

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 have advanced 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. Service providers are just beginning to offer fourth generation (4G) wireless networks. But, the definition of 4G is hotly debated, so 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.

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.

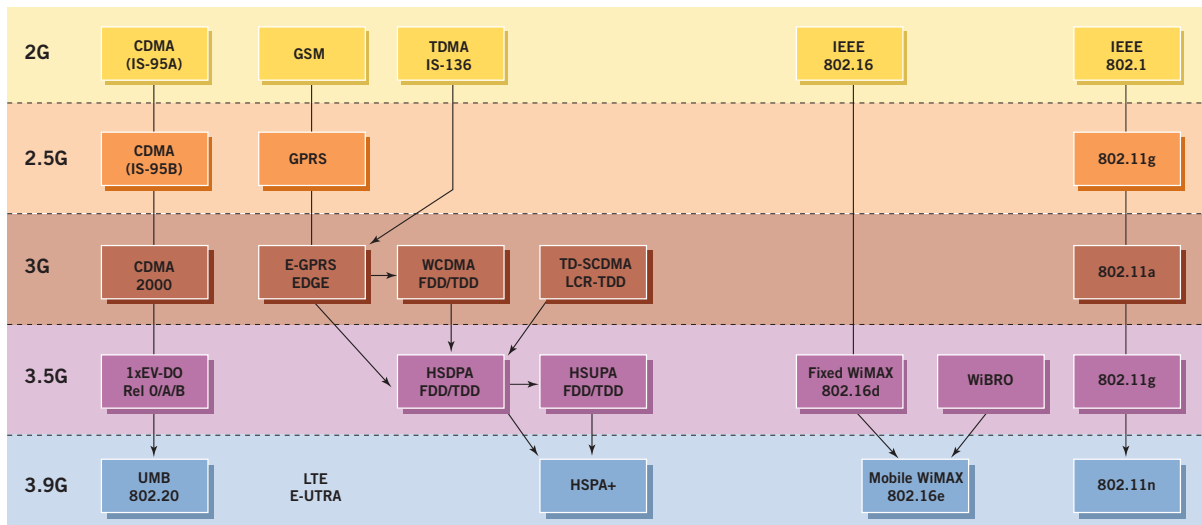


Figure 1. Per-application, per-subscriber, per-service flow level policy enforcement.

Figure 1 shows the path mobile networks 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). 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.

Developments on the Road to 4G

There's been widespread debate about the definition of real "4G" service. Many operators have marketed WiMax, LTE and HSPA+ as 4G services. No current 4G offering meets the ITU's requirements.

But, 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.

The ITU IMT-A Standard

The ITU emerged as the authority to define what constitutes 4G. To add to the 4G definition debate, the ITU recently agreed on specifications for IMT-Advanced, what some would argue is the "true" 4G technology. The group decided that LTE-Advanced and Wireless MAN-Advanced both qualify for IMT-Advanced status.

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."

Where Does WiMAX Fit In?

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 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 gained an official standard status from the ITU.

WiMAX (IEEE 802.16e) has gained acceptance globally as a mobile broadband technology, mainly in industrial sectors such as smart grids and defense, its spectrum allocation is inconsistent. As a

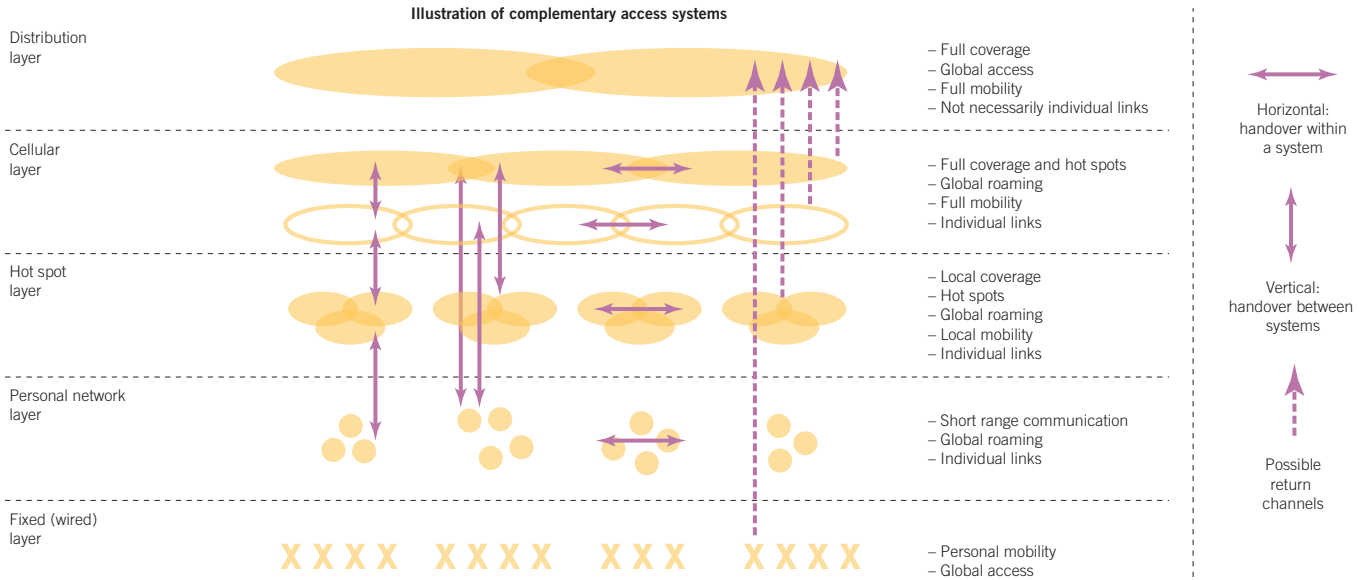


Figure 3. ITU’s vision of IMT-Advanced providing service continuity

result, 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

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.

Figure 3, 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, smartphones
- **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.
- **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

As financially sound business models evolve 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 4 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.
- **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** — 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

There are many key developments that affect operators’ 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 aspects 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

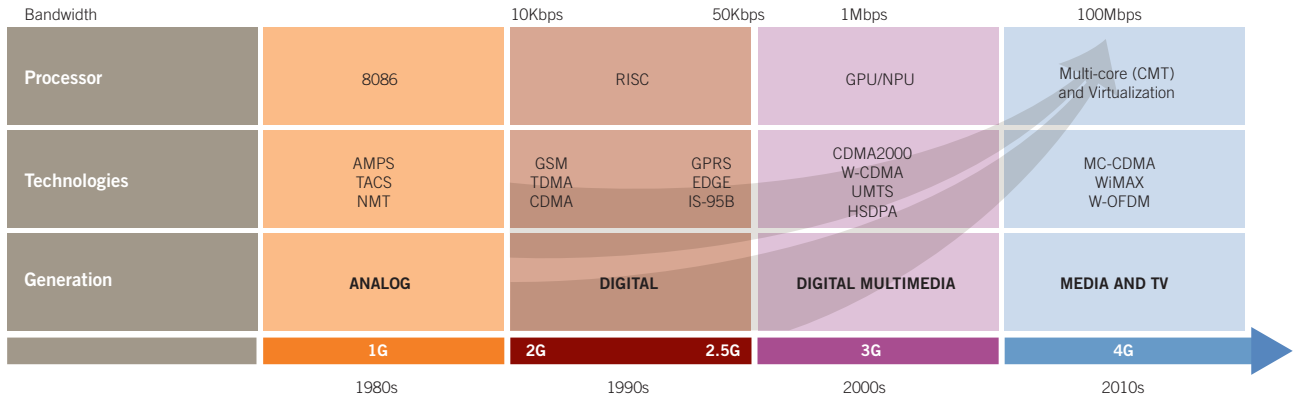


Figure 4. Evolution of processors and DSP technology for 4G

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 and, 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.

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).

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, but operators and standards bodies are making progress.

Next Step:

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