4G Wireless Networks

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4G wireless networks are receiving a lot of attention from researchers, wireless carriers, device manufacturers, and mobile users. This survey compares the original vision with current 4G offerings and considers future prospects.

In 2002, the number of wireless handheld devices reached one billion. By 2006, that number had doubled, and by December 2010, it had reached five billion (see www.itu.int/ITU-D/ict/statistics). Although this exponential growth will eventually slow down, given that there are seven billion people on the planet, in some countries, the number of mobile phones is more than the total population—the adoption rate is more than 100 percent.

Wireless networks offer these devices different levels of mobility support: room-level (personal area networks), cell-level (fixed wireless), campus-level (wireless LANs), country-level (3G/4G networks), and planet-level (satellites). In some cases—such as for implanted RFID sensors—the networks offer "human-level" support, and NASA is even working on interplanetary-level mobility. Wireless networks also offer different per-user bandwidth support, which can vary from a few kilobits per second (for old satellites and 1G or 2G networks) to a few megabits per second (for wireless LANs and PANs and 3G or 4G networks) to several Mbps (for fixed wireless networks). Figure 1 provides a current snapshot of mobility support versus bandwidth.

The emerging 4G networks will play a major role in improving both coverage and bit rate. Many applications, once thought futuristic, are becoming reality with high-resolution mobile telemedicine and sophisticated mobile commerce applications.

Cellular Networks

Table 1 shows how cellular networks have evolved from 1G to 4G, highlighting each generation's key features,[1] quality of service (QoS), and access technologies. All cellular networks use licensed spectrum. 1G networks operated in the 800 to 900 MHz band, while 2G operated in the 1,800 to 2,000 MHz band, and 3G networks operate between 1,800 and 2,200 MHz. The current 4G networks are based on some combination of 700,

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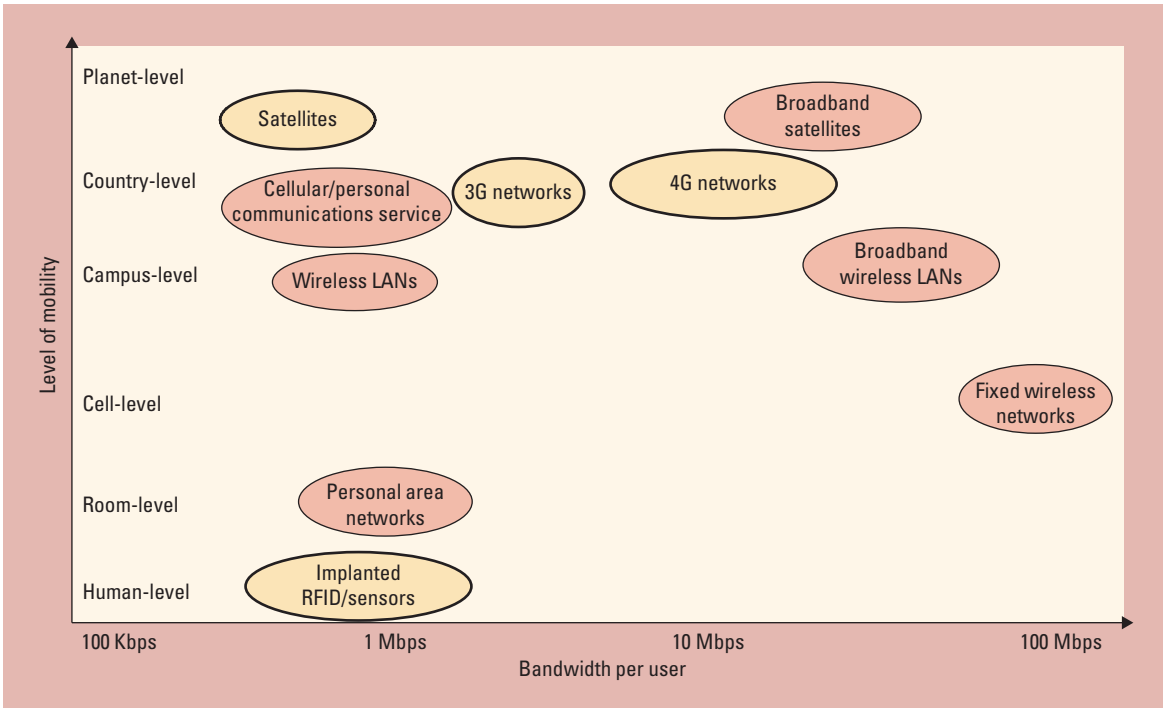

Figure 1. Mobility support versus bandwidth. These numbers continue to change.

Table 1. Different generations of commercial cellular networks.

Generation/ year	Key features and access capabilities	Reliability, QoS, and performance	Access protocols
1G/1982	– Uses analog signals, primarily for voice communications but some support for low rate data – Supports access to and roaming across a single type of analog wireless networks	– Affected by limited coverage – Rudimentary QoS – Performance didn't meet expectations	Frequency Division Multiple Access (FDMA), where each user is assigned a channel for the duration of the call
2G/1991	– Uses digital technology for secure voice and data – Supports access to and roaming across a single type of digital wireless network – Offers access to 1G networks	– Improved reliability with backup access to 1G networks – Better QoS – Performance didn't meet expectations	Time Division Multiple Access (TDMA), where a user time-shares a channel, or Code Division Multiple Access (CDMA), where a user is assigned a code for the duration of the call
3G/2000	– Supports multimedia content – Supports global roaming across a single type of wireless network (such as a cellular network), at speeds of 384 Kbps to several Mbps – Offers access to 2G networks	– Improved reliability with backup access to 2G (sometimes 1G) networks – Improved QoS – Performance is meeting expectation	TDMA and several variations of CDMA, including Wideband CDMA
4G/2010	– Supports global roaming across multiple high-bandwidth wireless networks (50 Mbps or even higher) – Offers IP interoperability for seamless access to the mobile Internet – Offers access to 2G and 3G networks	– Improved reliability with backup access to 3G (sometimes 2G) networks – Highly improved QoS – Performance is somewhat meeting expectations	Orthogonal Frequency Division Multiple Access with multiple antennas (single and multicarrier)

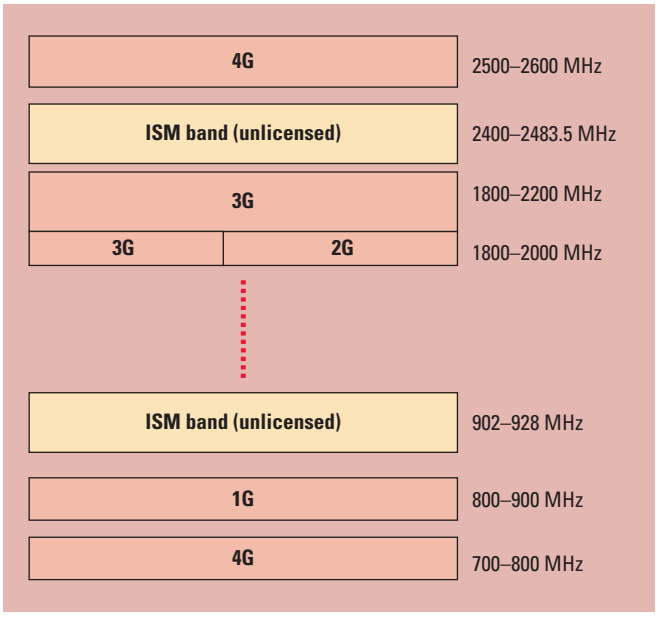

Figure 2. Some allocations for different cellular networks. The current 4G networks are based on some combination of 700, 800, and 2,600 MHz.

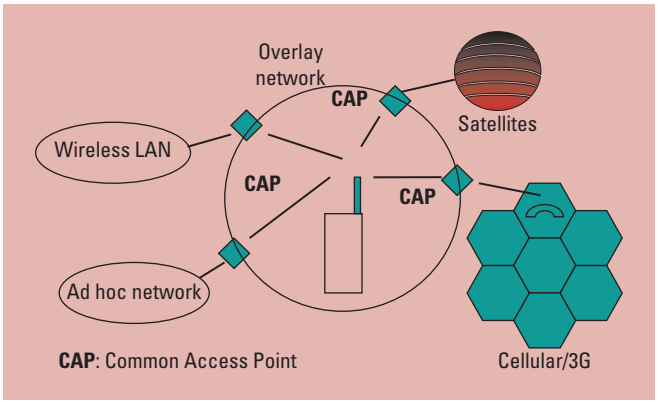

Figure 3. The early vision of a 4G network. Devices could access multiple wireless networks.

800, and 2,600 MHz (see Figure 2). These 4G networks are

- Long Term Evolution (LTE),
- Evolved High Speed Packet Access (HSPA+), and
- Worldwide Interoperability for Microwave Access (WiMax).

Because of the need for more data transmission, 4G wireless carriers are attempting to acquire, buy, or reuse many of the licensed bands.

The Original 4G Vision

In 2001, researchers envisioned giving devices access to multiple wireless networks using an overlay network or by integrating intelligence into the networks (see Figure 3).[2] Researchers have proposed common access points to let a wireless device access several different wireless networks[2] and have envisioned roaming across heterogeneous wireless networks, offering very high bit rates for multimedia services and providing packet-switched wireless communications.[2,3]

The goal for 4G wireless networks was to let users move from one type of wireless network to another. For example, when at home, a user could use the mobile device as a cordless phone to access the public switched telephone network, but when in the car, he or she could connect to a cellular network. When in an area not covered by a cellular service, the user could switch to a satellite-based network. After reaching the office, he or she could switch to a high-bandwidth wireless LAN. The factors distinguishing the 4G network from earlier networks would be the capability to roam across cellular networks, wireless LANs and WANs, satellites, and other networks; IP interoperability; and higher bit rates (50 Mbps or more).

Today's Reality

Currently, several carriers offer a 4G network service, but these 4G networks either use enhanced 3G technologies or offer only a minimal implementation of 4G technologies. The 3G networks that have been extended to 4G are Wideband Code Division Multiple Access (W-CDMA) and WiMAX. W-CDMA evolved into HSPA+, which AT&T currently uses. AT&T is also investing heavily in LTE and LTE Advanced. WiMAX has evolved into a 4G network and is used by Clearwire and sold by Sprint. The 4G network that's running at low speeds is LTE, used by Verizon.

However, these aren't true 4G networks, because they don't offer an International Mobile Telephony (IMT)-compliant 4G speed (bit rate) of 50 to 100 Mbps per user. Researchers are working toward IMT-compliant 4G systems, which could be offered in the next few years. Currently, this lower-level 4G service is mostly available in population centers and urban areas, with many nearby areas still having 3G or even 2G service (see Figure 4).

Orthogonal Frequency Division Multiplexing

OFDM is a variation of Frequency Division Multiplexing. It uses multiple carriers to support

higher bit rates per user. The frequencies of carriers are chosen by standards committees to be orthogonal, so there's no cross-talk or interference. Figure 5 shows how multiple carriers are created and then multiplexed to create a single carrier for transmission.

The access technologies can use advances in wireless antennas, such as multi-input, multi-output (MIMO) antennas. For 4G networks, MIMO is an important technical advance. Figure 6 shows how single-input, single-output (SISO) antennas (used in most mobile phones today) and MIMO antennas work. The MIMO allows either more capacity (bit rate) or improved quality of transmission (because the receiver can take the best signal out of multiple copies of the same signal it receives).

Existing 4G Technologies

The three different types of current 4G networks are based on

- HSPA+, sometimes using W-CDMA;
- LTE using OFDMA; and
- WiMAX using OFDMA.

Table 2 compares the three networks.

LTE. The 3rd generation partnership project (3GPP) led to the development of LTE.

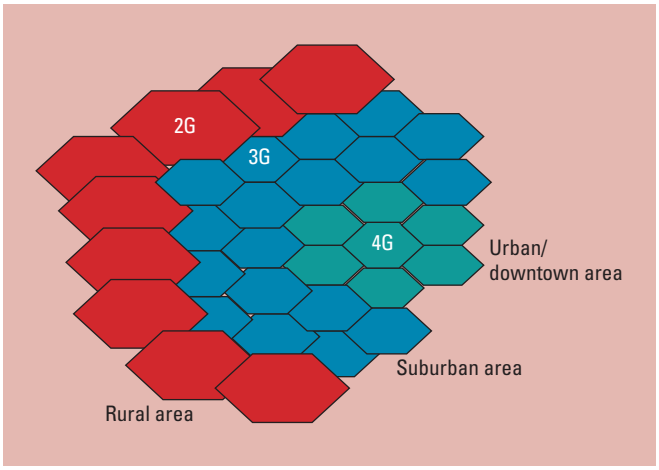

Figure 4. An example of 2G, 3G, and 4G wireless network coverage. Currently, 4G service is mostly available in population centers and urban areas, with many nearby areas still having 3G or even 2G service.

The downlink (from the base station to the device) uses OFDM access (OFDMA) or multiple carriers in the downlink. The uplink (from the device to the base station) uses a single-carrier FDMA. LTE supports multi-antenna technologies, such as MIMO, and has been adopted by Verizon as well as AT&T, T-Mobile, and Sprint. The ongoing work on LTE Advanced will result in "true" 4G speeds and bit rates.

HSPA+. 3GPP also developed HSPA+, which is based on W-CDMA and uses MIMO. The current rates are 2 to 10 Mbps, but it can offer 22 to

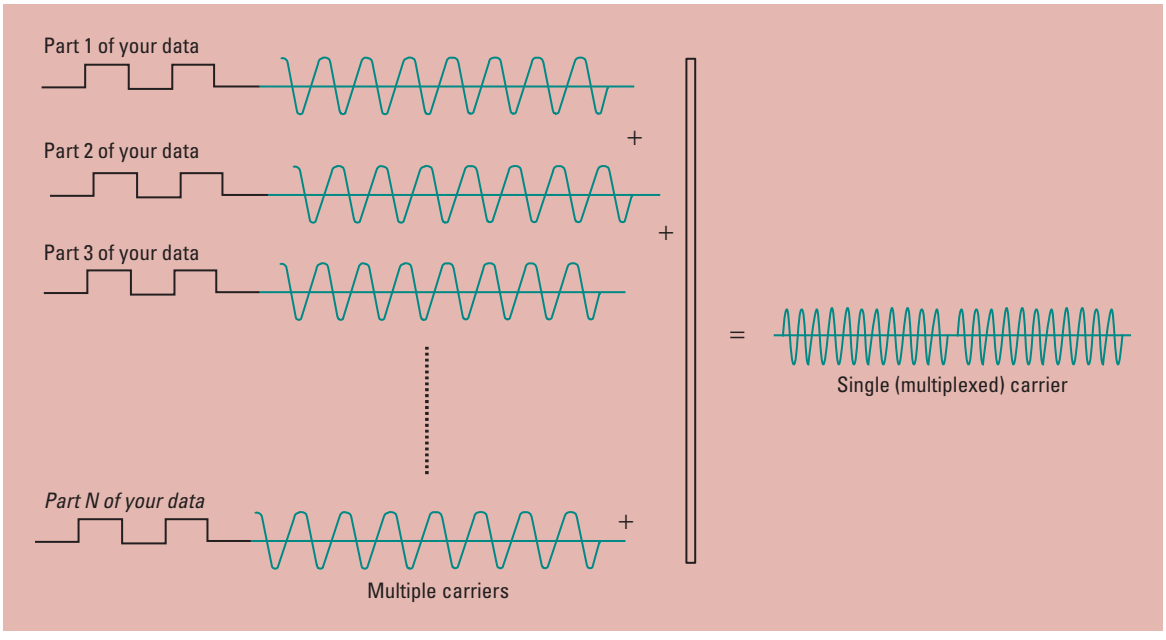

Figure 5. Multiple carriers and multiplexing to get a single transmission carrier.

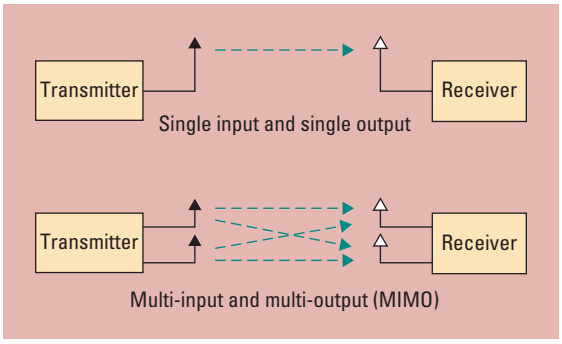

Figure 6. Single-input, single-output and multi-input, multi-output antennas. MIMO antennas offer either higher bit rates or improved transmission quality.

168 Mbps. The dominant players are AT&T and T-Mobile. AT&T claims that HSPA+ can deliver speeds four to 10 times higher than 3G speeds.

WiMax. This is a fixed wireless system (IEEE 802.16a, b, c, and d), but it has a standard for mobility support (IEEE 802.16e). The frequencies are 10 to 66 GHz for 802.16a, b, and c, but there are lower frequencies, such as 2 to 11 GHz for 802.11d and 802.11e (Mobile WiMAX). WiMax is based on OFDM (multiple carriers) and MIMO antennas. It offers quality of service by scheduling time slots for users. WiBro, the Korean standard for cell phone TV, and Hiperman, the European standard for metropolitan wireless networks, are compatible with WiMax.

The advantages are high bandwidth or great coverage (approximately 30 miles from the antenna), but availability is limited in most places. Major support for WiMax comes from Clearwire (and Sprint as a reseller), which is using 2.5 to 2.6 GHz licensed spectrum. The WiMax Forum is managing this network's progress.

Applications and Deployment

Current 4G applications include mobile telemedicine and monitoring, high-bandwidth mobile applications, and mobile entertainment and multiparty games. 4G networks are affecting businesses and individuals through upgrade costs, limited availability, and lost investments in 3G infrastructure (especially for those who recently switched to a 3G network). Barriers to 4G adoption and to the deployment of 4G applications include limited spectrum, power users and applications that consume too much of the network resources, and the lack of 4G availability and usability in some places.

The future for 4G LTE Advanced seems promising. Many carriers are using or moving to 4G LTE and so should eventually move to LTE Advanced (as opposed to WiMax). WiMax is likely to play a more limited role in 4G's future.

Many related advances are likely to affect how 4G (or even futuristic 5G) networks will be designed, deployed, used, and maintained. These include advances in smart radio, so a device can access any available wireless network by adjusting its frequency, power level, and access protocols. We'll also need to address issues related to network reliability, access, and coverage (population centers versus rural), as well as the ability to acquire and effectively use spectrum. The cost of infrastructure (legacy, existing 3G, and some 4G infrastructures), user-centered pricing, explicit QoS for sophisticated applications, and new business models will also affect future offerings. The demand for more sophisticated applications, such as content-rich mobile commerce, and high-end healthcare applications, such as mobile telemedicine and wellness monitoring, will affect the future of 4G and 5G networks.

Table 2. A comparison of various 4G technologies.

	LTE	HSPA+	WiMAX
Advantages	Most coverage and support from major carriers	Existing deployment	Potential for high-bandwidth or wide coverage
Limitations	Limited spectrum	Limited new deployment	Limited availability
Power consumption	Low (per base station)	Low (per base station)	High
Relative range	Small	Small	Wide coverage
Cost	Low	Low	High
Future	Promising	Likely to be phased out	Not clear

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