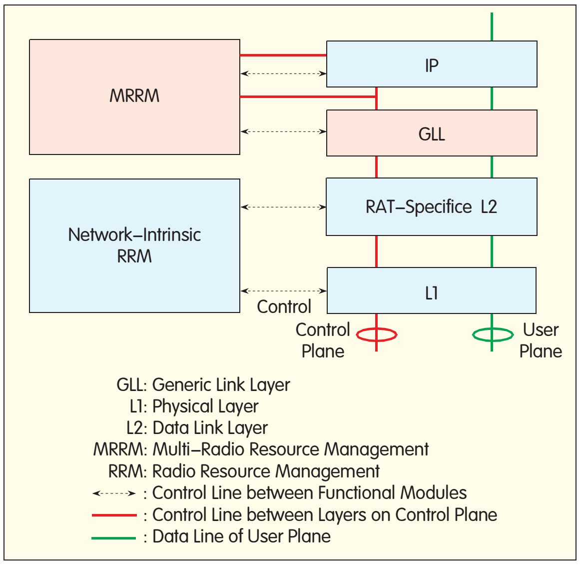

Figure 2. MRA architecture.

maintain or terminate end-to-end connectivity, but also tells the higher layer about its management capabilities and underlying network information. The ARI resides between the ACS and the connectivity layer, enabling the ACS to manage the connectivity resources, which can be routers, switches, or others. The ANI facilitates communication between the ACSs of different networks, creating the shared common control space that enables the internetworking capabilities the AN project aims to achieve. The ANI is also used for negotiation of network composition agreements and for transferring control information between the networks[1].

2 Multi-Radio Access

The presence of multiple accesses brings great challenge for achieving effective interconnection between heterogeneous networks. But on the other hand, it opens the potential to provide the user with access in an " Always Best Connected (ABC)" fashion by utilizing several access techniques simultaneously and associating with competing network operators.

The concept of multi-access in the AN is that the user can access any network, even an unauthorized one, through instant establishment of inter-network agreements and network compositions.

To implement this concept, the MRA architecture has been outlined in the AN project, which comprises two components: MRRM and Generic Link Layer (GLL)[2]. Figure 2 illustrates the MRA architecture.

2.1 Multi Radio Resource Management

The MRRM is responsible for joint management of radio resources between different radio accesses. It aims to provide extended capacity and service coverage of the entire system by merging various radio access technologies. Meanwhile, it gives a better trade-off between resource usage (spectrum, power, etc.), costs, end user performance and Quality of Service (QoS) requirements by selecting the most efficient radio access technology or a combination of radio access technologies.

2.1.1 Logical Structure of MRRM

Logically, the MRRM is divided into two parts: radio access coordination functions and complementing Radio Resource Management (RRM) functions, both of which are built on the existing network-intrinsic RRM functions, as shown in Figure 3.

The scope of radio access coordination functions spans over the available radio accesses. Such functions typically include: dynamic discovery of available radio accesses, communication between MRRMs of different networks, radio access selection, handover between different radio accesses, congestion control, load sharing, and adaptive coordination of resource allocation across various radio access networks.

The complementing RRM functions are specially designed for one or more specific radio access technologies. They just complement the existing RRM functions rather than replace them. The complementing RRM functions can provide RRM functions that are not available in existing radio access technology or complement those functions that are inadequate. For example, it can provide such functions as admission control, congestion control, and intra-RAT handover to Wireless Local Area Networks (WLAN).

Some network-intrinsic RRM functions of existing networks may have included coordination functions. For instance, load sharing and radio access selection have already been developed in 3rd Generation Partnership Project (3GPP). Although they are not specifically developed within the AN

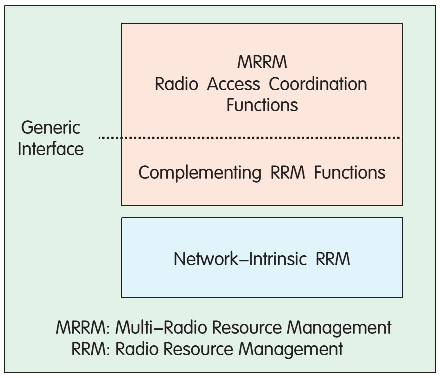

Figure 3. Logical structure of MRRM.

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context, these functions can be used by the radio access coordination functions. A clear split between the radio access coordination functions and the complementing RRM functions is achieved by a standardized and generic interface.

2.1.2 MRRM Functions

The MRRM is a control plane entity operating at the system, session and flow levels. At the system level, it performs spectrum, load and congestion control across two or more radio access technologies. At the session level, the MRRM matches associated flows, and its functions can be triggered by system level operations or directly by session/flow level events. At the flow level, the MRRM establishes and maintains radio accesses, which may be made up of parallel multi–hop routes.

(1) Session/Flow Level Functions

The functions of MRRR at the session/flow level mainly involve three aspects: radio access advertisement, radio access discovery, and radio access selection. For a dynamic network, it is quite important to timely advertise network resource information, such as bandwidth. Such advertisements should provide the MRRM with sufficient and proper information and could serve as a basis for starting negotiations in a network composition process. The advertisement informs about the presence of a network, the network's capabilities of service providing, and possibly cost information. The radio access discovery function uses the information in the advertisement to identify and monitor candidate radio accesses. The radio access selection function chooses the suitable radio access for different flows, from the radio accesses identified in radio access discovery[3].

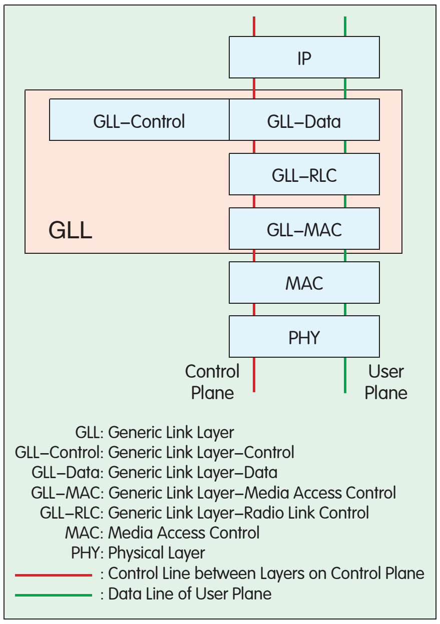
(2) System Level Functions

The system level functions of MRRM are mainly to observe, monitor and manage network load and resource efficiency. These functions span over the MRRMs of several networks, keeping an overall control of the resources in order to perform congestion control, load sharing, and spectrum control. Among them, congest control falls into two kinds: soft and hard. The purpose of the soft congestion control and load sharing is to detect upcoming congestion and take measures to prevent true congestion from occurring. In case soft congestion control fails to prevent true congestion, the hard congestion control function starts to forcibly drop flows. In the AN world, all nodes and terminals can negotiate in order to share their resources. A node in or near congestion can communicate with neighboring nodes to jointly solve the congestion situation. In addition, the introduction of inter–network measures, such as inter–network load sharing (directed handover) and spectrum control (channel borrowing), can enhance the potential of the system to prevent and solve the congestion problem. In this way, the networks can cooperate with each other to solve congestion situations, and offer a more efficient and flexible utilization of available resources by selling their spare spectrums. This is a new capability of the AN, which is not present in current system. However, further research is necessary for this capability.

2.2 Generic Link Layer

For the future communication systems consisting of varied radio access technologies, a great challenge is to provide a multi–radio access architecture that facilitates the interconnection of heterogeneous radio access networks and efficiently supports various services. To achieve this interconnection in a transparent way for users and services, it is required to extend the link layer. Hence, the AN project proposes the concept of GLL.

The GLL is on top of, or is partly replacing, the radio access specific parts of Layer 2 (L2). In design, the GLL can be coupled with the Media Access Control (MAC) layer to a certain degree. Generally, the higher the degree of coupling, the more complex the system's interconnection is, but the more access gain can be achieved. The toolbox of the link layer functions within the GLL provides a unified interface towards upper layers (IP and above) in the user plane, and an adaptation towards the underlying (remaining specific radio access technology) link layers. The functions of GLL often operate on the data flow of the user plane. For example, in the radio access selection process, the GLL dynamically maps data flows to any of the radio accesses selected by the MRRM within accurate time range, either in sequence or in parallel.



▲Figure 4. Logical structure of GLL.

2.2.1 Logical Structure of GLL

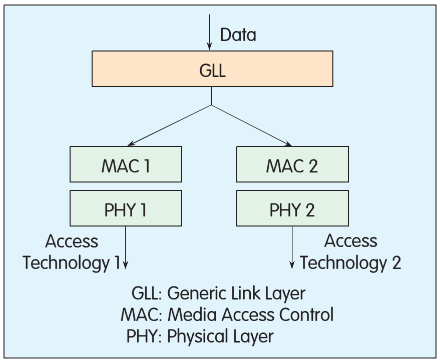
The GLL in the AN project is divided into four functional blocks: GLL–Control, GLL–Data, GLL–Radio Link Control (RLC), and GLL–MAC, as shown in Figure 4. GLL–Control is responsible for the link layer configuration and the interaction with the MRRM, including access selection control, resource monitoring and performance monitoring functions. The GLL performs or supports the following functions: mobility management, buffer management and context transfer (via GLL–Data), security management (via GLL–Data and GLL–RLC), access scheduling (via GLL–Data and GLL–MAC), error and flow control, segmentation and reassembly (via GLL–RLC).

2.2.2 New Features Enabled by GLL

The GLL supports two novel features: Multi–Radio Transmission Diversity (MRTD) and Multi–Radio Multi–Hop (MRMH)[4].

(1) MRTD

The MRTD implies the sequential or parallel use of multiple radio accesses for



▲Figure 5. Parallel MRTD for the downlink.

the transmission of a traffic flow. It assumes that access networks and mobile terminals can transmit and receive data over multiple radio accesses. That is to say, they are multi-mode. The MRTD can be further classified into two types: sequential and parallel. The sequential MRTD means a dynamic switching between different radio access technologies. Suppose the user originally employs one access. When the user changes its location during the data flow or when the used radio access cannot meet QoS requirements, the sequential MRTD allows the user to be switched to another radio access to continue data transmission. The parallel MRTD implies that the data flow between two communicating entities is split over different radio access technologies. As the attenuation of data flow is irrelative to radio access technologies, the parallel MRTD can achieve diversity gain, thus improving the reliability and robustness of the entire system. Moreover, in order to obtain the coding gain, the original data can be encoded before they are packeted for transmission, and at the receiver end, the received packets are processed with combined decoding algorithm. Figure 5 illustrates the parallel MRTD for the downlink.

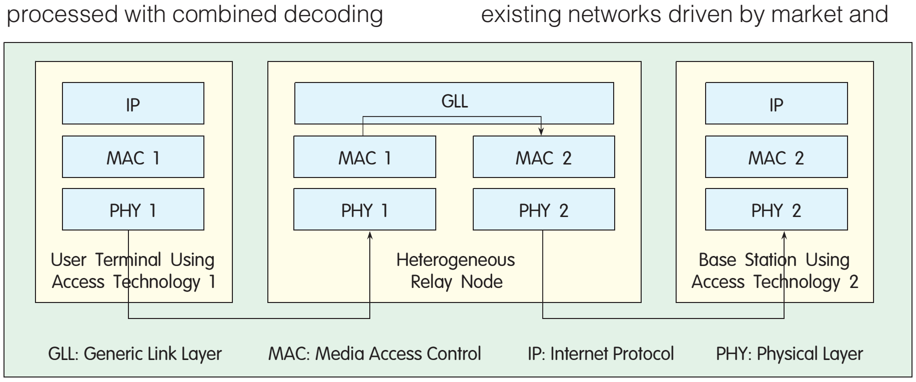
(2) MRMH

The MRMH is defined as the multi-hop communication between two entities through relay nodes that utilize different radio technologies. It achieves heterogeneous multi-hops between two entities mainly via relay nodes. Hence, it brings new features to the relay node. Traditional relaying technology, i.e. homogeneous multi-hop technology, is mainly used to enlarge the cell coverage and improve the communication quality at the edge of the cell; but in the converged heterogeneous network environment, relay nodes can not only forward data, but also switch between different radio accesses, enabling the user who employs a specific radio access technology to access to other, even unauthorized, networks. This is called heterogeneous multi-hop technology, which makes a main part of the MRMH. The AN project changes traditional relays into heterogeneous ones by adding GLL technology onto them. The implementation process of the MRMH is shown in Figure 6.

With the research going more extensive, more hot topics will be raised, for instance, deployment of heterogeneous relays, resource scheduling in heterogeneous multi-hop network, and cooperation between heterogeneous relays. All these research will promote continuous development of heterogeneous multi-hop technology.

3 Conclusions

Heterogeneous network convergence is a form of next generation network in the near future, and the development of existing networks driven by market and technology. The AN project within the EU's 6th Framework Programme proposes a novel concept regarding dynamic network composition, which enables the users to access to any network through instant inter-network agreements without making major changes to the existing network architecture. Although the EU takes the lead in the research on heterogeneous network convergence, its research is just a start because the heterogeneous network convergence is a long-term, sophisticated and tough evolution process, and some critical issues need to be addressed or further studied, for instance, the resource efficiency and scalability of the converged architecture, as well as the conflicts between self-organization and hetero-organization of the system.



▲Figure 6. Heterogeneous MRMH.

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