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Introduction to Mobile and Networks

The development of mobile and wireless communications was traditionally viewed as a sequence of successive generations. The first generation of analog mobile telephony was followed by the second or digital generation. The third generation enables full multimedia data transmission as well as voice communications. The fourth generation is completely Internet Protocol (IP)-based, including voice communications, and increases the throughput in parallel to these activities related to the evolution of current fourth-generation (4G) wireless technologies. There is also increased research effort on future radio access, referred to as fifth-generation (5G) radio access. Such future radio access is anticipated to take the performance and service provisioning of wireless systems a step further, providing data rates of up to 200 Mbps with wide-area coverage and up to 1 Gbps with local-area coverage. 5G technologies are being focused on as it is expected to eventually deliver approximately 10 Gbps. This can be considered as a normal evolution in response to increased user behavior, demand and quality of service (QoS) expectations.

In this chapter, we provide a brief overview of mobile and wireless networks (MWN). The objective is to present the background and context necessary for understanding subsequent chapters. We review the history of MWN, enumerate their applications and compare them in order to see the effect of such technology not only on the market drivers but also on research domain areas.

1.1. Mobile and wireless generation networks

The International Telecommunication Union (ITU) launched International Mobile Telecommunications (IMT-2000) as an initiative to cover high-speed, broadband and IP-based mobile systems featuring network-to-network interconnection, feature/service transparency, global roaming and seamless services independent of location. IMT-2000 aims to bring high-quality mobile multimedia telecommunications to a worldwide mass market by increasing the speed and ease of wireless communications, responding to problems due to increased demand to pass data via telecommunications, and providing "anytime, anywhere" services.

Two partnership organizations were born out from the ITU–IMT-2000 initiative: the Third Generation Partnership Project (www.3gpp.org) and the Third Generation Partnership Project 2 (www.3gpp2.org). The 3GPP and 3GPP2 developed their own version of 2G, 3G and later mobile systems. In parallel, the Institute of Electrical and Electronics Engineers (IEEE) was developing proper versions of the wireless networks that can be compared functionally with those of 3GPP and 3GPPP2 and their technology-based generations can be crossed with those of 3GPP and 3GPP2. Their terminologies are different but the goal is the same, which is to develop new technologies that make use of advances in the area of wireless and mobile technologies. This is why, we will summarize all the generations developed by these organizations as a path of evolution in the world of mobile and wireless networking.

1.1.1. *First generation mobile technology: 1G*

First-generation cellular networks (1G) were analog-based and limited to voice services and capabilities. Compared to today's technology, 1G technology was vastly inferior. In the late 1970s and early 1980s, various 1G cellular mobile communication systems were introduced; the first such system, the Advanced Mobile Phone System (AMPS) was introduced in the United States in the late 1970s. Other 1G systems include the Nordic Mobile Telephone System (NMTs) and the Total Access Communications System (TACS). While these systems offer reasonably good voice quality, they provide limited spectral efficiency. The evolution toward 2G was thus necessary to overcome the drawback of such technology.

1.1.2. *Second generation mobile technology: 2G*

The second-generation (2G) digital systems promised higher capacity and better voice quality than their analog counterparts. The two widely deployed 2G cellular systems are Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA) that was originally known as American Interim Standard 95, or IS-95 and is now called cdmaOne. Both the GSM and CDMA camps formed separate 3G partnership projects (3GPP and 3GPP2, respectively) to develop IMT-2000-compliant standards based on the CDMA technology. GSM differs from 1G by using digital cellular technology, Time Division Multiple Access (TDMA) transmission methods and slow-frequency hopping for voice communication. In the United States, 2G cellular standardization process utilized direct-sequence CDMA with phase-shift keyed modulation and coding.

There was an evolution of main air interface-related enhancements to GSM: (1) higher data-rates for circuit-switched services through aggregation of several time-slots per TDMA frame with high-speed circuit-switched data (HSCSD); (2) general packet radio service (GPRS), which had efficient non-real-time packet-data traffic support. GPRS reached peak data rates of up to 140 Kbps when a user aggregated all timeslots; and (3) enhanced data rates for global evolution (EDGE) increased data rates up to 384 Kbps with high-level modulation and coding within the existing carrier bandwidth of 200 kHz.

1.1.3. *Third generation mobile technology: 3G*

Further evolution of the GSM-based systems is handled under 3GPP to define a global 3G Universal Mobile Telecommunications System (UMTS). The main component of this system is the UMTS Terrestrial Radio Access Network (UTRAN) based on Wideband Code Division Multiple Access (WCDMA) radio technology, since it uses 5 MHz bandwidth and GSM/EDGE Radio Access Network (GERAN) based on (GSM) enhanced data rates.

3GPP2 implemented CDMA2000 in the 1.25 MHz bandwidth, which increased voice and data services and supported a multitude of enhanced broadband data applications, such as broadband Internet access and multimedia downloads. This technology also doubled user capacity over cdmaOne, and with the advent of 1xRTT, packet data was available for the first time.

The 3GPP2 first introduced high-rate packet data (HRPD), termed CDMA20001xEV-DO. This standard enables high-speed, packet-switched techniques designed for high-speed data transmissions, enabling peak data rates beyond 2 Mbps. 1xEV-DO expanded the types of services and applications available to end users, enabling carriers to broadcast more media-rich content.

The 3GPP enhanced the WCDMA system, providing high-speed downlink packet access (HSDPA) that brought spectral efficiency for higher speed data services in 2001. Then, High-Speed Uplink Packet Access (HSUPA) was introduced in 2005. The combination of HSDPA and HSUPA is called HSPA. The latest HSPA is HSPA+, which resulted from adding multiple input/multiple output (MIMO) antenna capability and 16QAM (Uplink)/64QAM (Downlink) modulation. Coupled with improvements in the radio access network for continuous packet connectivity, HSPA+ allows uplink speeds of 11 Mbps and downlink speeds of 42 Mbps.

As the successor of CDMA2000, CDMA2000 1xEV-DO Release 0 provides peak speeds of up to 2.4 Mbps with an average user throughput of between 400 and 700 Kbps. The average uplink data rate is between 60 and 80 Kbps. Rel. 0 makes use of existing Internet protocols, enabling it to support IP-based connectivity and software applications. In addition, Release 0 allows users to expand their mobile experience by enjoying broadband Internet access, music and video downloads, gaming and television broadcasts.

1xEV-DO Release 0 has been revised to produce Revision A (Rev-A), which increases peak rates on reverse and forward links to support a wide-variety of symmetric, delay-sensitive, real-time, and concurrent voice and broadband data applications. It also incorporates orthogonal frequency-division multiple access (OFDMA) technology to enable multicasting (one-to-many) for multimedia content delivery. As the successor of Rev-A, 1xEV-DO Revision B (Rev-B) introduces dynamic bandwidth allocation to provide higher performance by aggregating multiple 1.25 MHz Rev-A channels.

1.1.4. *Fourth generation mobile technology: 4G*

Fourth-generation or 4G technologies allow wireless carriers to take advantage of greater download and upload speeds to increase the amount and types of content made available through mobile devices. 4G networks are using full IP solutions that deliver voice, data and multimedia content to mobile users anytime and almost anywhere. They offer greatly improved data rates over previous generations of wireless technology. Faster wireless broadband connections enable wireless carriers to support higher-level data services, including business applications, streamed audio and video, video messaging, video telephony, mobile TV and gaming.

As a step toward 4G mobile broadband wireless, 3GPP began its initial investigation of the Long-Term Evolution (LTE) standard as a viable technology in 2004. LTE offers a number of distinct advantages over other wireless technologies including increased performance attributes, such as:

– high spectral efficiency;

– very low latency;

– it supports variable bandwidths;

– simple protocol architecture;

– compatibility and interworking with earlier 3GPP releases;

– interworking with other systems, e.g. cdma2000;

– Frequency division duplex (FDD) and time division duplex (TDD) within a single radio access technology;

– efficient multicast/broadcast.

Ultra-Mobile Broadband (UMB), for the cdma2000 cellular telecommunications system, is run under the auspices of 3GPP2. The UMB cellular telecommunications system offers many new features and techniques that enable it to fulfill high expectations, and compete with other new and emerging technologies:

– data rates of over 275 Mbps in the downlink (base station to mobile) and over 75 Mbps in the uplink (mobile to base station);

– uses an OFDM / OFDMA air interface;

– uses FDD;

– possesses an IP network architecture;

– has a scalable bandwidth between 1.25 and 20 MHz (OFDM/OFDMA systems are well suited for wide and scalable bandwidths);

– supports flat, mixed and distributed network architectures.

Despite this, UMB technology was abandoned in favor of 3GPP 4G.

1.1.5. *Fifth generation mobile technology: 5G*

Studies carried out by industry players and academic into the actual use of the Internet by users led to the development of 5G. Efforts converged to fix a general view about this technology including very high data rates everywhere with low latency of end-to-end communication due to ultra-reliability and availability. Such technology is promising up to 10 Gbps and can even reach 100 Mbps in situations of indoor communication in urban or suburban areas.

The definition of the technology can be represented by the evolution of LTE Advanced itself, but some evolution in terms of utilization of spectrum, higher frequency bands and advanced multi-antenna transmission techniques, and different kinds of communications can be included in this technology such as device-to-device communication with flexible spectrum usage.

1.2. IEEE technologies

LTE is not the only solution for delivering broadband mobile services. Several proprietary solutions, particularly for fixed applications, are already on the market. There are standards-based alternative solutions that at least partially overlap with LTE, particularly for portable and mobile applications. In the near term, the most significant of these alternatives are 3G cellular systems and IEEE 802.11-based WiFi systems. In this section, we compare and contrast the various standards-based broadband wireless technologies and highlight the differentiating aspects of LTE.

1.2.1. *IEEE 802.15: WPAN*

Wireless Personal Area Networks (WPAN) or short-distance wireless networks focus on communication and interoperability among of devices operating under the WPAN. One of the first technologies based on this standard was Bluetooth, which is based on IEEE 802.15.1. However, this standard evolved to include low power consumption with a higher data rate such as Zigbee technology or standard IEEE 802.15.3 targeting a higher data rate intended for point-to-point close-proximity communication including kiosk downloading and intradevice communication just like wireless data centers and wireless backhauling. Accordingly, some forums were founded within the IEEE working group itself in order to provide a higher speed ultra-wideband (UWB) for applications, which involved imaging and multimedia. As a result of all these standards and technologies based on these standards, WiMedia Alliance was created to be responsible for the adoption, regulation, standardization and multi-vendor interoperability of UWB technologies.

1.2.2. *IEEE 802.11: WLAN*

The Wireless Fidelity (WiFi)-based-system is used to provide broadband wireless. It is based on the IEEE 802.11 family of standards and is primarily a local area networking (LAN) technology designed to provide in-building broadband coverage. Current WiFi systems based on IEEE 802.11a/g support a peak physical-layer data rate of 54 Mbps and typically provide indoor and outdoor coverage over a few 1000 m^2, making them suitable for enterprise networks and public hot spot scenarios such as airports and hotels.

WiFi offers remarkably higher peak data rates than 3G systems, primarily since it operates over a larger 20 MHz bandwidth. The inefficient Carrier Sense Multiple Access (CSMA) protocol used by WiFi, along with the interference constraints of operating in the license-exempt band, is likely to significantly reduce the capacity of outdoor WiFi systems. Further, WiFi systems are not designed to support high-speed mobility.

A major benefit of WiFi over World Wide Interoperability for Microwave Access (WiMAX) and 3G is the wide availability of terminal devices. A vast majority of laptops have a built-in WiFi interface. WiFi interfaces are now also being built into a variety of devices, including Personal Data Assistants (PDAs), cordless phones, cellular phones, cameras and media players. This will enable an easy use of broadband network services using WiFi. As with 3G, the capabilities of WiFi are being enhanced to support even higher data rates and to provide better QoS support. In particular, using multiple-antenna spatial multiplexing technology, the IEEE 802.11n standard supports a peak layer-2 throughput of at least 100 Mbps. It is expected that MIMO antennas will use multiple antennas to coherently resolve more information than possible using a single antenna.

1.2.3. *IEEE 802.16: WMAN*

WiMAX IEEE 802.16 standard for the global deployment of broadband Wireless Metropolitan Area Networks is available in two versions: fixed and mobile. Fixed WiMAX, which is based on IEEE 802.16-2004, is ideally suited for delivering wireless, last-mile access for fixed broadband services. It is similar to digital subscriber line or cable modem services. Mobile WiMAX, which is based on the IEEE 802.16e standard, supports both fixed and mobile applications while offering users improved performance, capacity and mobility.

Mobile WiMAX provides higher data rates with OFDMA support and introduces several key features necessary for delivering mobility at vehicular speeds with QoS comparable to broadband access alternatives. Several features that are used to enhance data throughput are: Adaptive Modulation and Coding (AMC), Hybrid Automatic Repeated Request (HARQ), fast scheduling and bandwidth efficient handover. Mobile WiMAX is currently TDD operating at 2.5 GHz. Mobile WiMAX has higher tolerance to multipath and self-interference and provides orthogonal uplink multiple access with frequency selective scheduling and fractional frequency reuse.

1.2.4. *IEEE 802.21: MIHS*

Media Independent Handover Service (MIHS) (standard IEEE 802.21) specified interhandover management through different technologies regardless of type or family of standardization (3GPP or IEEE). It provides a cross-layer solution that triggers the handover at the most appropriate time when moving from one network to another. The aim is to ensure continuity of service when a user is changing its home network to another network which is using different technology. The ultimate goal is to ensure the QoS of an ongoing communication anytime and anywhere. The standard has defined many services and primitives that allow communication that propagates multilayer information from a physical layer to a higher layer so the higher layer is aware of what is going on in the lower layer, is thus handover occurs at the best time.

1.2.5. *IEEE 802.22: WRAN*

This group is mainly working on "enabling broadband wireless access using cognitive radio technology and spectrum sharing in white spaces". Its work focuses mainly on regional networks and this is why the standard is called Wireless Regional Area Networks as they use a cognitive method to detect the white space in TV broadcast bands and reuse them again without causing any interference to the licensed users in the same band. The standard specifies operation in bands that allow spectrum sharing where the communication devices may opportunistically operate in the spectrum of the primary service such as 1,300–1,750 MHz, 2,700–3,700 MHz and the VHF/UHF TV broadcast bands between 54 and 862 MHz.

1.3. Conclusion

The move from analog to digital has paved the way for new generations of WAN. All technologies, regardless of standardization family, IEEE or 3GPP or 3GPP2, are trying to fully IP-orient networks, and this is the reason behind the fast evolution that we are witnessing.

Progress and the fast evolution of wireless networks is due to the evolution of users' demands and expectations, as well as the evolution of the nature of traffic that the Internet is experiencing through different kinds of applications. Such traffic is very greedy in terms of data rate and has strict requirements in terms of QoS parameters. Such progress could not occur if there were no advanced modulation technologies in the physical layer making it possible to have such diversity in current wireless technologies.

Finally, industrial and academic research communities, even though they have had different concepts and points of view of how technology can be implemented and deployed, have been a principal factor in network development.

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