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Introduction

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Despite the promises of feature-rich, highly interactive and high bit-rate multimedia services of third-generation (3G) systems for end-users and increased revenues for the operators, the research community has perceived the limitations of these systems in terms of user throughput and cost of operation and consequently has started to work towards next-generation (NG) systems that are also being addressed as beyond third-generation (B3G) or fourth-generation (4G) systems. NG systems, which encompass B3G, 4G systems, and so on, are expected to allow subscribers to transparently access broadband multimedia services via multiple wireless and wireline access networks as if they are connected via broadband modems to the Internet.

1.1 Standardization

The NG mobile networks are expected to be introduced according to the roadmap shown in Figure 1.1 and are being developed according to the general guidelines and rough specifications of various organizations worldwide.

The Wireless World Research Forum published its Books of Vision in 2000, 2004 and 2006 (Tafazolli, 2005), which outlined technologies suited to NG systems, and the roadmap for their introduction.

The European Union is continuously updating its Information Society Technology (IST) Framework Program, which started in the early 1990s, and is funding a large number of research projects in the domains of broadband access, mobile technologies and services. Examples of these are WINNER, Ambient Networks, E2R and Smart Mobile Life that cooperate under the Wireless World Initiative.

The ITU-R approved Recommendation M.1645 as the baseline for all activities involved in the World Radio Conference 2007 (WRC-2007) for the potential identification of new spectra for mobile and wireless communication.

At the end of 2004 3GPP initiated a study on the further evolution of 3G systems with the major requirements on the radio interface of peak data rates up to about 100 Mbit/s with very low latency. The requirements are far below the ITU-R requirements for systems beyond 3G.

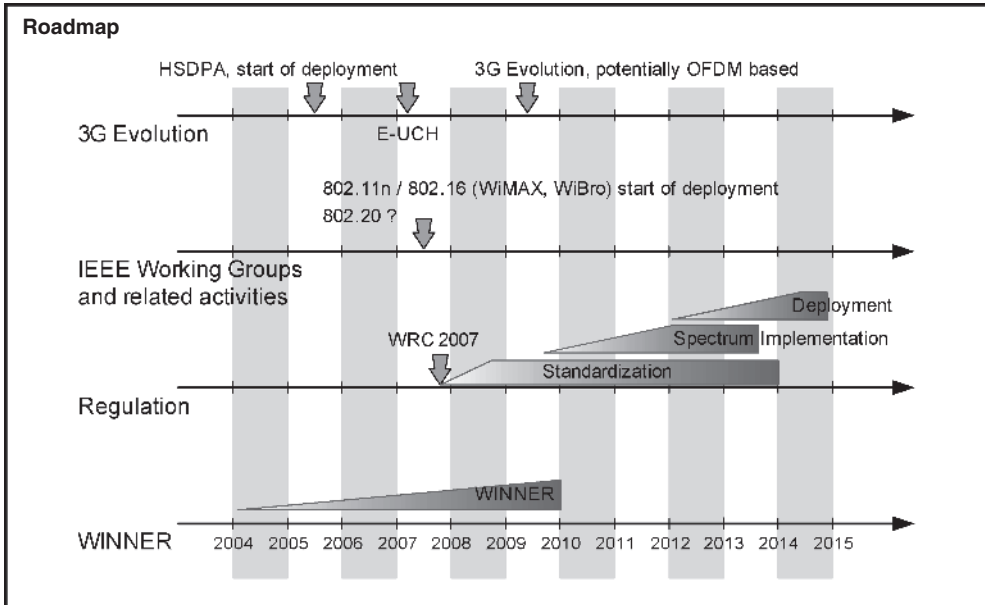


Figure 1.1 Roadmap according to the plans by 3GPP, IEEE, ITU-R and IST-WINNER. Reproduced by permission of © 2005 IEEE¹.

In Japan, the mobile IT Forum (mITF) was established in 2001 to realize future mobile communications systems and services such as the 4G system and mobile commerce services. mITF published roadmaps towards 4G in 2001 and 2004. The National Institute of Communication Technology (NiCT), a public research organization, runs the New Generation Mobile Network Project, which is developing technologies for B3G systems. NTT DoCoMo has developed a system proposal for systems beyond 3G and a demonstrator.

In Korea the Next Generation Mobile Committee (NGMC) is developing guidelines for 4G services, 4G spectra and technologies, and is coordinating 4G technology-related activities in Korea. ETRI of Korea is driving a national program on wideband mobile communications (Wireless Broadband – WiBro) to be deployed during the year 2006.

The Chinese government launched a national research project, Future Technologies for Universal Radio Environment (FuTURE), in the framework program 863 in the area of mobile communications for the time frame of the tenth five-year plan 2001–2005. Project phase 2 is planned up to 2010 and aims to achieve international leadership in mobile communications. The FuTURE project has focused on the development of radio transmission technologies, which satisfies the future needs for the time frame 2005–2010.

In the United States, the IEEE, a globally operating organization with its headquarters in the US, has developed standards for wireless local area networks and is now expanding that work to drive the development of future systems with extended capabilities. These alternative radio standards including activities on interworking and the support of mobility management may have an impact on 3G and its enhancements as well as NG systems. Another major player in North America is the Defense Advanced Research Project Agency (DARPA). The DARPA neXt Generation (XG) communications program is developing the technology to allow multiple users to share use of the spectra through adaptive mechanisms.

The wireless IT sector specifies radio interface systems on the lower layers in IEEE Project 802. In addition, industry standards and proprietary solutions are being developed for special applications. All these standards only focus on parts of the system. Their integration in existing networks is not yet solved. From a capabilities point of view these systems do not fulfill the requirements on systems beyond 3G with respect to supported throughput, latency, mobility and flexibility.

1.2 Next-generation Systems

NG systems according to Figure 1.1 will be shaped by emerging standards for wireless access from mobile terminals, like “3G evolution” and IEEE 802 wireless systems evolution, e.g., 802.11n (“a quarter Gigabit WLAN”), 802.16e (“mobile WiMax”, cf. WiBro), 802.16j (Mobile Multi-hop Relaying, MMR), 802.20 (Mobile Broadband Wireless Access, MBWA) and 802.21 (for handover and interoperability between heterogeneous network types including both 802 and non-802 networks). Figure 1.1 also shows the ITU-R regulation activities represented by WRC-2007, which is expected to specify new bands where NG systems will operate. In view of IST-WINNER, in 2012 the spectrum implementation will start permitting deployment of NG systems from 2014 on.

The main characteristics of NG systems are seamless use of a multitude of existing and forthcoming access network types by mobile terminals (not a replacement of predecessor systems by a new design). Evolution towards NG mobile networks is already taking place through the interworking of 3G cellular systems such as UMTS/HSDPA, cdma2000 and GSM/EDGE with other broadband wireless access technologies such as Wi-Fi hotspots and the forthcoming WiMax metropolitan networks to provide mobile users with anytime anywhere access to broadband multimedia services over the Internet, as shown in Figure 1.2.

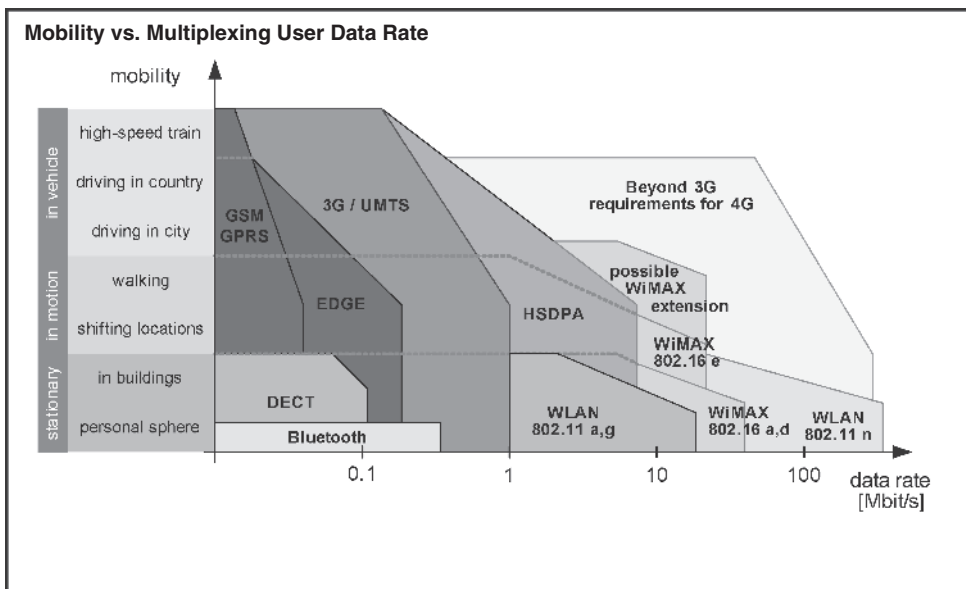


Figure 1.2 Mobility versus multiplexing user data rate of various mobile and wireless systems. Reproduced by permission of © 2005 IEEE¹.

The NG mobile networks will also be shaped by emerging standards for wireless access from mobile terminals, e.g., IEEE 802.20, and for the integration of heterogeneous wireless access networks, e.g., IEEE 802.21, which will establish interworking of IEEE wireless and wireline systems and any other mobile systems. This type of interworking may result in a converged global network and will provide many technical challenges.

Owing to the heterogeneity in the wireless access techniques and the requirements of multimedia and VoIP services, QoS provisioning and enforcement in the future generation mobile networks will become a demanding issue for wireless access equipment vendors, networks service providers and customers.

Multi-carrier based transmission and spatial multiplexing will be the dominating transmission technologies of future broadband networks. Cross-layer protocol engineering along with application-oriented signaling and creation of new services will be required for efficient network resource utilization and to bring profitability to the service providers.

1.3 The IEEE 802 Project

In 1963 the “American Institute of Electrical Engineers (AIEE)” and the “Institute of Radio Engineers (IRE)” merged to become the “Institute of Electrical and Electronics Engineers (IEEE)”. Today, the IEEE is a leading authority for standards, research and scientific exchange in the fields of aerospace, computers, telecommunications, biomedical engineering, electric power, consumer electronics, and many more.

As of 2006, IEEE has more than 365,000 members in over 150 countries. IEEE plays an important role not only for the industry but also for academia. More than 1430 student branches at colleges and universities in 80 countries prove IEEE’s presence in the research community. In 2006, IEEE published over 128 transactions, journals and magazines. Currently, IEEE sponsors more than 300 international conferences worldwide. Out of 900 active, the IEEE 802 LAN/MAN IEEE Standards Committee is one of the most well known.

Authorization for formation of Project IEEE 802 was requested in December 1979. Since then, “The IEEE 802 LAN/MAN Standards Committee (LMSC) develops Local Area Network standards and Metropolitan Area Network standards (IEEE, 2006a).” Approved on March 13, 1980, LMSC was formed by the IEEE Computer Society. Today, 22 Working Groups (WGs) in IEEE 802 consider mainly the lowest two layers of the ISO/OSI reference model. Currently, the following WGs are active:

- 802.0, Wireless Coordination Activity Group
- 802.1, Higher Layer Local Area Networks (LAN) Protocols
- 802.3, Ethernet
- 802.11, Wireless Local Area Networks (WLAN)
- 802.15, Wireless Personal Area Networks (WPAN)
- 802.16, Wireless Metropolitan Area Networks (WMAN)
- 802.17, Resilient Packet Ring
- 802.18, Radio Regulatory Technical Advisory Group (TAG)
- 802.19, Coexistence TAG
- 802.20, Mobile Broadband Wireless Access (MBWA)
- 802.21, Media Independent Handoff
- 802.22, Wireless Regional Area Networks (WRAN)

Inactive WGs hibernate until their reactivation is demanded. They have standards published, but do not work or hold meetings, currently:

- 802.2, Logical Link Control (LLC)
- 802.5, Token Ring
- 802.12, Demand Priority

Disbanded WGs have not published standards or their standards have been withdrawn:

- 802.4, Token Bus
- 802.6, Metropolitan Area Network
- 802.7, Broadband TAG
- 802.8, Fiber Optic TAG
- 802.9, Isochronous LAN
- 802.10, Security
- 802.14, Cable Modem Working Group
- QOS/FC, Executive Committee Study Group

Each of the WGs can have further subgroups. Such subgroups are referred to as Task Groups (TGs). Participants of an IEEE 802 WG may initiate the formation of a Study Group (SG), to study new problems and future extensions. Similar to a TG, the lifetime of an SG is limited. Its main task usually is the development of two documents, the Project Authorization Request (PAR) and the 5 Criteria (5C), which are used to propose the establishment of new TGs. The documents are reviewed by the New Standards Committee (NesCom), which is a body independent of the 25 IEEE societies and councils, LMSC being an example council. NesCom decides about the proposal. For decision making, the 5C used are market potential, compatibility, distinct identity, technical and economic feasibility. The PAR is used to define the charter of a new project or TG and gives the scope of the proposed standard or amendment.

1.4 Motivation and Outline

In this book, we intend to describe and evaluate the main wireless standards that have been created during the last years. We further discuss and propose improvements and regulatory constraints, which are currently targeted at the various standardization groups, and will lead to the next generation systems of the future.

Some fundamentals of wireless communication are reviewed in Chapter 2. A detailed introduction to radio transmission and medium access is given to form a basis for the common understanding of our topic of interest.

The regulation of the radio spectrum is discussed in Chapter 3. Manifold regulation bodies and global institutions are summarized followed by a discussion on approaches to spectrum regulation.

Chapter 4 gives an insight into the basics of wireless mesh networking. Challenges because of radio propagation and specific routing problems are highlighted.

WLANs of the IEEE 802.11 standard and its enhancements are introduced in Chapter 5. Initially, the structure of the 802.11 WG is described. The Medium Access Control (MAC) according to the 802.11 base standard is discussed together with an overview on the different Physical Layer (PHY) supplements for operating in frequency bands at 2.4 and 5 GHz. The capability to support QoS with the means of the 802.11e amendment is examined with the help of simulation.

The ongoing standardization efforts of the IEEE in the context of WPANs in the WG 802.15 are summarized in Chapter 6. The main focus is thereby on high-speed data WPANs of 802.15.3. Different proposals for the PHY and MAC layers are discussed rounded up through a simulation analysis of a candidate MAC proposed by the WiMedia Alliance.

A comprehensive description of IEEE 802.16 WMANs is given in Chapter 7. After introducing the scope of 802.16 and its system concept an overview on the structure of the 802.16 WG and their organization for standardization is given. The multi-carrier PHY of 802.16 based on OFDM and the MAC layer, with a focus on the TDD mode, is described in detail thereafter. Finally, the performance of 802.16 is evaluated by analytic approximation and simulation.

Approaches to wireless mesh networks in IEEE and industry are introduced in Chapter 8. Extensions of IEEE 802.11 and IEEE 802.16 for multi-hop operation to realize homogeneous multi-hop networks are discussed followed by an approach to heterogeneous multi-hop networks of 802.16 and 802.11.

The coexistence of 802 wireless networks is discussed in Chapter 9 from the perspective of medium access control. The realization of homogeneous coexistence, i.e., spectrum sharing of wireless networks of the same technology/standard, is introduced at the example of 802.11e WLANs. Further, the heterogeneous coexistence is addressed in proposing methods that allow the unlicensed operation of 802.16 in a shared spectrum with 802.11.

Chapter 10 gives an overview on and motivation for broadband cellular multi-hop networks to stimulate standardization activities of the IEEE 802 WGs. The introduced relay-based deployment concept founds the basis for standardizing a mesh enhancement of 802.16.

The integration and cooperation of complementary radio access networks with a special focus on mobility and handover procedures is highlighted in Chapter 11.

Chapter 12 reflects major drawbacks of state-of-the-art MAC protocols and proposes a solution for the architecture and protocols of a Mesh Distributed Coordination Function (MDCF) for interconnecting a large number of APs.

Cognitive radio and spectrum sharing as approaches to overcome the current scarcity and waste of radio spectrum are discussed in Chapter 13. A detailed introduction and definition of cognitive radio is given together with a comprehensive overview on flexible spectrum access and spectrum sharing.

This book is summarized in Chapter 14 with a conclusion.

As an extra resource, the companion website contains slides of the figures and tables ready for download for course presentation. Also, a complete implementation of a protocol emulator is available for download to help facilitate an understanding, visualization and performance evaluation of IEEE 802.11. Please go to www.ieee802-wireless-systems.com.

Note

1. Reproduced by permission of © 2005 IEEE. Source: Wireless World Initiative New Radio – WINNER 2005.