

Chapter 2

Heterogeneous Wireless Networks

In this chapter, we will review the underlying mechanisms for the evolution of wireless communication networks. We will first discuss macro-cellular technologies used in traditional telecommunication systems, and then introduce some micro-cellular technologies as a recent advance in the telecommunications industry. Finally, we will describe existing interworking techniques available in literature and in standardization, including loosely and tightly coupled, I-WLAN and IEEE 802.21.

2.1 Macro-cellular Technologies

The term macro-cell is used to describe cells with larger sizes. A macro-cell is a cell in mobile phone networks that provide radio coverage served by a high power cellular base station. The antennas for macro-cells are mounted on ground-based masts and other existing structures, at a height that provides a clear view over the surrounding buildings and terrain. Macro-cell base stations have power outputs of typically tens of watts [18]. Most wireless communication systems maintained by traditional mobile network operators are powered by macro-cellular technologies.

2.1.1 1G/2G/3G Networks

In the 1980s, the 1G wireless communication system came to the mobile communication environment, which provided a data speed of 2.4 Kbps to support data communication with mobile phones. An example is Nordic Mobile Telephone (NMT). However, this generation still worked in analog system and there were tight limitations in terms of the system capacity and data rate.

In the last decades of the last century, 2G wireless communication systems with increased capacity and higher speed gradually replaced the previous generation through technology development and performance enhancement. It was worth noting that 2G wireless systems supported digital communication, such as in Global System for Mobile Communication (GSM). After the transition to the 2G systems, some protocols were developed to increase the data speed that produced the 2.5G wireless systems. The General Packet Radio Service (GPRS), the most common one of those protocols, provided a speed up to 144 Kbps. Later on, the 2.75G wireless system came with a higher data rate than previous generations and provided more enhanced performance in terms of high speed in data service. For example, by adopting advanced coding schemes and transmission mechanisms, Enhanced Data rates for GSM Evolution (EDGE) achieved higher bit-rates per radio channel, resulting in a threefold increase in capacity and performance compared with an ordinary GSM/GPRS connection.

In the late 1990s, the 3G wireless communication system emerged with better multimedia capability and greater networking speed to meet the ever-increasing demand on data services. There are several widely used protocols and standards in the 3G systems, including UMTS, WCDMA, CDMA2000/EVDO, CDMA2000/EVDV, CDMA2000/EVDO-Rev A. In addition, for the economic concern, telecommunication operators usually adopted the evolution by efficiently integrating both 3G and previous generations to reduce the upgrade cost. Beyond 3G system was developed to improve the performance the conventional 3G system and provide a higher speed of up to 14.4 Mbps. As one of the technologies in the 3.5G wireless communication system, High Speed Downlink Packet Access (HSDPA) provides a dramatic performance improvement, based on the bandwidth's substantial increase and support more applications, such as graphics-intensive web browsing, on-demand video playing and multi-user video conferencing.

2.1.2 4G Networks

In the early twenty-first century, some telecommunication operators began to upgrade the 3G to 4G wireless communication systems, which provide a more comprehensive commercialized communication solution with a much higher data rate and better system performance, in terms of high reception ratio, low packet loss ratio and low packet delivery latency. International Telecommunication Union (ITU) has stated that 4G technologies require a data transmission rate of at least 100 Mbps while a user moves at high speed and a much high data rate up to 1 Gbps in a fixed location to support better multimedia applications, such as video-on-demand services. There are several challenges to achieve such performance criteria in mobile scenarios, including routing optimization technique, fast handover technique, integration technique between Mobile IP and cellular IP, multi-path technique, mobility management technique for all-IP networks.

In October 2010, ITU Radiocommunication Sector (ITU-R) completed the assessment of six candidate proposals for the future 4G mobile wireless broadband technology, called IMT-Advanced. Among these candidates, two technologies were accorded as the official designation of IMT-Advanced, including WirelessMAN-Advanced and LTE-Advanced.

WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunication protocol [12], which is designed to deliver next-generation, high-speed mobile voice and data services and wireless *last-mile* backhaul connections that could potentially displace a great deal of existing radio air network infrastructure. The first version of IEEE 802.16 Standard was released in 2001, and defined the basic air interface specification for wireless metropolitan area networks (MANs). Subsequently, physical layer technologies, such as orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA), and new features, such as power-saving, idle mode, handover and an improved OFDMA physical layer, were amended to the original draft. The WirelessMAN-Advanced specification was incorporated in IEEE 802.16 standard beginning with approval of IEEE 802.16m standard.

In the evolution tree of mobile communication technologies, LTE (Long Term Evolution) is considered to be the latest standard, whose first release was published in March 2009 and is referred to as LTE Release 8 [2]. 3GPP has developed the LTE standard for 4G wireless communication systems based on orthogonal frequency-division multiplexing (OFDM) waveform for downlink and single-carrier FDM (SC-FDM) waveform for uplink communications, mainly to improve the user experience for broadband data communications [6]. The LTE-Advanced specification was developed by 3GPP as LTE Release 10 and Beyond.

To conclude this section, we summarize the generations of cellular networks with mainstream technologies in Table 2.1.

2.2 Micro-cellular Technologies

Compared to macro-cellular wireless networks, micro-cellular networks are served by low power base stations or access points to cover smaller areas, such as an office, and support a fewer number of mobile users. Typically, the range covered by micro-cell networks is less than 2 km wide. The flexibility of cell size is a significant factor contributing to capacity improvement, and power controlling can largely reduce the interference from neighboring cells in the overlapping radio frequencies.

2.2.1 IEEE 802.11 Based WLAN

IEEE 802.11 based WLAN is the most popular micro-cellular wireless communication system in the world. However, WLAN technology was not initially

Table 2.1 Generations of cellular networks

Generations	Protocols	Data rate	Features
1G	AMPS NMT TACS	N/A	• Only support voice service • No data service
2G	CDMA GSM PHS	Up to 20 Kbps	• Digital voice service • Push-to-talk (PTT) • Short message service (SMS) • Conference calling • Simple data applications such as email and web browsing
2.5G	GPRS CDMA2000 1×RTT	114 Kbps (30–40 Kbps) 144 Kbps (60–80 Kbps)	All 2G features plus: • MMS (multimedia message service) • Web browsing • Real-time location-based services, such as directions • Basic multimedia, including support for short audio and video clips, games and images
2.75G	EDGE EGPRS IMT-SC	384 Kbps 473 Kbps (uplink)/1.2 Mbps (downlink) 600 Kbps	• Better performance for all 2/2.5G service
3G	WCDMA CDMA2000 /EVDO CDMA2000 /EVDO-RevA TD-SCDMA	2 Mbps 2.4 Mbps 3.1 Mbps 2.8 Mbps	Support for all prior 2G and 2.5G features plus: • Full motion video • Streaming music • 3D gaming • Fast web browsing
3.5G	HSDPA/HSUPA CDMA2000 /EVDO-RevB	14.4 Mbps 46 Mbps	Support for all prior 2/2.5/3G features plus: • On-demand video • Video conferencing • Faster web browsing (especially graphics intensive sites)
4G	WiMAX UMB LTE	100 Mbps 35 Mbps 100 Mps	Support for all prior 2G/3G features plus: • High quality streaming video • High quality Video conferencing • High quality Voice-over-IP (VoIP)

designed for short range communication. When the proprietary Direct Sequence Spread Spectrum (DSSS) technology over 900 MHz was adopted, it could set up quite a long distant link providing data throughput of 860 Kbps. In 1990s, the working frequency of WLAN was set to 2.4 GHz and it could support a higher data throughput of 1 Mbps or 2 Mbps in a shorter distance. The year 1992 witnessed the start of drafting of the IEEE 802.11 standard for wireless LAN technologies, which had proposed 1 Mbps as a standard data rate and 2 Mbps as a Turbo mode. Since then, a series of IEEE 802.11 standards have been proposed to improve the performance of WLAN, some of which are listed as follows.

- IEEE 802.11a: IEEE 802.11a-1999 High-speed Physical Layer in the 5 GHz band
- IEEE 802.11b: IEEE 802.11b-1999 Higher Speed Physical Layer Extension in the 2.4 GHz band
- IEEE 802.11d: an approved amendment to the IEEE 802.11 specification that adds support for additional regulatory domains
- IEEE 802.11e: an approved amendment to the IEEE 802.11 standard that defines QoS Enhancements, including packet bursting
- IEEE 802.11g: IEEE 802.11g-2003: Further Higher Data Rate Extension in the 2.4 GHz Band
- IEEE 802.11h: an approved amendment to IEEE 802.11 standard that adds Spectrum and Transmit Power Management Extensions
- IEEE 802.11i: an approved amendment to the original IEEE 802.11 that specifies security mechanisms for wireless networks and implements WPA2
- IEEE 802.11n: an approved amendment to the IEEE 802.11 standard to improve network throughput using multiple input multiple output (MIMO) technology
- IEEE 802.11p: an approved amendment to the IEEE 802.11 standard to support Wireless Access for the Vehicular Environment
- IEEE 802.11r: an approved amendment to the IEEE 802.11 standard to permit continuous connectivity aboard wireless devices in motion, with fast and secure handovers from one access point to another, managed in a seamless manner
- IEEE 802.11s: an approved amendment to the IEEE 802.11 standard to support mesh networking
- IEEE 802.11u: an approved amendment to the IEEE 802.11 standard to add features that improve interworking with external networks.

The 802.11 standards define two types of communication modes: infrastructure mode and ad hoc mode. In infrastructure mode, the wireless network consists of a wireless access point (AP) and multiple wireless clients. The AP acts as a base station and is also responsible for security management. All wireless clients communicate with external networks through the access point, which provides the connection from the wireless communication media to the hard-wired communication media. Since the wireless communication media is open, all wireless clients within the communication range can receive the packets. But in the default protocol operation, only those clients with the appropriate destination address will handle the packets.

In the ad hoc mode, the wireless network is only comprised of IEEE 802.11 wireless clients, which communicate directly with each other without forwarding packets to an access point. This mode is convenient for quickly setting up a wireless network in a meeting room, hotel conference center, or anywhere else where sufficient wired infrastructure does not exist.

2.2.2 Wireless Mesh Network

A wireless mesh network (WMN) is a new wireless communications network consisting of mesh routers, mesh clients and gateways, which are self-organized in mesh topology. Wireless mesh networks can be implemented with various wireless technology, including IEEE 802.11, IEEE 802.15, IEEE 802.16, cellular technologies, or combinations of more than one type. Wireless mesh networking is a promising technology for next-generation wireless communication systems, with the capability of rapid deployment and flexible reconfigurability for disaster recovery, convention centers and hard-to-wire areas. WMN is also an alternative for long-term network infrastructure to extend wireless broadband access in dense urban areas and low-cost backbone networking to Internet gateway in remote rural areas (Fig. 2.1).

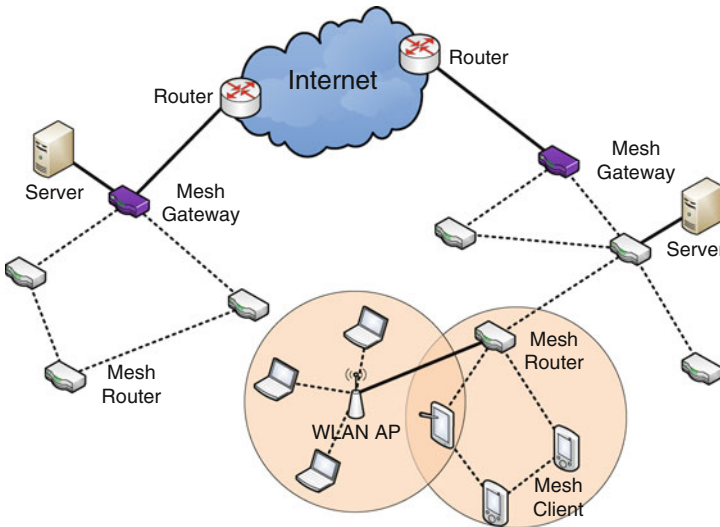


Fig. 2.1 Wireless mesh networks

There are three kinds of network structures in wireless mesh networks, including infrastructure-based WMN, client-based WMN and hybrid WMN. In the first architecture, mesh routers establish a backbone network with the wireless technologies, and mesh clients obtain the network access through the core network.

If some of the mesh routers have a connection to the Internet via wireless or wired links, they can be set to be the gateways, which provide the entire network Internet access service. In addition, mesh routers are usually stationary in the whole network. In client-based WMNs, it allows peer-to-peer networking between mesh clients, with no dedicated mesh routers. To a certain extent from network topology aspect, a client-based WMN is the same as a traditional ad hoc network. To meet diverse requirements of different application scenarios, a hybrid WMN is proposed to combine the above two networks.

The characteristics of WMNs [3] are listed as follows:

- **Multi-hop and ad hoc wireless networking.**
One of the most important features in wireless mesh networks is its multi-hop and ad hoc wireless networking technology to forward data packets, which can effectively extend the network coverage constrained by a single base station in WLAN, and achieve non-line-of-sight propagation, which is impossible for high radio frequency.
- **Capability of self-organization and self-healing.**
Due to the distributed nature of multi-hop and ad hoc networking, WMN can simplify network design and deployment, thus reduce network construction and maintenance costs. WMNs can also upgrade network performance in terms of load balance and fault tolerance. Due to these features, WMNs have low initial construction costs, and can be deployed in an incremental fashion.
- **Various mobility and access patterns of mesh nodes.**
Different mobility patterns exist in WMNs, including the stationary mesh routers and moving mesh clients. In addition, there are also different network access patterns, including only peer-to-peer communication between mesh routers, and hybrid communications among mesh clients. All these differences will require different protocol design and strategy adoption.
- **Different Power-consumption constraints for mesh nodes.**
Mesh routers are almost stationary, and usually do not have much constraints on power consumption. However, mobile mesh clients are powered by battery and may meet the power efficiency requirements. Thus, the MAC or routing protocols optimized for mesh routers need to not be appropriate for mesh clients.
- **Compatibility and interoperability with existing wireless networks.**
Since WMN can be implemented in multiple wireless communication technologies, compatibility and interoperability will be solved in the radio access layer. The researchers may focus on the MAC layer and upper layers to design suitable protocols and applications.

2.2.3 Femtocell

Femtocells are small base stations with low transmission power, and almost all of the cellular functionalities, but a limited coverage to end users in indoor environments, such as houses and offices. Femtocells connect to core networks of service providers

via broadband Internet connections. A femtocell allows service coverage extended to indoor environments, especially where wireless access would be limited or unavailable, without expensive deployment cost. Femtocells use the same physical layer technology as cellular networks and are standardized since 3GPP release 8, where it is called Home NodeB (HNB) in WCDMA systems and Home eNodeB (H(e)NB) in LTE systems (Fig. 2.2).

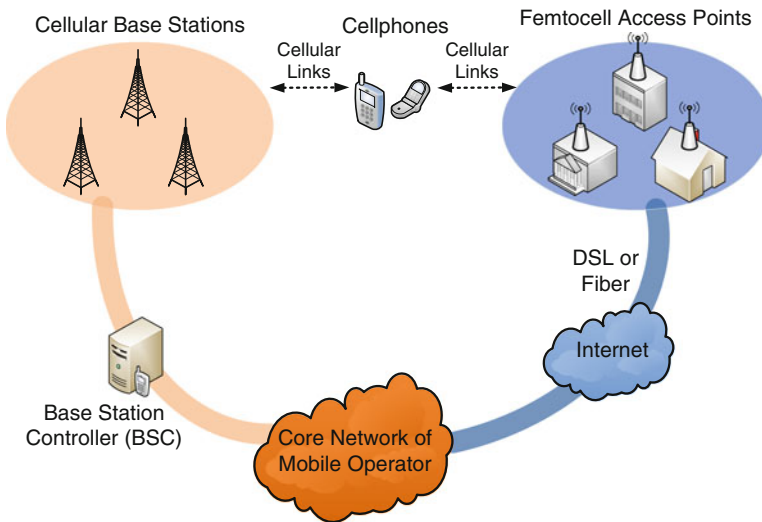


Fig. 2.2 Femtocell networks

The key benefits of femtocells [5] are summarized as follows.

- **Larger coverage and higher capacity.**
Due to their low power transmission, femtocells can largely avoid interference between other co-channel signals, and provide a high quality communication channel for mobile users. Therefore, femtocells improve spectral efficiency in terms of user numbers per unit coverage. In addition, due to the short distance to base station, mobile terminals can also achieve energy efficiency by lowering transmission power and prolonging battery life.
- **Improved macro-cell reliability.**
In the presence of femtocells serving indoor mobile clients, macro-cellular networks can provide much more reliable data service for outdoor mobile users, due to the reduced overhead required to handle poor signals from indoor users.
- **Reduced deployment and maintenance cost.**
Femtocell can be deployed with reduced construction and maintenance costs for networks operators. As reported by a research study dated in 2007, the maintenance cost drops from \$60,000 per year per macro-cell base station to just \$200 per year per femtocell base station [4].

- **Decreased subscriber turnover.**
Poor in-building coverage causes customer dissatisfaction, encouraging customers to either switch operators, or maintain a separate wired line whenever indoors. The enhanced home coverage provided by femtocells will decrease the motivation for home users to switch carriers.

2.3 Interworking Technologies

Interworking architectures between heterogeneous wireless networks can be divided into two main categories: loose and tightly coupled architectures. For the convenience of description, we will take interworking between 3G networks and WLANs as examples. We first briefly introduce the above two architectures, and then present two standard implementations for interworking between these two types of wireless networks, including I-WLAN interworking solution from 3GPP, and Media Independent Handover from IEEE.

2.3.1 Loosely Coupled Architecture

In a loosely coupled architecture, interconnected wireless networks are relatively independent from each other in terms of handling data flows and signaling messages. There is a common component in all loosely coupled solutions, which is the adoption of Mobile IP as mobility management protocol to integrate multiple wireless networking systems. A typical loosely coupled architecture is shown in Fig. 2.3.

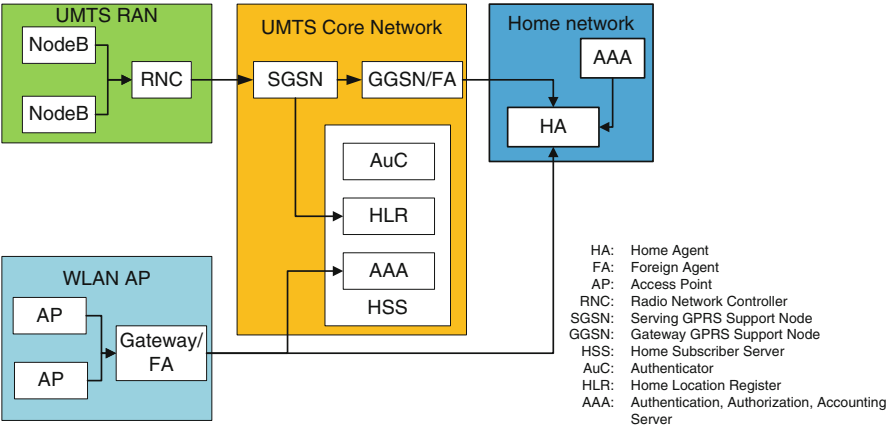


Fig. 2.3 System architecture of loosely coupled approach

Since the concerned networks are usually independent of each other, the internal operations in each network can easily migrate to the interworking scenarios nearly without modification. Therefore, the improvement on roaming performance is almost developed in the interaction part between two networks. Some approaches [10] are listed below.

1. Effective handover initiation and accurate handover decision

This approach aims at determining when mobile clients take handover, and which access network mobile clients connect to after handover. Related work on handover initiation and decision algorithms usually considers various parameters from both the client and network sides, including the received signal strength of the current access network at the client side, the current dominant traffic pattern, and handover overhead from different networks.

2. Optimization on Mobile IP procedures

In standardized Mobile IP protocols, there exists several signal interactions between three participants in the whole procedure. The main objective of the optimization on Mobile IP procedures is to shorten the delay caused by the execution of the protocols related to Mobile IP operations. Some proposed mechanisms have been proposed to reduce the handover latency by improving the efficiency of signaling passing in both intra-domain and inter-domain scenarios, or by utilizing cross-layer information to capture the accurate handover trigger.

3. Policy-based solutions

Different from the approach 1 using real network metrics to predict handover occurrences, policy-based solutions evaluate handover behaviors by the information derived from policy-based criteria, including the jitter requirement for on-line video streaming applications, the security capabilities of terminal for high-confidential applications. To obtain the complex network context from different wireless access networks, they propose new network entities between different network operators, such as context management, handover decisions, and interoperability.

2.3.2 Tightly Coupled Architecture

In a tightly coupled architecture, non-cellular wireless networks, such as IEEE 802.11 based WLANs, are connected to the core network of cellular networks as access networks to provide cellular radio coverage. There are two common approaches to achieve mobility management in the closely coupled architecture, namely reuse of some functionality in cellular networks as the integration point and adoption of Mobile IP protocols. In the first approach, some modifications need to be made to facilitate the additional wireless access technologies, while the other approach needs to deploy new network entities to implement Mobile IP functionality.

According to different degrees of integration between cellular and non-cellular wireless access networks, solutions for the tightly coupled architecture can be categorized into the following three groups, namely coupling at GGSN level, coupling at SGSN level and coupling at RNC level. Among them, coupling at RNC level requires the tightest relationship between the two networks.

2.3.2.1 Coupling at the GGSN Level

One of the tightly coupled solutions to support seamless roaming between UMTS and WLAN is presented in [15], which implements coupling at the GGSN level. In this architecture, as illustrated in Fig. 2.4, a new logical node, called the Virtual GPRS Support Node (VGSN), is designed to interconnect the UMTS and WLAN core networks. VGSN in UMTS networks acts as normal GPRS Support Node (GSN) and is also an access router in WLAN. The main tasks of VGSN are signaling conversion of subscriber/mobility information and data forwarding between the two heterogeneous networks.

In this architecture, both networks are independent of each other and handle their own subscribers in coverage separately; VGSN serves as the point of integration to connect two networks. When mobile users roam between UMTS and WLAN networks, VGSN will take charge of the SGSN functionality in the network where the users will move to. In the normal operation mode, the subscriber in WLAN will not generate data traffic to UMTS networks, and data flows caused by UMTS users in UMTS networks will bypass the WLAN. In roaming scenarios, VGSN takes charge of GGSN in UMTS networks, which is between the WLAN gateway and SGSN in the forwarding path of out-going packets to mobile terminals.

The main advantage of the GGSN-level coupling approach is simplicity, in terms of the interactions between two networks and the introduction of additional functionality. For example, the two networks can handle their own subscribers independently until the handover occurs. Mobile IP is not needed, so the system design can be simplified. Moreover, the simulation results in [15] showed that the performance is much better than other tightly coupled solutions. For example, the VGSN approach obtains similar average per-user bandwidth, but significantly lower handover latency compared with amount of Mobile IP based solutions. The main disadvantage of this architecture is that the successful integration of two heterogeneous wireless networks requires a strong roaming agreement between UMTS and WLAN operators, since the VGSN entity does not belong to any network and should be controlled by the administrative party for the cooperation.

2.3.2.2 Coupling at the SGSN Level

In [14] and [13], another type of coupling architecture was proposed at the SGSN level. The key functional entity in the system is the GPRS Interworking Function (GIF), which is connected to a WLAN and to a serving SGSN. The main function

of the GIF is to convert the WLAN functionalities to a unified interface to the core network of cellular networks, and to mask the technology heterogeneity of WLAN technology. From the perspective of cellular networks, WLAN is a special radio access network which consists of only one cell. To achieve this goal, the WLAN adaption function (WAF) is developed to identify the time when the WLAN radio subsystem is enabled and to inform the upper layers, which subsequently redirects signaling and data traffic to the WLAN. The WAF is deployed in both mobile stations and on top of GIF functionality. WAF functionality includes hardware management service, location management service, QoS support services. The system architecture of this approach is shown in Fig. 2.5.

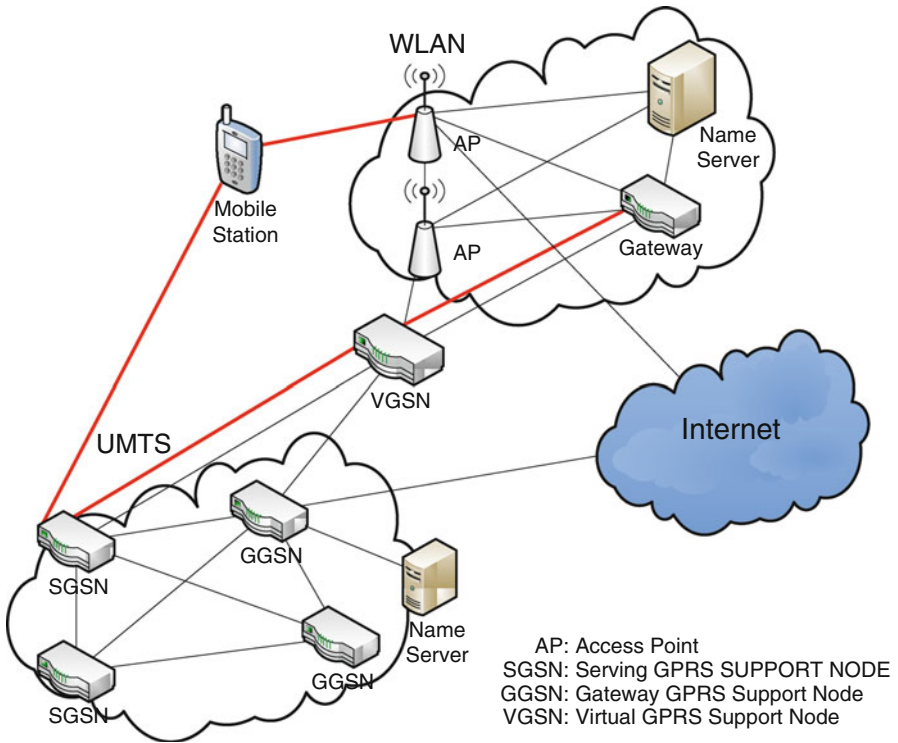


Fig. 2.4 System architecture of GGSN-level coupling approach (Reprinted from [15])

The main advantage of this solution is the enhanced mobility support for roaming across two domains, entirely based on cellular mobility management protocols, which guarantee service continuity including authentication, authorization, accounting, billing systems and other data sources. By reusing the GPRS core network resources, the network deployment cost can also be reduced in terms of

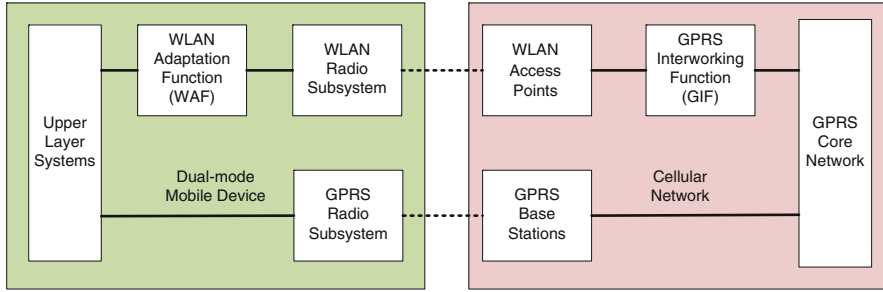


Fig. 2.5 System architecture of SGSN-level coupling approach (Reprinted from [13])

infrastructure with similar functionalities. However, the business model for this kind of coupling is only beneficial to cellular operators, since WLAN only acts as the access part in this architecture. In addition, due to the large amount of WLAN traffic redirected to cellular networks via the SGSN, the core network should be improved to support the new characteristic.

2.3.2.3 Coupling at the RNC Level

The third type of coupling architecture, as proposed in [16], implements the integration of UMTS and WLAN networks at the RNC level. A new network entity, called Inter-Working Unit (IWU), is introduced between the RNC and WLAN, as shown in Fig. 2.6. The IWU functionality is on the network integration and radio access. Some of these modifications imply corresponding modifications of the protocol stack on the mobile terminal. When integration is done on the wireless access networks, there exist several options to forward the signal messages and data flows in both networks. For example, user data in the WLAN can be provided only in the downlink, it can be transferred bidirectionally. The WLAN-related signaling can be exchanged via the WLAN network interface or via the WCDMA interface. An additional distinction includes the fact that access to the network can be provided via the WLAN and WCDMA interfaces simultaneously, or on only one of the interfaces at a time.

The main advantage of this type of architecture is the significant reduction in handover latency, due to the tighter coupling design and functionality reuse in most entities of cellular networks. However, the main drawback is that the architecture is only suitable for network operators deploying both access networks due to the tighter correlation between the two networks. In addition, it requires functionality and protocol modification of both communication systems, which is more complex in system design and implementation.

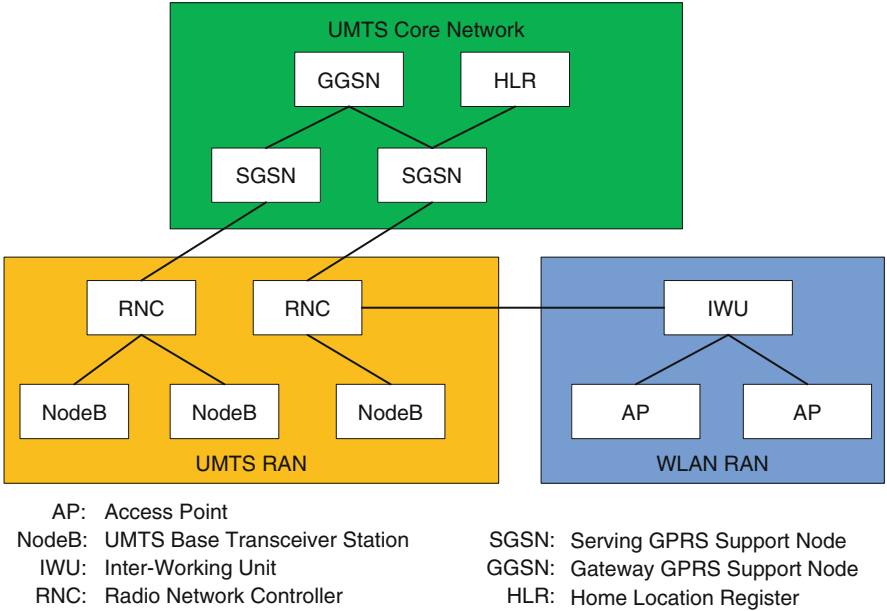


Fig. 2.6 System architecture of RNC-level coupling approach (Reprinted from [16])

2.3.3 Interworking Wireless Local Area Network

The interworking wireless local area network (I-WLAN) was proposed in the 3GPP Release 6 specifications [1], which provides an integration architecture between 3GPP networks and WLANs. As shown in Fig. 2.7, there are three main entities, namely a WAG (Wireless Access Gateway), a PDG (Packet Data Gateway) and a AAA Server. The mobile terminal is typically equipped with multiple network interfaces, such as 3G radio and Wi-Fi card.

In the coverage of WLANs, the mobile terminal can connect to a WLAN access network using a Wi-Fi interface card; and out of the coverage, it can switch to 3G networks, whose service is assumed everywhere. The WAG is a gateway through which the data to/from the WLAN Access Network shall be routed to provide a WLAN-interface enabled terminal with 3G packet-switched based services in a WLAN 3GPP IP Access enabled system. The PDG in the I-WLAN architecture works as a gateway to 3GPP PS based services, which may be accessed via a Packet Data Gateway in the user’s home network, or via a PDG in the selected visiting network. When entering into the coverage of a WLAN access network, the mobile terminal informs the I-WLAN infrastructure of its association thus establishing a secure tunnel between the mobile terminal and PDG. Packet Switched (PS) domain signaling and user plane data are carried into this secure tunnel over the air interface.

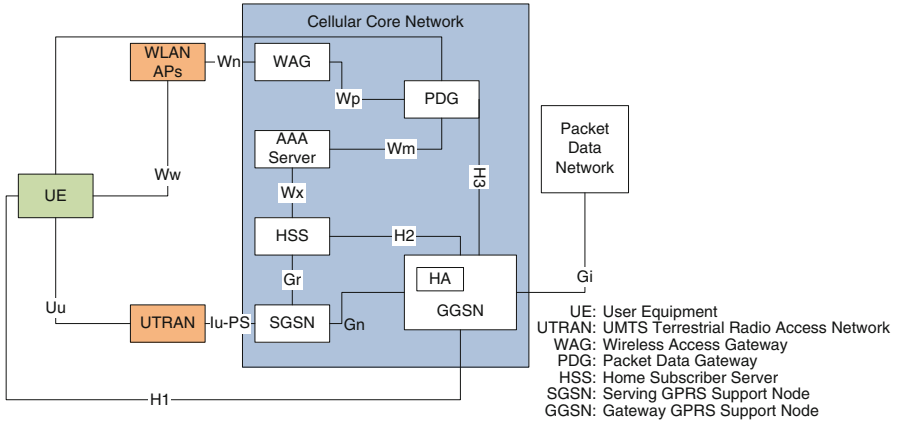


Fig. 2.7 System architecture of I-WLAN interworking (Reprinted from [1])

A new framework for an evolution or migration of the 3GPP system to a higher-data-rate, lower-latency, packet-optimized system, called System Architecture Evolution (SAE), was developed in 3GPP Release 7. To enhance the capability of the 3GPP system to cope with rapid growth in IP data traffic, the packet-switched technology utilized within 3G mobile networks requires further enhancement. Additionally, it is expected that IP-based 3GPP services will be provided through various access technologies. Therefore, I-WLAN is included in the SAE to ensure a smooth migration path from the R6 I-WLAN work to a generic multi-access solution. Apart from seamless mobility across heterogeneous radio access technologies, I-WLAN R7 also supports access to IP Multimedia Subsystem (IMS) and private networks from I-WLAN, LoCation Service (LCS) for I-WLAN in order to enlarge the scope of location-services deployed for GSM/UMTS.

2.3.4 IEEE 802.21 Media Independent Handover

The IEEE Working Group on IEEE 802.21 Standard [8], Media Independent Handover (MIH), is developing a standard to enable handover and interoperability between heterogeneous network types, including both IEEE 802 and non IEEE 802 networks. The standard is proposed for vertical handovers between different network technologies and administrative domains, which can also be used in homogeneous handovers.

The MIH standard comprises a handover-featured framework, a set of handover-enabling functions (MIH Functions – MIHF), and a MIH Service Access Point (MIH SAP and MIH LINK SAP). In MIHF, the functions can be classified into three categories, including the Media-Independent Event Service (MIES), the Media-Independent Command Service (MICS), and the Media-Independent Information

Service (MIIS). MIES provides event classification, event filtering and event reporting corresponding to dynamic changes in link characteristics, links status, and link quality. MICS enables MIH users to manage and control link behavior relevant to handovers and mobility. MIIS provides a two-way channel for all the layers to share necessary information that is useful in making handover decisions[9].

In the MIH framework, information and command services of the mobility management system between other MIHF entities are supported by MIHF through the MIH SAP, which is also responsible for information exchange between the lower layers of access networks surrounding MNs through the MIH LINK SAP primitives. The system architecture of the MIH framework is shown in Fig. 2.8.

It should be mentioned that improvements in the IEEE 802.21 MIH have recently been discussed outside the IEEE working group [7]. More and more extensions and enhancements are first proposed in academic research. For example, an Enhanced Media Independent Handover (EMIH) framework [17] for the original IEEE 802.21 MIH standard was proposed to leverage additional information from higher layers, such as application layers, user context and network context. To achieve this, EMIH considered two important problems from future communication systems, including how to utilize partial information due to incomplete measurements, and how to handle the robustness problem due to inaccurate measurements. Novel algorithms were developed to optimize the decision-making factors and facilitate handover in

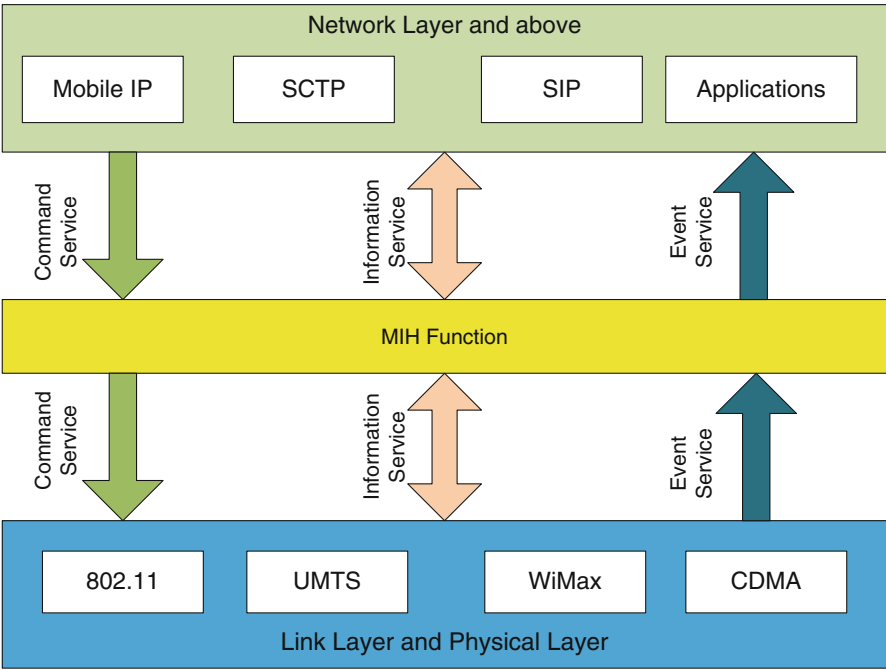


Fig. 2.8 System architecture of IEEE 802.21 MIH framework

heterogeneous wireless networks. Although there were some drawbacks in their system, such as only considering static values in context, the cross-layer design concept of the enhancement framework is an important improvement on the original IEEE 802.11 MIH framework.

In addition, the IEEE 802.21 MIH framework has become the basis to handle the handover between heterogeneous wireless networks, and is considered to be the channel to provide parameter inputs for handover decision-making procedures. For example, a Vertical Handover Decision (VHD) system [11] was proposed to facilitate optimization of overall performance of the integrated system of access networks, specifically in terms of overall battery lifetime and load balancing. In the system, the proposed VHD algorithm is implemented in multiple VHD controllers (VHDCs), which are located in the access networks. From the perspective of the protocol stack on VHDCs, the VHDC algorithm is based on the MIHF layer, which is located above the physical layer and link layer.

References

1. 3GPP: Ts 23.234 v6.10.0 3gpp system to wireless local area network (wlan) interworking; system description (release 6) (2006)
2. 3GPP: Evolved universal terrestrial radio access (e-utra) and evolved universal terrestrial radio access network (e-utran);overall description; stage 2 (release 10) (2009)
3. Akyildiz, I.F., Wang, X., Wang, W.: Wireless mesh networks: a survey. *Comput. Netw. ISDN Syst.* **47**(4), 445–487 (2005). DOI 10.1016/j.comnet.2004.12.001. URL <http://dx.doi.org/10.1016/j.comnet.2004.12.001>
4. Analysys: Picocells and femtocells: Will indoor base-stations transform the telecoms industry (2007). URL <http://tinyurl.com/a4galjt>
5. Chandrasekhar, V., Andrews, J., Gatherer, A.: Femtocell networks: a survey. *Communications Magazine, IEEE* **46**(9), 59–67 (2008). DOI 10.1109/MCOM.2008.4623708
6. Damnjanovic, A., Montojo, J., Wei, Y., Ji, T., Luo, T., Vajapeyam, M., Yoo, T., Song, O., Malladi, D.: A survey on 3gpp heterogeneous networks. *Wireless Communications, IEEE* **18**(3), 10–21 (2011). DOI 10.1109/MWC.2011.5876496
7. Fernandes, S., Karmouch, A.: Vertical mobility management architectures in wireless networks: A comprehensive survey and future directions. *Communications Surveys Tutorials, IEEE* **14**(1), 45–63 (2012). DOI 10.1109/SURV.2011.082010.00099
8. IEEE: IEEE 802.21-2008 – IEEE standard for local and metropolitan area networks – media independent handover services (2008). URL <http://standards.ieee.org/findstds/standard/802.21-2008.html>
9. IEEE: IEEE standard for local and metropolitan area networks – media independent handover services (2012). URL <http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=STDPD95845&contentType=Standards>
10. Lampropoulos, G., Passas, N., Merakos, L., Kaloxylos, A.: Handover management architectures in integrated wlan/cellular networks. *Communications Surveys Tutorials, IEEE* **7**(4), 30–44 (2005). DOI 10.1109/COMST.2005.1593278
11. Lee, S., Sriram, K., Kim, K., Kim, Y.H., Golmie, N.: Vertical handoff decision algorithms for providing optimized performance in heterogeneous wireless networks. *Vehicular Technology, IEEE Transactions on* **58**(2), 865–881 (2009). DOI 10.1109/TVT.2008.925301

12. Pareit, D., Lannoo, B., Moerman, I., Demeester, P.: The history of wimax: A complete survey of the evolution in certification and standardization for iee 802.16 and wimax. *Communications Surveys Tutorials*, IEEE **14**(4), 1183–1211 (2012). DOI 10.1109/SURV.2011.091511.00129
13. Salkintzis, A.: Interworking techniques and architectures for wlan/3g integration toward 4g mobile data networks. *Wireless Communications*, IEEE **11**(3), 50–61 (2004). DOI 10.1109/MWC.2004.1308950
14. Salkintzis, A., Fors, C., Pazhyannur, R.: Wlan-gprs integration for next-generation mobile data networks. *Wireless Communications*, IEEE **9**(5), 112–124 (2002). DOI 10.1109/MWC.2002.1043861
15. Tsao, S.L., Lin, C.C.: Vgsn: a gateway approach to interconnect umts/wlan networks. In: *Personal, Indoor and Mobile Radio Communications*, 2002. The 13th IEEE International Symposium on, vol. 1, pp. 275–279 vol.1 (2002). DOI 10.1109/PIMRC.2002.1046704
16. Vulic, N., Niemegeers, I., de Groot, S.: Architectural options for the wlan integration at the umts radio access level. In: *Vehicular Technology Conference*, 2004. VTC 2004-Spring. 2004 IEEE 59th, vol. 5, pp. 3009–3013 Vol.5 (2004). DOI 10.1109/VETECS.2004.1391476
17. Wang, Y., Zhang, P., Zhou, Y., Yuan, J., Liu, F., Li, G.: Handover management in enhanced mih framework for heterogeneous wireless networks environment. *Wirel. Pers. Commun.* **52**(3), 615–636 (2010). DOI 10.1007/s11277-008-9628-5. URL <http://dx.doi.org/10.1007/s11277-008-9628-5>
18. Wikipedia: Macrocell (2012). URL <http://en.wikipedia.org/wiki/Macrocell>



<http://www.springer.com/978-1-4939-0415-0>

Seamless and Secure Communications over
Heterogeneous Wireless Networks

Cao, J.; Zhang, C.

2014, XIII, 98 p. 55 illus., Softcover

ISBN: 978-1-4939-0415-0