

4G: The What, Why and When

The worldwide adoption and growth of wireless are the fastest technological achievements in history.

Executive Summary

Moving from basic analog to high-speed digital in a mere 25 years is quite a feat. Wireless networks are now advancing to third generation (3G) capabilities, providing increased data transfer rates that make it easier to access applications and the Internet from mobile devices.

Continuous improvements in semiconductor and computing technologies encourage the wireless industry and consumers to automatically anticipate what's next. While service providers are just beginning to offer 3G-enabled services, the concept of fourth generation (4G) wireless networks is already under discussion. But, without a standard definition of 4G, there are many confusing claims about the capabilities, breakthroughs and the potential of so-called 4G technologies. Much of this can be attributed to the breadth of technology covered under the 4G banner, the wide range of business interests involved in creating the 4G vision and the uneven progress of the contributing factors that can make 4G real.

The purpose of this paper is to:

- Clarify the definition of 4G from a technology perspective
- Present business benefits of 4G-enabled services
- Propose a realistic timeline for the adoption of a 4G standard

The Current State of 3G

Before beginning a discussion of 4G technologies and business applications, it is important to understand the current state of 3G networks. There is no official definition by a standards group of what constitutes 3G. The term evolved in the wireless industry and generally includes the International Standards Union's (ITU) IMT-2000 technology definition and related features.

IMT-2000 is an ITU term that defines globally recognized 3G technologies for use in IMT-identified radio frequency bands. Technologies currently recognized as meeting these requirements include WCDMA, CDMA2000, TD-CDMA and EDGE.

Over the last decade, several incremental improvements in radio technology and command-and-control software have been classified as 3G technologies. To denote their significance properly, the technologies are commonly (and unofficially) named as higher and higher variants of 3G such as 3.5G and 3.9G. The different 3G technologies use more or less the same repertoire of tools with different combinations and variations to optimize bandwidth usage.

Enabling 3.xG

Radio advancements of 3G are classified as antenna techniques or coding/modulation schemes. Several new radio techniques are employed to achieve high rates and low latencies. They include Space Division Multiplexing via Multiple Input/Multiple Output (MIMO), Space Time Coding (STC) using higher order of modulation and encoding schemes, sophisticated beam forming and beam directionality control, and inter-cell interference mitigation.

Of these, MIMO and beam forming are advanced antenna technologies. Essentially, MIMO creates multiple channels to carry user information, leading to higher capacity. It is analogous to Wave Division Multiplexing (WDM) used in fiber optic networks. Beam-forming techniques temporarily improve gain and offer higher capacity. Properties of a beam are "tuned" or customized for a subscriber to achieve this capability for a limited duration. Some vendors have combined the two techniques to offer a beam-forming MIMO architecture that provides additional gain by steering grouped signals to a CPE on the network, beneficial especially at the edge of the cell.

Coding and modulation techniques improve the number of bits transmitted per Hz of available bandwidth via turbo codes and/or higher order QAM. These techniques lead to higher capacity as required by advanced networks. Additionally, techniques that reduce interference are also used to further boost the capacity.

Networks beyond 3.5G will use a variant of Orthogonal Frequency Division Multiplexing (OFDM). WiMAX uses OFDM in both the downlink — from base station to mobile — as OFDMA and the uplink as OFDM/TDM. 3G Long Term Evolution (3G LTE) uses OFDMA in the downlink, but SC-FDMA in the uplink to avoid the high Peak to Average Ratio (PAR) of OFDM with the expectation of reducing the battery power usage requirement of the mobile terminal.

UMB, expected to be ready commercially by 2009, offers flexibility in spectrum management where multiple carriers can be used with different technology — CDMA or OFDM. While CDMA is well-suited for voice, OFDM can be a better transport mechanism for data. With a mix of technologies, backward compatibility is possible while potentially better spectrum utilization can be achieved if capacities on different carriers also match the load. The cost is the overhead to maintain multiple carriers and control mechanisms.

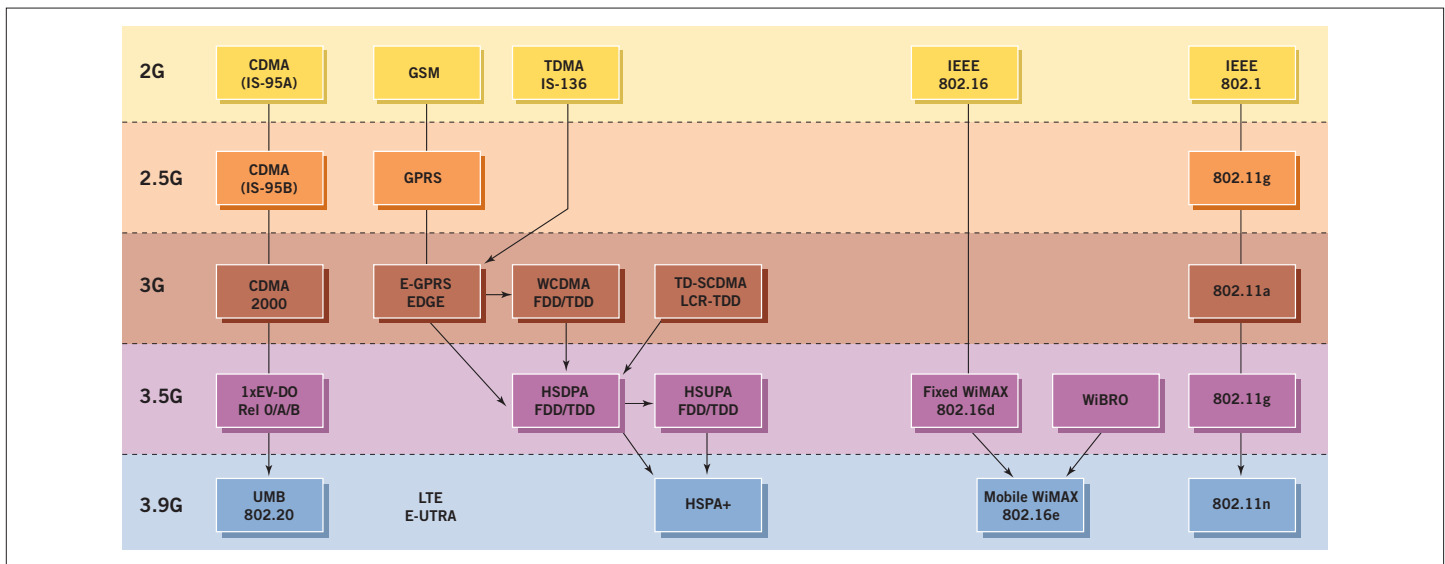


Figure 1. Evolution to 3.9G

Figure 1 shows the path mobile networks will take as they evolve to what is considered by many in the industry as 3.9G. When 3.9G is deployed, a network-wide data rate of several hundred Mbps is possible for the entire cell coverage area.

The CDMA standards use Multi-Carrier CDMA (MC-CDMA) along with several other radio techniques to achieve up to 288 Mbps in the downlink (base station to mobile subscriber) if and when Ultra Mobile Broadband (UMB) is implemented. The UMTS standards (the evolution path for GSM) are expected to provide around 182 Mbps in the downlink via HSPA+ technology. Mobile WiMAX, or 802.16e, is expected to peak at a maximum of 79 Mbps.

Note that all data rates are for the entire cell coverage areas using at least 20 MHz of bandwidth and include various overhead bits, reducing the actual capacity available to mobile subscribers to a lower value.

Definition of 4G: From the Source(s)

Currently, no industry group has a mandate to create a formal definition of 4G. So, no technology can officially be classified as 4G. This has resulted in some near term technologies such as WiMAX or 3G Long Term Evolution (LTE) being classified as 4G in some quarters.

The ITU IMT-A Standard

The ITU may emerge as the authority to define what constitutes 4G. ITU's IMT — Advanced (IMT-A) is a concept that intends to build on the success of IMT-2000 as a benchmark for 3G. IMT-A systems are envisioned to have capabilities surpassing those of IMT-2000 by orders of magnitude.

IMT-2000-based 3G systems generally provide peak data rates of around 1–5 Mbps. The IMT-A concept outlined in the ITU IMT-2000 document states:

“With the expectation that there will be a need for commercial services in multi-user environments targeting peak data rates approaching 100 Mbps for ‘highly mobile’ users, and up to 1 Gbps for nomadic (low mobility or stationary) users, the IMT-A concept requires mandatory backward compatibility with prior systems to match these high data rates.”

Highly mobile users are further defined as accessing the network at speeds up to 125 KMph, while maintaining network connectivity at speeds of up to 350 KMph. Data rates are not yet specified.

3G radio improvements are considered as IMT-2000 Enhanced. Additional capabilities will also be available from an integrated network under the IMT-A or 4G umbrella. Under 4G, access is not confined to mobile users only, but is expanded to stationary or nomadic users just as the network itself is not limited to Radio Access Networks (RANs), but includes the whole: wireline access, wireless radio access, core command, and control and back office functions in a unified system.

Figure 2 represents the ITU's high-level view that delineates IMT-2000 and its Enhanced version versus what is to follow — IMT-A.

IMS Support

Support for mature IP Multimedia Systems (IMS)-based network is another requirement to be considered in the definition of 4G. Originally, concepts and specifications for IMS were developed by the 3GPP group in cooperation with IETF to meet the needs of GSM operators in providing IP-based services. With IP as the underlying transport protocol, standardization relies on mature technologies and the focus is shifted to what matters most to the subscribers and operators: services. The IMS concept is further evolved to include the complexities introduced by 4G networks.

A move to 4G should constitute a leap from 3.xG, not just another incremental change in data rates. Given the goals of IMT-A, it is appropriate to use this concept as the foundation for 4G to make it more than just a slight step up from 3G. With this stipulation, technologies delivering peak rates under 100 Mbps to a user could not be considered 4G.

Human Requirements

Finally, how people use wireless networks is a consideration when defining 4G. Table 1 summarizes the evolution of how the basic senses of sound and sight — as well as knowledge — are fulfilled by various generations of mobile wireless networks.

HUMAN SENSE	SOUND	SIGHT	KNOWLEDGE
NETWORK GENERATION			
1G-2G	Voice	—	Low Speed Data
3G	Voice	Images	Hypertext (HT)
4G	Voice, Speech	Video	Files (Speech, HT, Video)
Typical Bandwidth	10–80 Kbps	1–20 Mbps	0.5–10 Mbps
Required Latency	<160 ms	<100 ms	<5 s
Principal Application	Communication	Entertainment	Information

Table 1. Mobile wireless generations and applications

Expanding 4G Beyond Wireless

Figure 3 shows the concept of a unified architecture employed by the IMT-A network that is built on IP as the common transport layer protocol. A rich interface regime fosters and facilitates new services that enable the use of communication networks by devices yet-to-be-developed. With substantial improvements in access speeds, applications popular in the wireline world can be ported under the advanced wireless networks in a uniform, seamless way so the participating end users do not notice nor care how they access a service.

Developments on the Road to 4G

Some service providers and equipment manufacturers have already staked claims to 4G service by providing mobile access rates above 3G’s 1–5 Mbps along with lower latencies. Rival camps claim services with higher data rates under the banner of 3.5 or even 3.9G. But, just improving access speeds alone should not qualify as 4G without an entire suite of network-level integration.

The dilemma faced by 3G groups — 3GPP and 3GPP2 — is that they cannot claim anything to be 4G under their 3G banner. The notion of 3G LTE has been established for a number of years now. But, technology developments outpace the reality of the standard-making process.

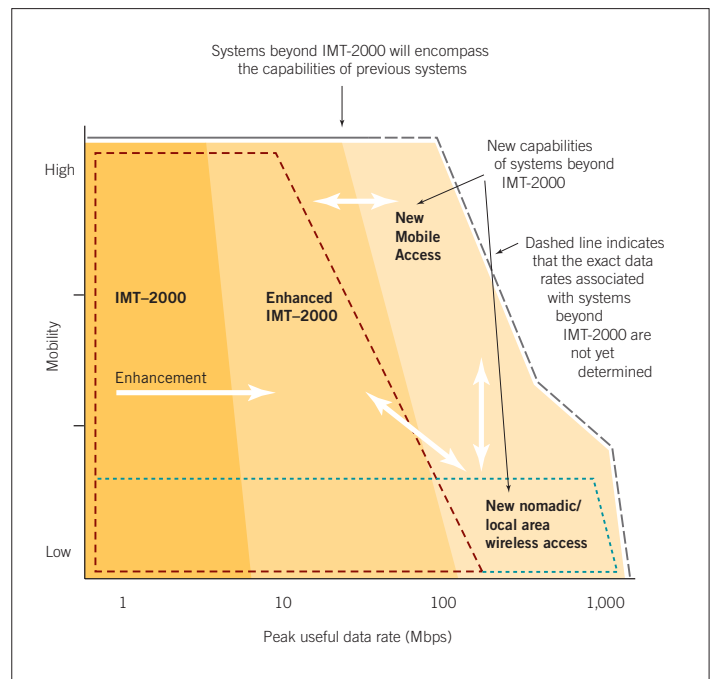


Figure 2. Boundaries of IMT systems

Today, 3G is deployed in most developed countries. 3GPP began with the 2G GSM base to evolve via WCDMA as the core technology. 3GPP2 evolved from CDMA to CDMA2000. Both standards groups promise comparable performance consistent with availability of radio spectrum. Both have adopted OFDMA as the standard for at least the downlink (base station to mobile user) direction and have further promised to allow IP as the preferred packet format, beyond unique MAC layers.

Networks based on 3G LTE are expected to be available by the 2010–11 timeframe, allowing for a convenient entry for 4G in the subsequent years. According to this schedule, there is no room for a near-term 4G-network deployment. So what about WiMAX, the 4G wannabe?

Where Does WiMAX Fit In?

Recently, ITU delegates declared WiMAX as an IMT-2000 technology. The technology under consideration for inclusion in IMT-2000 is IP-OFDMA. A specific variant of this technology is used by the IEEE 802.16e mobility standard, commonly referred to as WiMAX. As a result, WiMAX now has gained the coveted status of a 3G technology. While contradicting claims that WiMAX is a 4G technology, it nevertheless is significant that the IEEE standards embedded in WiMAX gain an official standard status from the ITU.

IEEE is pursuing a next-generation version of the technology embedded in WiMAX under Study Group 802.16m. A stated goal of this study group is to provide wireless data rates in excess of 100 mbps. This technology is expected to reach standards status by 2009 and could be a candidate for 4G.

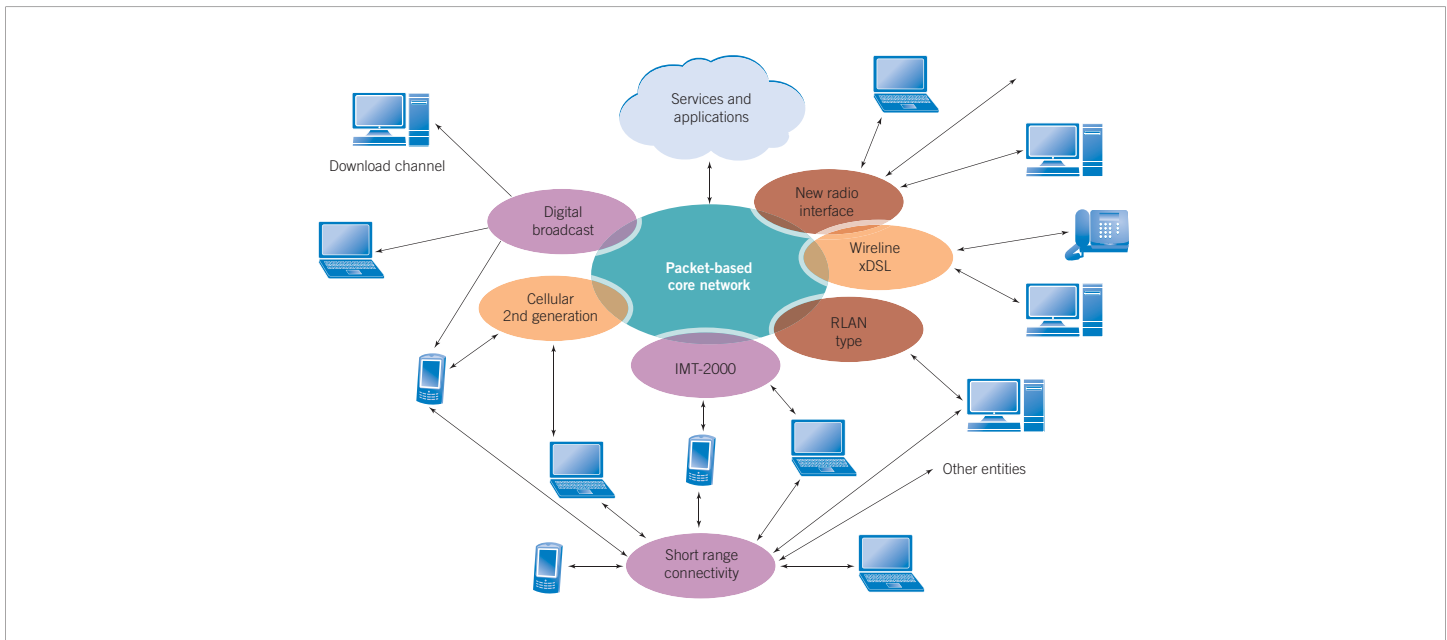


Figure 3. Unified architecture for IMT-Advanced systems

While WiMAX (IEEE 802.16e) has gained acceptance globally as a mobile broadband technology, its spectrum allocation is inconsistent. As a result, it is not fully recognized in some countries that would like to follow ITU specifications strictly: China being a case in point. The frequency of 2.5 GHz is included in the WiMAX standard as a valid profile and authorized in the United States, Russia and the United Kingdom, but is reserved by IMT-2000 for WCDMA in some other countries.

Implementing 4G Services

When a standard definition of 4G is accepted, it will encompass all existing generations of fixed and mobile wireless technologies with major improvements in performance and capabilities. Fundamentally, 4G intends to alter the paradigm of user-network communication via a single device connected to a (mostly) single network. Since 4G is expected to be more than 3G phone service, it allows all sorts of portable devices onto “the” network.

The Always Best Connected (ABC) character of 4G provides the service with the most suitable network to a device. Embedding broadband in all types of consumer devices is a goal of 4G. The World Wireless Research Forum anticipates some 17 trillion devices connected for seven billion people by the year 2017.¹ If reality matches that scale, 4G will do for portable consumer devices what 3G is predicted to do for individual phones and laptops in terms of advances in connectivity and productivity.

Figure 4, published by the ITU, depicts the IMT-A vision of various access systems (“networks”) interconnected to provide services in a cooperating manner. To achieve this vision, ITU defines layers of network based on the geographic scope of coverage and extent of mobility offered by each layer.

There are four access layers:

- **Fixed (i.e., DSL, cable, fiber)** — fixed wireline networks
- **Personal (i.e., Bluetooth, UWB)** — cars, cell phones, PDAs
- **Hot-spot (i.e., Wi-Fi/802.11)** — restaurants, coffee shops, planes
- **Cellular (i.e., UMTS, WiMAX)** — highly-mobile users

The standards groups covering existing technologies mentioned above are working on the next-generation versions, which include higher speeds and more advanced network integration and enablement for service offerings.

Interactions among networks are not limited to horizontal (intra network) or vertical (inter network) handoffs for service continuity, but encompass complex functions of billing, security, privacy, Quality of Service (QoS), network resilience, fault location and recovery to provide a “seamless” experience to the user. This vision essentially eliminates the need for the user to know anything about the network (operator, topology, radio or other technology), and requires a lot of heavy lifting by the networks to make it a reality.

Key Attributes of 4G

Based on the requirements for seamless interaction between networks, 4G is characterized by the following key attributes:

- **Support for Multiple Applications and Services** — Efficient support for unicast, multicast and broadcast services and the applications that rely on them. Prompt enforcement of Service Level Agreements (SLA) along with privacy and other security features. Minimally, service classes include delay sensitive, loss sensitive, delay and loss sensitive and best effort.

¹System Concept and Requirements for the Future Wireless World: The WWRF View, January 2006.

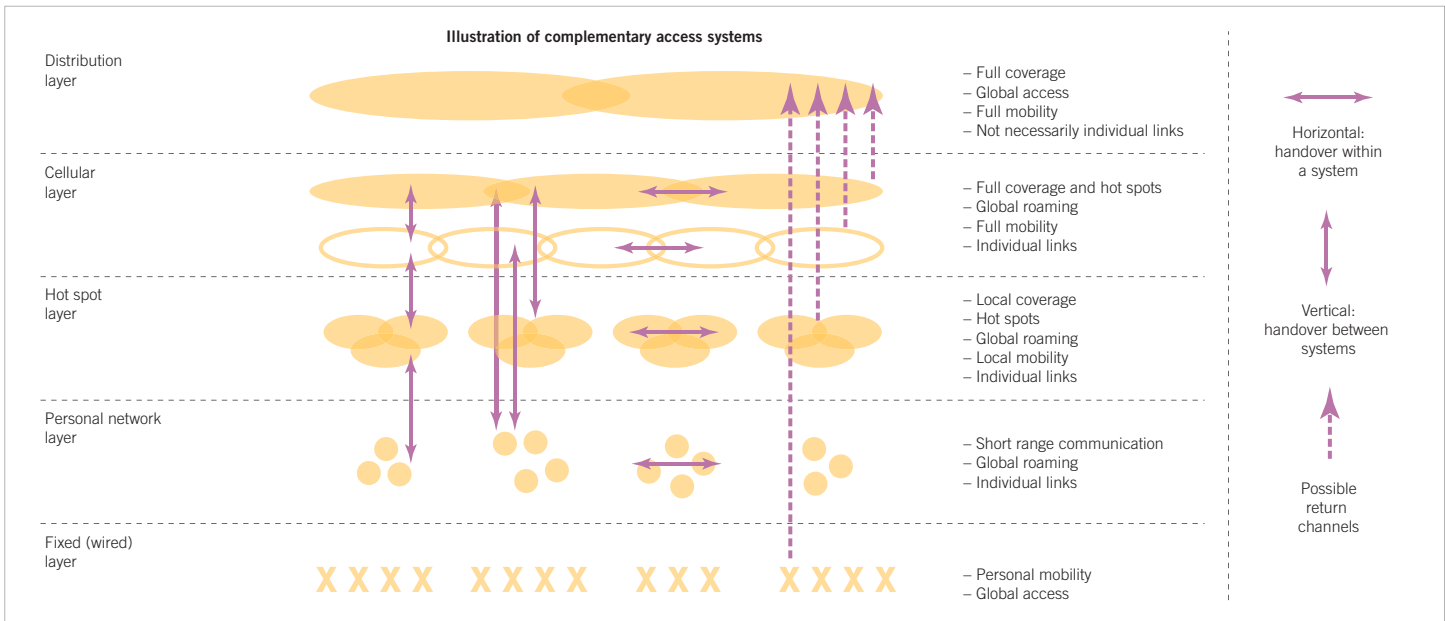


Figure 4. ITU's vision of IMT-Advanced providing service continuity

- **Quality of Service** — Consistent application of admission control and scheduling algorithms regardless of underlying infrastructure and operator diversity.
- **Network Detection and Network Selection** — A mobile terminal that features multiple radio technologies or possibly uses software-defined radios if economical, allows participation in multiple networks simultaneously, thereby connecting to the best network with the most appropriate service parameters (cost, QoS and capacity among others) for the application. This requires establishing a uniform process for defining eligibility of a terminal to attach to a network and to determine the validity of link layer configuration.
- **Seamless Handover and Service Continuity** — A “base station” that features intra- and inter-technology handovers, assuring service continuity with zero or minimal interruption, without a noticeable loss in service quality. Support for this function requires continuous transparent maintenance of active service instances and inclusion of various access technologies, from WiFi to OFDMA.
- **Technology and Topology Independence** — Service capabilities to transcend generations of technologies. Services not constrained by topology or technology limitations, but rather achieve the “Always Best Connected” characteristic.

The Business Case for 4G

The vision of 4G is a framework for an advanced infrastructure consisting of architecture, core technologies and open interfaces for building, deploying and providing applications to achieve ubiquitous, converged broadband services. 4G is much more than high access speeds — it is a whole new “whole.”

- **Ubiquitous** — any service at any place and any time via any network to any person on any device
- **Converged** — portability, seamlessness and continuity
- **Broadband** — capacity-agnostic services

If a financially sound business model evolves to support the 4G vision, how do service providers and vendors evolve in a timely manner to foster its existence and growth?

- What can the user community do with it?
- What are the costs?
- Is the cost low enough to make it attractive to users?
- Can usage patterns encourage application developers to continue to innovate?

The short answer to the “Why 4G?” question is not why, but when.

There are several factors to consider:

- **Business Need and Opportunity** — 3G operators are learning that future average revenue per user (ARPU) does not come from traditional service like voice and allied products (like ring tones). Rather, data services such as mobile, video, music, games, Internet access, navigation and messaging (SMS and MMS) are the path to greater revenue. The trend is unmistakable and leads to more services that exploit infrastructure offered by advanced technology.
- **Technology Pull** — As Figure 5 shows, the key processor and component semiconductor technology required to make progress towards 4G is likely to reach economical levels as 4G comes to fruition. Advances in power technology and radio receiver technology are likely to converge with processor technology to make the solutions viable.
- **Rate of Innovation** — Adoption of application software that combines media, location, user profiles and security fosters a higher rate of innovation. This in turn hastens the march towards solving the complex problems related to ubiquity via presence technologies.

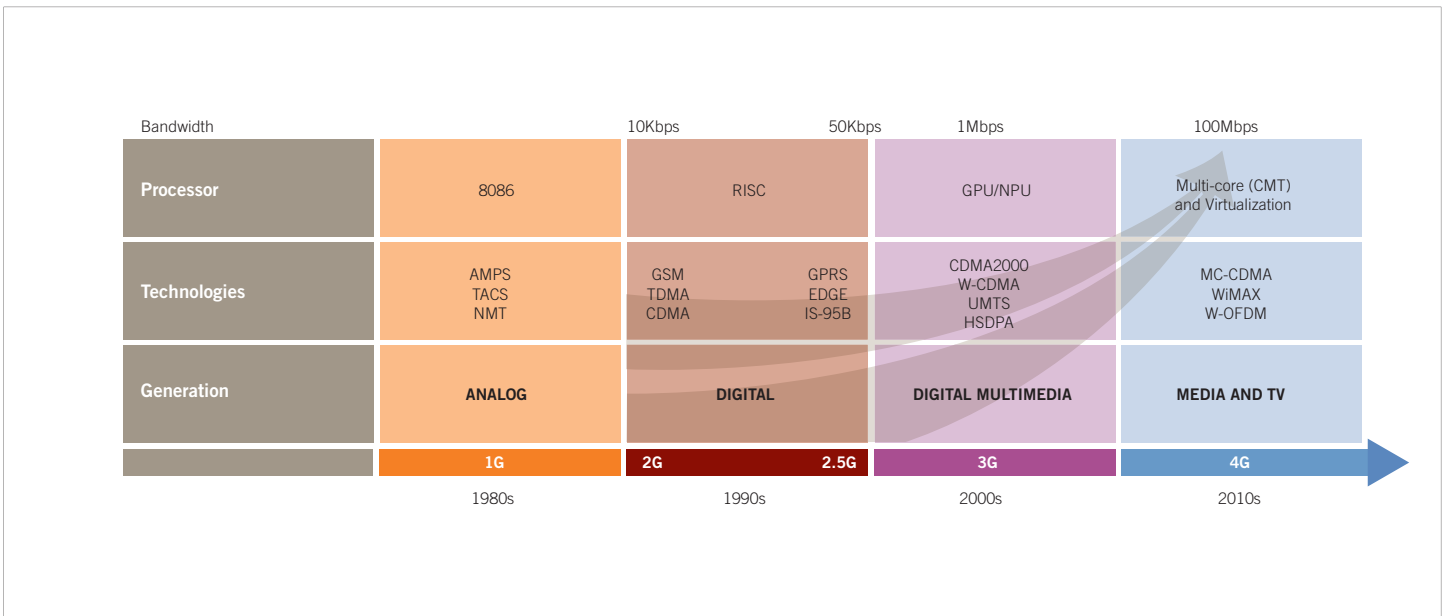


Figure 5. Evolution of processors and DSP technology for 4G

- **Disruptive Technologies** — Always a wild card, new technologies tend to accelerate the pace of growth and at times cause fragmentation. In the past, disruptions have steered the industry off a planned path and actually slowed the pace of growth. The factors behind disruptions such as technical talent, venture capital financing and a willing buyer of the end product are very real.
- **Standardization** — Use of a higher Layer Protocol (IP) as transport medium affords intelligence at every stage within the network relative to a service. IP's unparalleled scalability can only be an asset and its flexibility as a tool in forging a resilient and fault tolerant infrastructure can help support functions such as security. Standards in the area of Radio Technology such as affordable Software Defined Radio (SDR) are likely to help as well.
- **New Revenue Opportunities** — There is a growing cultural acceptance of ad-based business models and entry-level service packages for broadband. Tiered services with premium offerings that include advanced features are also becoming popular. This trend bodes well as a way to offset expensive infrastructure build-outs.
- **Developments in the Wireline World** — Figure 6 shows projected need for bandwidth for the next 25 years by the FTTH Council based on high-definition video services. Compelling video experiences in the wireline world put some pressure on the wireless video experience, especially when near-field technologies such as Bluetooth, Wi-Fi or UWB are available. Wireline developments have the potential to drive the requirements for 4G applications, especially in the areas of data and video.

A Realistic Timeline for 4G

Based on the definition of 4G proposed in this paper, it will take several years before “real 4G” is operational. There are many key developments that affect the timeline for 4G that can either speed up or slow down the process:

- **3G Reaching Maturity and Profitability** — 3G deployments began as early as 2003 in some countries and by now, most advanced countries have implemented some 3G networks with coverage in excess of one billion subscribers. Today, 3G data services range from 0.5 Mbps to 5 Mbps depending on the operator. Profitable usage of data remains a challenge. Standard applications such as Internet access are commonplace, although most operators apply a maximum limit of 1–3 Gb of data transfer a month. It may take 2–3 years before current data pipes are saturated as usage patterns evolve to take advantage of increased speeds. 3G operators worldwide are challenged by the returns on their investments. Only when subscribers more fully embrace 3G services and operators realize profitability will improvements to networks be considered.
- **Development and Deployment of IMS and Multiservice Networking** — As network integration with IMS progresses and more applications suitable for the handheld screen become available, demand for higher speeds increases. Concepts such as dynamic resource management and admission control for policy management need to reach maturity. IMS and non-IMS networks need to interwork. Successful integration of IMS is an accelerator of 4G; however, it will take longer than anticipated.

- **Validation of Radio Technologies** — Several new technologies improve access speeds: OFDMA, MIMO, beam forming and higher order of modulation, among others. Some aspect of each of these technologies need validation from a practical perspective. How well the promise matches reality “on the ground” dictates the acceptance rate of new services. For example, OFDMA requires more power on handheld devices than is available today. Does that limit WiMAX for use only on laptops? When can operators offer high-speed services using these sophisticated techniques at price points acceptable to end users?
- **Cost and Availability of Spectrum** — This elephant in the room transcends politics, regulation, capital and competition. The WWRF projects a severe shortage of spectrum (of the order of tens to hundreds of GHz) to fulfill the vision of 4G. Cost of leased spectrum figures in greatly in reaching profitability. For example, WiMAX is experiencing some initial resistance from the investment community in the United States, forcing operators to look for creative ways to raise capital, including use of novel business models.
- **Issues Related to Content Ownership** — Availability of content is critical when new services rely on media from commercial consolidators. With legalized P2P services coming to life, it may be less critical.
- **Ecosystem Development** — Development of applications, training of support staff, creating smooth troubleshooting procedures are asynchronous events. Timing of what becomes available when and in what form is unpredictable. To be profitable, new technology needs to scale, be cost competitive and not lose the focus on value creation. It is impossible to assure that all of this can happen in a synchronous manner.

With an ambitious definition of 4G, ITU speculates that standards and technology will be available by 2012 and commercial services will take hold in some countries by around 2015. Interestingly, since 4G is an all-encompassing concept, it is not viewed as a singular technology as has been the case with prior generations. With the merging of wireline and wireless networks, services offered by operators are expected to blur that distinction. So, the scope of 4G expands access to non-mobile methods, wireless (such as IEEE 802.11 or WiFi) and wireline (such as broadband cable, DSL and fiber).

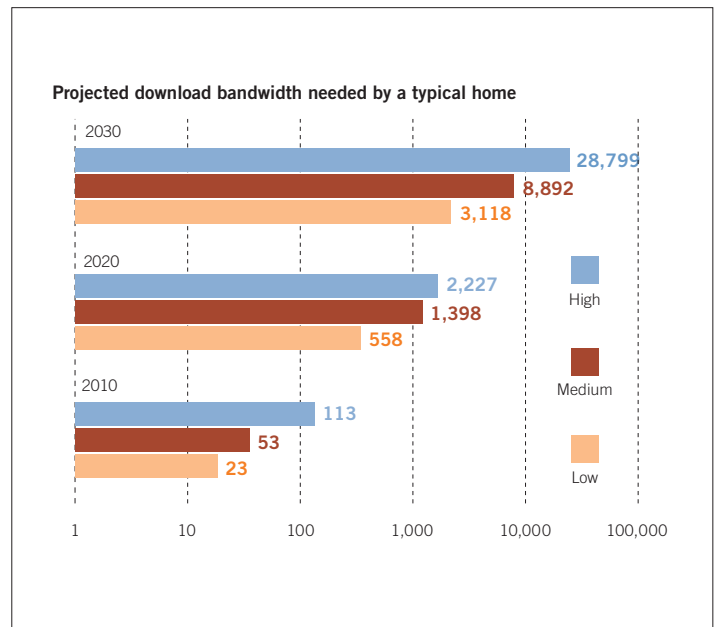


Figure 6. Wireline bandwidth demand projection for the next 25 years

Conclusion

There are many complex and interdependent moving parts that must work together before a standard definition of 4G is solidified. The benefits to service providers and end users drive the adoption of 3G services that, in turn, lead to the demand for even more advanced services. The realization of 4G tears down the wall between wireless and wireline services, a challenging endeavor. Realistically, wide-scale availability of 4G is several years away — somewhere in the middle of the next decade.

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