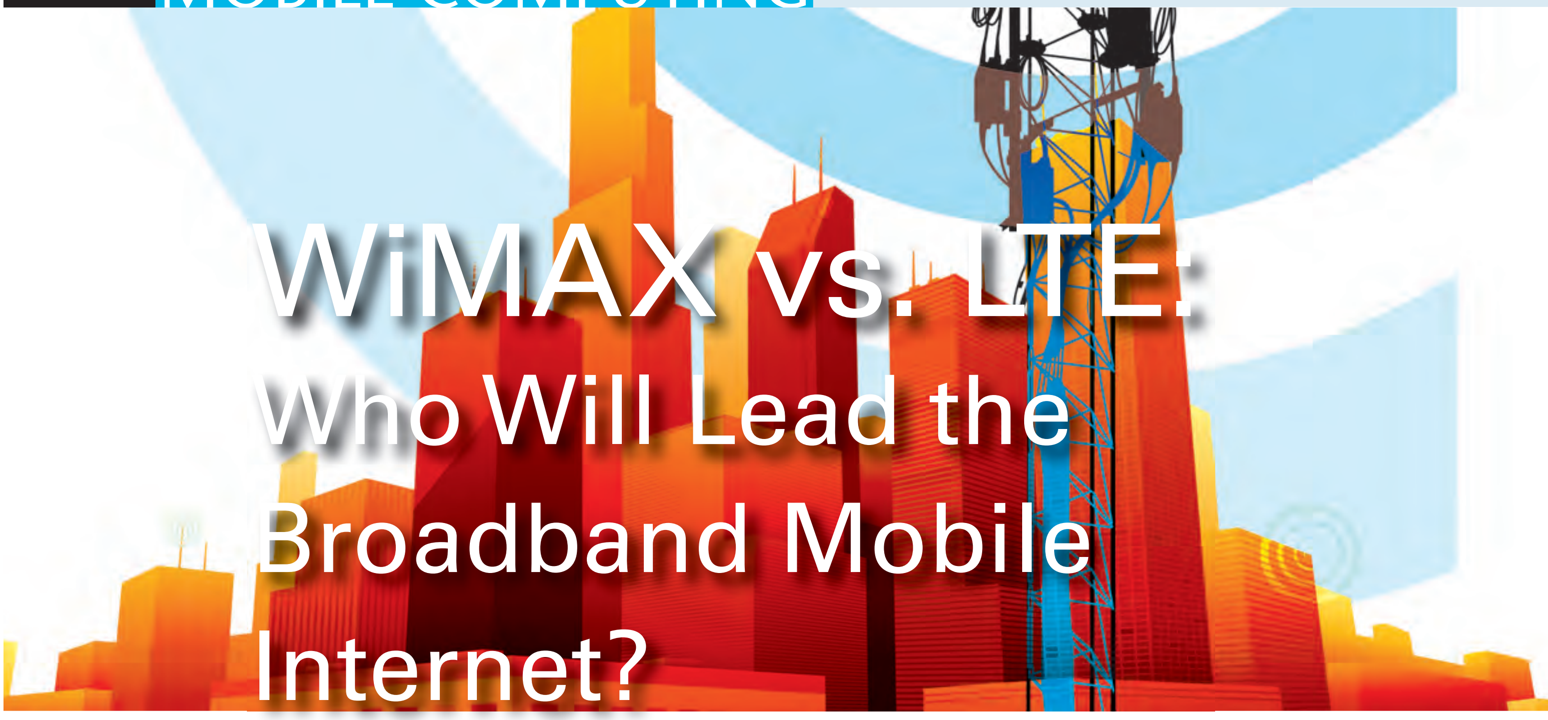

WiMAX vs. LTE: Who Will Lead the Broadband Mobile Internet?

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Two main technologies are competing for the International Mobile Telecommunications (IMT)-Advanced initiative: WiMAX and LTE. This comparison reviews their development and deployment and provides an outlook on their adoption as 4G technologies.

In recent years, the demand for mobile Internet access has grown significantly. The number of pages viewed on the mobile Web browser Opera grew from 1.8 billion pages in January 2008 to 23 billion pages in January 2010.[1] However, the 3G technology that promised mobile broadband hasn't been widely successful because of its low transmission rate and high service costs. As of the third quarter of 2009, the number of 3G subscribers was only around 11 percent of the number of 2G subscribers (www.gsacom.com/news/statistics.php4).

To enable the mobile Internet, the International Telecommunication Union's (ITU) Working Party 5D launched the International Mobile Telecommunications (IMT)-Advanced initiative, seeking proposals from communication standards organizations regarding 4G technologies. They've received several proposals, mainly based on two technologies: WiMAX, which refers to the IEEE 802.16 family of standards, and Long-Term Evolution (LTE), developed by the 3rd Generation Partnership Project (3GPP; www.3gpp.org).

Here, we review WiMAX and LTE, considering issues that could affect their deployment and adoption as 4G technologies.

Standards Development and Status

Figure 1 shows the evolution of the WiMAX and LTE standards. All of the standards in Figure 1 were developed by either 3GPP or IEEE.

WiMAX

IEEE developed the IEEE 802.16 standards,[2] which include notably IEEE 802.16-2004, the first major WiMAX standard for fixed access. This was superseded by IEEE 802.16e-2005, known as Mobile WiMAX, which provides both fixed and mobile access.[3] In October 2009, the IEEE 802.16 Working Group submitted its proposal for IMT-Advanced based on IEEE 802.16m,

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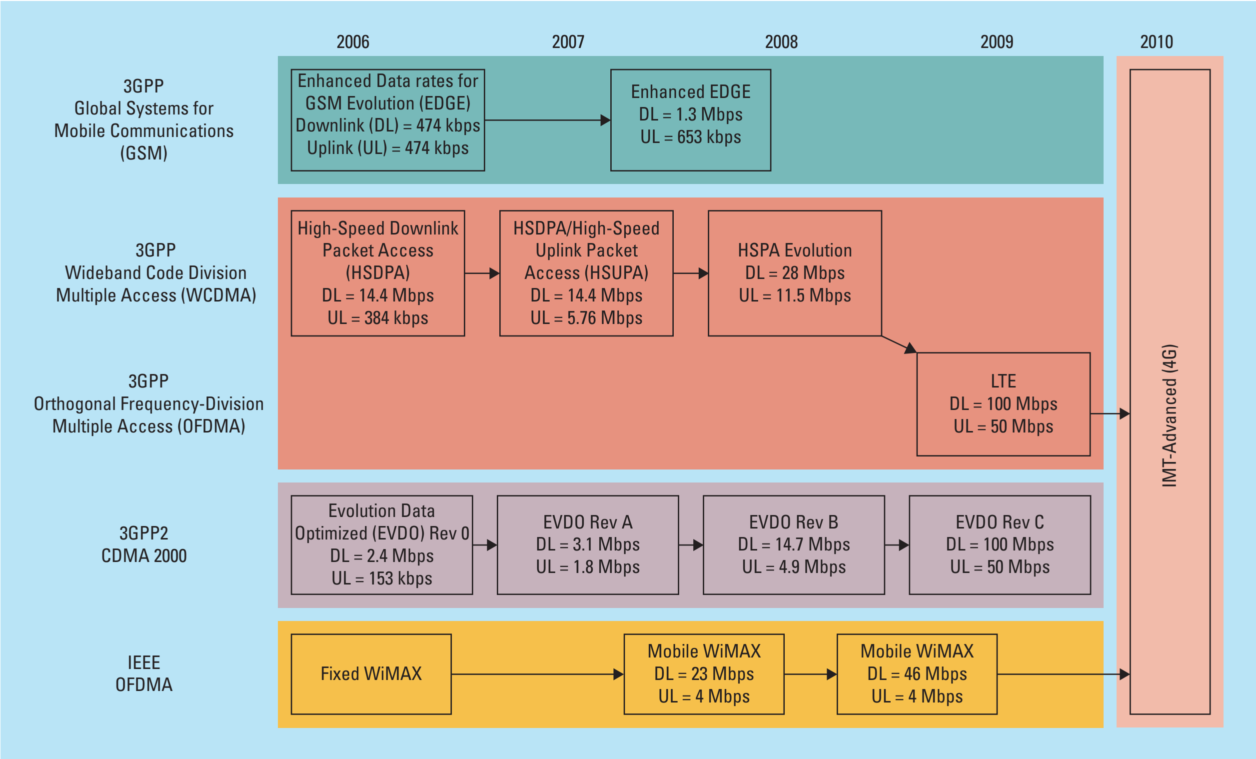

Figure 1. The Long-Term Evolution (LTE) and WiMAX standards' development. 3GPP2 is an organization structured similar to 3GPP. Evolution Data Optimized (EVDO) was developed to target IMT-2000 (3G) and is considered a predecessor of LTE.

which enhances IEEE 802.16e-2005 to meet the IMT-Advanced requirements.

The WiMAX Forum, which comprises more than 300 companies from the computer and telecommunications industries (www.wimaxforum.org), certifies interoperability of WiMAX products from various vendors and has been working to secure spectrum around the globe for WiMAX deployment. Furthermore, hundreds of WiMAX networks have been commercially deployed around the world. In the US, Clearwire has large operations with service offerings in cities such as Chicago, Philadelphia, and Las Vegas. Xanadoo offers service on a smaller scale to a few markets in the US.

LTE

3GPP's LTE standard evolved from the High-Speed Packet Access cellular standards (www.3gpp.org/ftp/Specs/html-info/21101.htm).[4] 3GPP comprises several international standardizations bodies from the US, Europe, Japan, South Korea, and China. The 3GPP partner from the US is the Alliance for Telecommunications Industry Solutions. ATIS members include leading telecommunications companies such as AT&T, Cisco, and Verizon.

The LTE standard is officially known as "document 3GPP Release 8." LTE Release 8 almost achieves full compliance with IMT-Advanced requirements, so some call it 3.9G. In September 2009, 3GPP submitted its LTE-Advanced proposal for IMT-Advanced, officially called "document 3GPP Release 10."

In December 2009, Swedish telecom operator TeliaSonera launched the first commercial deployments of LTE in Stockholm, Sweden and Oslo, Norway.[5,6] Stockholm's network was supplied by Ericsson while Oslo's network was supplied by Huawei. The modems were supplied by Samsung.

Technical Specifications

Table 1 shows the main technical specifications for WiMAX and LTE.

For WiMAX, the designation of release (R1.0 or R2.0) indicates the system profile. When certifying various vendors' equipment, the WiMAX Forum creates the system profile (such as R1.0), selecting features from the standard to test. The WiMAX Forum tests a subset of features in every system profile. (Because the standard contains a plethora of features, it's nearly impossible to test

Table 1. LTE and WiMAX technical specifications.

	LTE (3GPP R8)	LTE-Advanced (3GPP R10)	WiMAX 802.16e (R1.0)	WiMAX 802.16m (R2.0)
Physical layer	DL:* OFDMA† UL:* SC-FDMA‡	DL: OFDMA UL: SC-FDMA	DL: OFDMA UL: OFDMA	DL: OFDMA UL: OFDMA
Duplex mode	FDD and TDD§	FDD and TDD	TDD	FDD and TDD
User mobility	217 mph (350 km/h)	217 mph (350 km/h)	37 to 74 mph (60 to 120 km/h)	217 mph (350 km/h)
Channel bandwidth	1.4, 3, 5, 10, 15, 20 MHz	Aggregate components of Release 8	3.5, 5, 7, 8.75, 10 MHz	5, 10, 20, 40 MHz
Peak data rates	DL: 302 Mbps (4 × 4 antennae) UL: 75 Mbps (2 × 4) at 20 MHz FDD	DL: 1 Gbps UL: 300 Mbps	DL: 46 Mbps (2 × 2) UL: 4 Mbps (1 × 2) at 10 MHz TDD 3:1 (downlink/uplink ratio)	DL > 350 Mbps (4 × 4) UL > 200 Mbps (2 × 4) at 20 MHz FDD
Spectral efficiency	DL: 1.91 bps/Hz (2 × 2) UL: 0.72 bps/Hz (1 × 2)	DL: 30 bps/Hz UL: 15 bps/Hz	DL: 1.91 bps/Hz (2 × 2) UL: 0.84 bps/Hz (1 × 2)	DL > 2.6 bps/Hz (4 × 2) UL > 1.3 bps/Hz (2 × 4)
Latency	Link layer < 5 ms Handoff < 50 ms	Link layer < 5 ms Handoff < 50 ms	Link layer ~ 20 ms Handoff ~ 35 to 50 ms	Link layer < 10 ms Handoff < 30 ms
VoIP capacity	80 users per sector/ MHz (FDD)	>80 users per sector/ MHz (FDD)	20 users per sector/ MHz (TDD)	>30 users per sector/ MHz (TDD)

**Downlink/uplink, †Orthogonal frequency-division multiple access, ‡Single-carrier frequency-division multiple access, §Frequency-division duplexing and time-division duplexing*

them all at once.) Typically, later releases contain more features and mechanisms.

Most of the WiMAX base stations and products on the market are based on 802.16e. The standard created for the IMT-Advanced proposal, 802.16m (see www.ieee802.org/16/tgm), hasn't proliferated the market yet.

Physical Layer

It's worth mentioning that both LTE and WiMAX use orthogonal frequency-division multiple access (OFDMA) in the downlink, but they differ in the uplink. WiMAX continues to use OFDMA, while LTE's approach is more advanced.

Using OFDMA is power inefficient, but it's tolerable in the downlink because the power amplifier is placed at the base station (or at the *e-Node-B* in 3GPP terminology). At the base station, power is available, and the many mobile terminals share the extra complexity.

However, in the uplink, the transmissions start from mobile devices, which are battery powered. The mobile devices are also constrained because they must be low cost to enable mass deployment. 3GPP specifications thus propose a reduced peak-to-average-power ratio (PAPR) transmission scheme for the uplink signal. This scheme is called single-carrier frequency-division multiple access (SC-FDMA). This makes it easier for the mobile terminal to maintain a highly efficient signal transmission using its power amplifier. The LTE uplink signal achieves this property and saves power without degrading system flexibility or performance.

Latency

The latency requirement in the WiMAX and LTE specifications is small enough to support real-time applications, such as voice applications. A voice application could tolerate a delay of between 50 and 200 ms without the user perceiving a decrease in quality. Low latency is thus essential in these mobile broadband standards.

The low latency is also coupled with high data rates to satisfy bandwidth-intensive applications. Both standards support mobility in that users can carry the device travelling at speeds of up to 350 km/h. So, users on a high-speed train, for example, could connect to a 4G network.

Quality-of-Service-Oriented Resource Allocation

Both WiMAX and LTE aim to support quality of service (QoS), allocating bandwidth to users to satisfy their demands. This enables multimedia applications such as streaming audio or video.

Because LTE evolved from cellular standards, the QoS-based approach was both necessary and natural; a voice conversation requires sufficient resource allocation. Yet WiMAX also supports QoS. In fact, both WiMAX and LTE use reservation-based

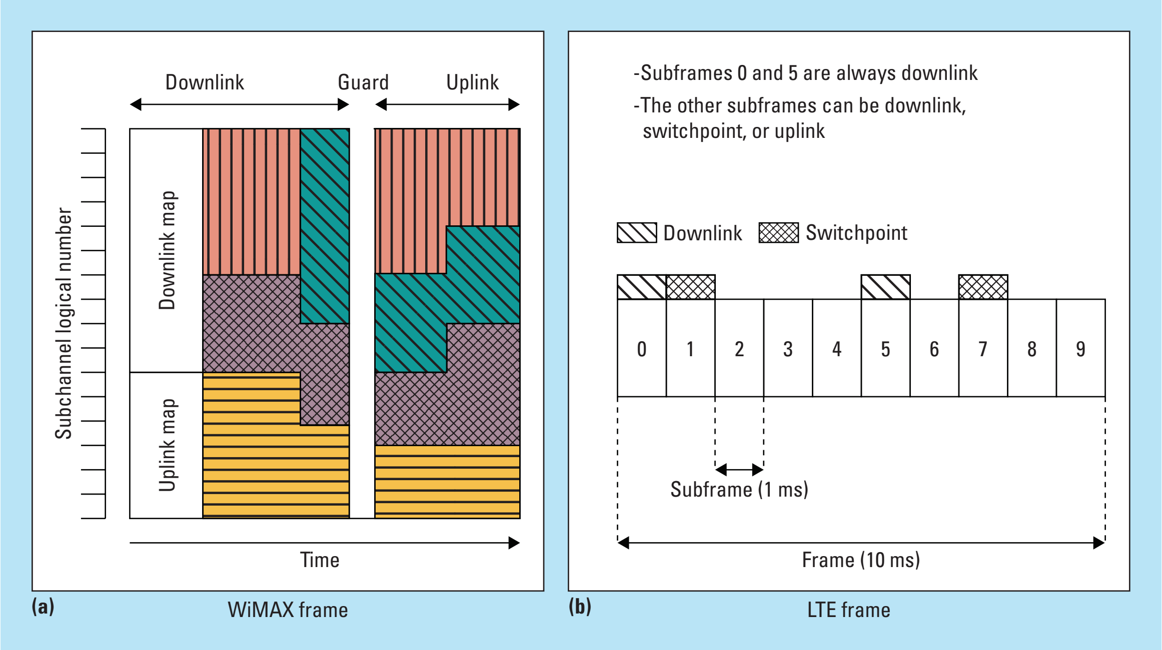

Figure 2. Both WiMAX and LTE employ reservation-based access using the concept of frames. Frames in (a) WiMAX (the different colors represent different users) and (b) LTE standards.

access, meaning they use *frames* to reserve resources for a connection (see Figure 2).

WiMAX divides the time into frames. The duration of a WiMAX frame ranges from 2 to 20 ms. Each frame consists of downlink and uplink portions. The downlink traffic goes from the base station to a subscriber station or mobile station. The uplink traffic goes from a mobile or subscriber station to the base station. At a frame's start, the base station transmits the downlink map and uplink map. These maps specify the resource allocation during a frame (see Figure 2a).

LTE similarly divides the time into frames (see Figure 2b). Each frame lasts 10 ms and consists of 10 subframes of 1 ms each. Subframes 0 and 5 are always reserved for downlink. This lets the base station transmit any special information to manage the subsequent transmissions.

LTE also uses a concept called *switchpoint*; it designates when the transmission will switch between the downlink and uplink. This can happen multiple times in a frame. For example, in Figure 2b, there's a switchpoint at subframe 1. This means that subframe 0 is a downlink and that subframe 1 starts with a downlink, continues with a guard period, and finishes with an uplink. Subframes 2, 3, and 4 continue the uplink until we reach subframe 5, which is a downlink. In the second half of the frame, subframes 5 and 6 are downlink and subframes 8 and 9 are uplink.

A closer look at the resource allocation in WiMAX and LTE hints at the type of traffic occurring in these two technologies. LTE's switchpoint method offers a more dynamic way of allocating traffic, because we can switch from an uplink to a downlink several times in a frame. Again, LTE's cellular background likely inspired this, since a cell phone conversation could have an equal amount of traffic going from one end to the other. Switching between uplink and downlink supports the traffic in both directions with little delay.

Although WiMAX is also flexible and can allocate the traffic between uplink and downlink in any ratio, its heritage is networking standards. The downlink traffic from the Internet to a computer typically exceeds the uplink traffic from a computer to the Internet. However, both WiMAX and LTE adequately support voice and data traffic.

Power Conservation

Power-saving mechanisms are essential in any standard that supports devices running on batteries. This is especially true for mobile devices. Because WiMAX and LTE aim to increase transmission rates by tenfold over their respective previous standards, they require power conservation both in the hardware circuit and protocols.

A classic power-saving mechanism in battery-operated communication devices is to turn off the transceiver when there's no data to transmit or receive. LTE used this concept to introduce Discontinued Reception (DRX) and Discontinued Transmission (DTX). The DRX mode has an on/off cycle for the user's radio. In the "on" mode, the radio can transmit and receive data. In the "off" mode, it doesn't communicate with other equipment and thus saves power. Even in the middle of a voice conversation, the radio can be turned off during long pauses, such as when no packets are arriving or awaiting transmission.

WiMAX also has provisions for a sleep mode. It lets a device negotiate with the base station concerning when the device will turn off its radio. The base station won't schedule the user for transmission or reception when the radio is off. The WiMAX standard specifies three power-saving classes (Type I, II and III). These classes have varying on/off cycles and other parameters related to the type of data being transmitted. For example, best-effort traffic (such as a file download) can have an elongated off period; the download will resume once the radio is on again. However, for a real-time conversation, the radio must be on when new traffic arrives.

Security

Both WiMAX and LTE also provide security mechanisms, which are fundamental for wireless networks.

WiMAX provides privacy so that eavesdroppers can't read the data transmitted over the network.[7] It also provides authentication so that unauthorized users can't use the network's services. IEEE 802.16 defines a security sublayer at the bottom of the Medium Access Control (MAC) layer. This sublayer has two protocols: a Privacy and Key Management (PKM) protocol and an encapsulation protocol. The PKM protocol distributes security keys between the base station and the subscriber or mobile station, and the encapsulation protocol encrypts the transmitted data. WiMAX also features a Multicast and Broadcast Rekeying Algorithm to refresh traffic-keying material to ensure secured multicast and broadcast services.

LTE provides similar security mechanisms, using security keys between the mobile devices and the base station to encrypt the communication. The LTE standard presents a key derivation protocol in addition to other mechanisms, such as resetting the connection if it detects a corrupt key.

Outlook

In the battle between WiMAX and LTE for adoption as 4G technologies, there are several issues to consider.

Industry Support

The main difference between WiMAX and LTE is that WiMAX benefits from its earlier development and deployment, while LTE has the advantage of being developed by telecommunications companies who get to choose which technology to deploy.

WiMAX jumpstarted the mobile broadband market. According to the WiMAX Forum, WiMAX has about 519 deployments worldwide with more than 10 million subscribers. Also, WiMAX has spectrum allocated for it in 178 countries, and many telecommunications companies are involved in WiMAX activities.

However, now that LTE's development has picked up, some telecommunications companies have backed away from WiMAX. Recently, Cisco announced that it will discontinue offering WiMAX base stations and will focus on radio-agnostic IP core solutions. Alcatel-Lucent made a similar announcement. However, companies such as Clearwire that have invested in WiMAX don't have to discontinue their offerings. WiMAX could coexist in the broadband arena with LTE.

We expect the ITU to make its recommendations for IMT-Advanced this summer. However, this doesn't necessarily mean that WiMAX or LTE will prevail at that time, as we've learned from previous ITU recommendations. The IMT-2000 (3G) recommended several independent technologies that meet the same goals. For example, in 2007, ITU added OFDM as part of 3G at the request of IEEE. Thus, ITU can include multiple standards in its recommendation, which means the real battle between WiMAX and LTE will be how successfully they're deployed and used.

Niche Applications

In terms of deployment, some niche applications might favor one technology over the other. For example, WiMAX has been targeting emerging markets that have little infrastructure, because WiMAX deployment would be faster and more cost-effective than laying a wired infrastructure. Besides, many people in these markets don't even have computers. Thus, as Intel starts embedding

Table 2. WiMAX vs. LTE.

	WiMAX	LTE
Current deployment	More than 500 networks	Only 1 network
Support	IEEE and computer companies; waning support from telecommunications companies	Telecommunications companies and international standards bodies
Performance	Similar data rates, mobility support, and latency	
Special technical feature	—	Innovative SC-FDMA uplink saves battery power
Support of emerging markets	Strategy of targeting emerging markets and developing a relays standard could prove beneficial	—
Strength	Leverages wide deployment, so it could remain a 4G technology even if LTE gathers more support from now on	Benefits from the support of telecommunications companies because it evolved from previous telecommunications standards
Major benefit from IMT-Advanced proposal	Taking a chunk of the mobile market, which was typically telecommunications territory	3GPP continues to lead mobile technology in the new era of broadband services

WiMAX chips in its popular Centrino 2 platform for notebook computers, these markets will have an incentive to adopt WiMAX.

Support for Relay Stations

WiMAX has also developed the IEEE 802.16j-2009 standard, which supports relay stations. This architecture can have a base station that's connected to the Internet, and several relays without Internet connectivity can relay wireless data back to the base station to extend its range.

Relays would be cheaper than a base station and easier to install at any site, because they don't need the wired network. This could prove rewarding for WiMAX in markets that require this type of architecture.

A Standardized Interface

WiMAX, however, needs to solve the issue of providing an open standard for the interface that connects WiMAX base stations to the Access Service Network (ASN) gateway, which is linked to the IP's core network. This interface is called R6 and is out of scope for the WiMAX standard, which focuses on the physical and MAC layers.

The WiMAX Forum has established a Network Working Group to develop standardized specifications for R6. Without an open standard for R6, service providers would have to match one brand of base stations with an ASN gateway, which would limit the choices for operators or force them to use multiple ASN gateways where one would usually suffice.

Patent Management

Management of the patents covered in LTE might also play an important role. The royalty costs incurred by patents must be manageable; a high royalty rate can doom a technology. The limited use of 3G networks has partly been blamed on high royalty rates.

For LTE, there have been calls for patent pooling by several licensing management companies—notably, Sisvel, Via Licensing, and MPEG LA. Patent pooling lets several companies use each other's patents pertaining to a certain technology, leading to lower royalty rates for the products. Then, when the market grows, all of the companies will benefit from increased sales.

WiMAX and LTE have several similarities, yet they differ in their evolution, industry support, and deployment models (see Table 2). It will be interesting to see what role these two technologies play in the 4G market, which aims to achieve mass deployment of broadband mobile services. IT

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