The 3G Evolution

Taking CDMA2000
into the Next Decade

October 2005

Prepared by: Michael W. Thelander
Signals Research Group, LLC

White Paper developed for the CDMA Development Group

On behalf of the CDMA Development Group (CDG), Signals Research Group, LLC (SRG) researched and wrote the following white paper. In order to obtain the best possible information on performance characteristics, the evolution of CDMA2000®, and the impact that this evolution will have on the industry and the competitive landscape, we interviewed a number of constituents, including equipment suppliers, technology enablers, and mobile operators. We believe that we have obtained an accurate view that is based on factual information, real world performance measurements from commercial networks, and the current 3GPP2 vision for the technology's evolution. As the paper's sole author, SRG supports the information, analyses and conclusions presented in this report although it also recognizes that many factors go into an operator's decision to deploy and launch a commercial 3G service. Performance of the underlying technology and its evolution are only two criteria out of many that an operator will use to select its next-generation wireless technology of choice.

1.0 Executive Summary

Proving the business case for 3G (third-generation) wireless networks is sometimes considered to be a daunting challenge since it is assumed that 3G requires a massive amount of new hardware, large capital commitments, and new spectrum, all of which are further compounded by interoperability constraints between newly-deployed 3G networks and existing 2G networks. Nothing could be further from the truth.

From its inception, the CDMA2000 evolutionary path was designed to minimize the impact of its introduction into an operator's network. It has achieved its objective in several distinct ways, most notably:

Backward and Forward Compatibility – 3G CDMA2000 1X ("1X") is backward and forward compatible with 2G (second-generation) IS-95, meaning that 2G handsets are fully functional in a 1X network, and 1X handsets are fully functional in an IS-95 network, albeit without the 3G-enabled features. This is very advantageous for an operator when it migrates its network from a 2G to a 3G technology.

In order to take full advantage of an all-IP network and an air interface that has been optimized for data, CDMA2000 1xEV-DO ("EV-DO") does require multi-mode devices to be fully backward compatible. However, as discussed in this paper, the tradeoff is very compelling as a large amount of infrastructure reuse minimizes the impact of this migration. Further, once EV-DO (Release 0) has been introduced, future revisions (through Revision B) will be fully backward and forward compatible.

Hardware Reuse – The migration of the radio access network (RAN) from IS-95 to 1X and EV-DO (all revisions) is almost as simple as inserting a new channel card in a previously deployed base station. This is very compelling for operators that don't want to deploy and maintain an entirely new and completely separate RAN.

"In-band" Migration – Starting with IS-95 and continuing with 1X and EV-DO, the CDMA2000 family of technologies has utilized a 1.25MHz radio carrier in the same spectrum bands. From an operator's perspective, this attribute provides tremendous flexibility when deploying advanced 3G services since it doesn't have to "re-band" its already dedicated radio channels in order to free up enough contiguous spectrum to deploy an additional 3G carrier or to deploy the latest EV-DO revision. Additionally, an in-band migration greatly reduces the engineering nightmare associated with deploying an overlay in a new spectrum band that has different RF propagation characteristics.

Hybrid Network Configuration – The world's first cellular/OFDM hybrid network is based on CDMA2000, whereby an OFDM waveform has been introduced into CDMA2000 1xEV-DO Revision A to offer high capacity multicast capabilities that will allow operators to offer lower cost multicast services while maintaining a robust high-speed mobile network with CDMA2000.

The advanced performance characteristics of 1X and EV-DO provide the operator more "bang for the buck," which provides an additional incentive to begin the transition. Real world measurements indicate that 1X nearly doubles the voice capacity of an IS-95 network, and offers higher voice capacity than other 3G technologies. With the introduction of EV-DO, these operators can further enhance their service offering with broadband Internet access and rich multimedia content. When normalized for a 5MHz channel bandwidth, EV-DO meaningfully outperforms WCDMA (Wideband CDMA) for data traffic and should perform well against HSDPA (High Speed Downlink Packet Access) when the technology is eventually introduced later this year in North America and in 2006-2007 in other regions of the world.

Likewise, EV-DO Revision A should perform admirably versus HSUPA (High Speed Uplink Packet Access), its peer technology, which will probably be behind Revision A by at least two years. In addition to improved data rates in the reverse link, Revision A introduces QoS (Quality of Service) mechanisms that support the prioritization of individual packets and a dramatic reduction in latency, thus paving the way toward full multimedia capabilities, including VoIP and video telephony, on an all-IP radio access and core network. Although generally not recognized, these QoS mechanisms, combined with the efficiencies of an all-IP network, represent the most impressive features of the forthcoming revision.

By being first to market with 3G technologies (1X and EV-DO), the CDMA2000 ecosystem is well established with more than 186 million 3G subscribers, including more than 16 million EV-DO subscribers.[1] These subscribers can select from more than 740 CDMA2000 devices, including close to 140 for EV-DO.

Although Revision A will not be commercially available until mid-2006, work is already progressing on future revisions to the EV-DO standard, beginning with Revision B, which could be completed as early as the first quarter of 2006. Revision B will provide peak data rates of up to 46.5Mbps, although 9.3Mbps is more likely in commercial networks. (Note: a recent proposal which introduces a 64-QAM modulation scheme – requiring a hardware upgrade – could further increase data rates to 73.5Mbps and 14.7Mbps, respectively). Initial discussions are also underway on Revision C and the possible use of technologies such as smart antennas and OFDM (orthogonal frequency division multiplexing) to take the CDMA2000 family of technologies well into the next decade.

As EV-DO is IP-based, CDMA operators will be able to evolve their existing circuit switch core network to an all-IP core network with the ability to support rich applications that take advantage of MMD (multimedia domain). Further, with the inherent features of the Revision A air interface, operators will be able to offer VoIP services, which may further boost network capacity, reduce operating expenses, and support integrated voice and data services such as video telephony and “see what I see.”

While the planned advancements of EV-DO will be exciting to witness, there is also a need to support those underserved markets where placing a voice call today is considered a luxury. In order to address those market needs, the CDMA2000 community is working to lower the cost of entry-level handsets, which in combination with a spec-

[1] *CDMA Development Group, June 2005*

trally-efficient and data-capable technology, will enhance the business case for wireless telecommunication services in developing markets where high concentrations of people live.

2.0 The CDMA2000 Evolution – From a Standards Perspective

Although the focus of this white paper is to provide a market update on 1X and EV-DO and to illustrate how the technology's evolution will continue into the next decade, it is also important to understand CDMA2000 from a standards perspective since there is a fair amount of confusion about what is and is not 3G, and how 3G will evolve into 4G.

2.1 IS-95

The first CDMA standard for mobile networks is referred to as Interim Standard 95A (IS-95A), and is considered to be a 2G technology. The IS-95A standard was completed in 1993 and served as a digital wireless technology that could replace analog systems. IS-95B, which is an upgrade to IS-95A, was deployed in a few markets including South Korea, Japan, and Peru.

2.2 CDMA2000 1X

1X is the technology that follows IS-95. The term 1X is an abbreviation of 1xRTT (1x Radio Transmission Technology), and a fallback to the period when 3xRTT was being considered within the CDMA2000 community. In this case the "1" and "3" refer to the number of 1.25MHz radio carriers that are combined together, with the de facto number being 1.

One common misconception is that 1X is not a 3G standard, with the moniker "2.5G" sometimes used by various entities when referring to the standard. The ITU (International Telecommunications Union), however, explicitly acknowledged 1X as a 3G technology in November 1999. Interestingly, the ITU does not officially recognize terms such as "2.5G," "3.5G" and "4G," as they are not well-defined terms within the body. Instead, various organizations use these terms as marketing tools when trying to segregate various advancements for a given technology. Examples include GPRS ("2.5G"), HSDPA ("3.5G") and WiMAX ("4G").

2.3 CDMA2000 1xEV-DO

The ITU has explicitly recognized 1X and EV-DO has 3G technologies.

Operators who have selected the CDMA2000 evolutionary path are now in the process of deploying, or have already deployed, EV-DO (Evolution – Data Optimized). As the name suggests, EV-DO is a data centric technology that allows operators to take advantage of the performance characteristics of the technology to offer advanced data services. Like 1X, EV-DO is an ITU-recognized 3G technology, with the standard (cdma2000 High Rate Packet Data Air Interface, IS-856) approved in August 2001. As discussed in this paper, the combination of an EV-DO and 1X service is very compelling for operators that want to maximize voice capacity in their networks while still being able to deliver advanced revenue-generating data services.

With the recent decision by Sprint Nextel to deploy EV-DO, work within the standards body on 1xEV-DV (Evolution – Data and Voice) has ceased and is instead focused on future enhancements to the first implementation (Release 0) of EV-DO. EV-DO Revision A (TIA-856-A) is the first in a series of planned upgrades for Release 0. The Revision A standard was approved in March 2004, with commercial services beginning as early as the end of 2006. EV-DO Revision B logically follows Revision A, with indications that this revision will become a standard in the first quarter of 2006. Through Revision B, all planned EV-DO revisions are fully backward and forward compatible. Ultimately, there could be several “phases” of Revision B, with each phase introducing greater functionality and richer features.

Figure 1. The CDMA2000 Evolution

IS-95 → CDMA2000 1X → EV-DO Rel 0 → EV-DO Rev A → EV-DO Rev B

IS-95

- IS-95A
  - Voice
  - 14.4kbps
- IS-95B
  - Voice
  - 64kbps

CDMA2000 1X

- Backward compatible with IS-95
- ~2x increase in voice capacity
- 153kbps/ 153kbps
- Commercially available

EV-DO Rel 0

- 2.4Mbps/ 153kbps
- Optimized for data
- Best effort VoD
- Gold Multicast (requires software upgrade)
- Commercially available

EV-DO Rev A

- 3.1Mbps/ 1.8Mbps
- Fully compatible with Rel 0
- QoS
- VoIP ready
- Platinum Multicast (requires software upgrade)
- Available in 2H/06

EV-DO Rev B

- 46.5Mbps/ 27Mbps in 20MHz
  - Software upgrade to Rev A (may require hardware)
- With 64-QAM FL = 73.5Mbps in 20 MHz
  - Hardware upgrade to Rev A
- Fully compatible with Release 0 and Rev A
- Available in 2007

Source: Signals Research Group, LLC

3.0 A CDMA2000 Market Update

It is helpful to highlight all that has been accomplished to date with CDMA2000, as well as to look at some of the attributes that make CDMA2000 a compelling technology for both operators and consumers.

3.1 The 1X and EV-DO Ecosystem

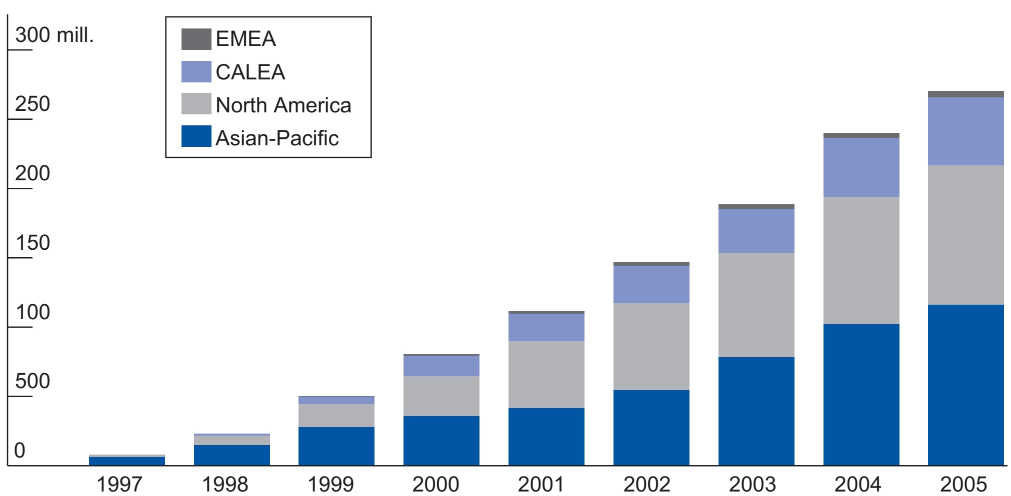
The ability of a technology to enhance network efficiency is an important criterion to minimize the total cost of ownership of a 3G system. A well-established ecosystem can also help drive down costs through economies of scale which are achieved by a large subscriber base, while higher levels of competition are made possible by a multitude of handset and infrastructure suppliers.

3.1.1 1X and EV-DO Subscriber Growth

Based on operator-provided figures, at the end of June 2005 there were 270.2 million CDMA subscribers in the world, spread across more than 193 networks in 70 countries. The Asia Pacific and North American regions represented the largest number of subscribers at 116.2 million and 100.4 million, respectively, followed by the Caribbean and Latin America at 49.2 million and EMEA (Europe Middle East and Africa) at 4.4 million. Additionally, the installed base of CDMA subscribers continues to grow in all regions of the world with a compound average growth rate of 27% across all regions since 2000.

Arguably, the number of GSM subscribers (~1.5 billion) is a more impressive number to tout, but the aggregate number of subscribers, in and of itself, does not reflect the entire picture. For example, despite a very large 2G base, its adoption of 3G [WCDMA] has actually fallen short of 1X and EV-DO. At last count, there were 33 million WCDMA sub-

Figure 2. CDMA Subscriber Growth (1997-June 2005)



Source: CDG

scribers on 61 commercial networks, including 16.5 million on NTT DoCoMo's network, which, as discussed later, is a proprietary implementation of WCDMA. For comparison purposes, of the 270.2 million CDMA subscribers, 185.6 million (69%) are CDMA2000 subscribers, with more than 16 million using an EV-DO handset. From a network perspective, operators representing more than 80% of the CDMA installed subscriber base have either deployed EV-DO, or are currently trialing the technology for a future deployment.

The point in making these comparisons is not to suggest that 1X and EV-DO will be able to retain their lead over WCDMA. Instead, it should be recognized that CDMA operators have seemingly had an easier and more successful experience when transitioning from 2G to 3G voice and data services. This time to market advantage is discussed in Section 3.2.

3.1.2 The 1X and EV-DO Suppliers

A large subscriber base helps drive down the cost of handsets and infrastructure due to economies of scale. According to Qualcomm's financial results, in 2004, 148 million CDMA2000 handsets were sold versus 22 million WCDMA handsets. Likewise, a large ecosystem of handset and infrastructure suppliers leads to increased competition, more attractive prices, and a better selection of handsets with rich and compelling features.

CDMA2000 subscribers can select from more than 740 1X handsets and close to 140 EV-DO devices.

To date, over 740 CDMA2000 devices, including close to 140 for EV-DO, have been commercially introduced. For comparison purposes, approximately 90 WCDMA models have been introduced, including 32 FOMA handsets.[2]

With respect to infrastructure, there are more than one dozen companies that offer CDMA2000 equipment, as well as a large number of subsystem and core network suppliers. The list includes some of the leading companies in the industry, as well as private companies and aggressive suppliers from Asia.

The CDMA2000 ecosystem of device suppliers has introduced a number of advanced features, which in many instances are unique to 1X/EV-DO handsets, or they were first introduced on 1X/EV-DO handsets. Examples include:

- The world's first 7 megapixel camera phone
- The world's lightest 3G phone (98 grams)
- The world's first 3G phone with an internal hard drive

These features will not necessarily remain exclusive to CDMA2000 handsets, nor does it imply that all new features appear first on CDMA2000 handsets. However, it demonstrates that the portfolio of CDMA2000 handsets is very attractive and that leading handset manufacturers recognize and aggressively pursue the market opportunity.

[2] *UMTS Forum web site*

3.2 Time to Market Advantages

As highlighted in this section, and further discussed in Chapter 6, 1X delivers the highest voice capacity of any commercially available 3G technology, while EV-DO data performance is proving to be superior to WCDMA and should exceed that of HSDPA. Likewise, EV-DO Revision A is broadly comparable with HSUPA in regards to the performance in the reverse link. There is another attribute, however, in which the CDMA2000 family of technologies has an undisputable advantage, and that is a time to market advantage.

CDMA2000 has a time to market lead that operators have used to their advantage.

In competitive markets, operators need to be able to offer their subscribers the latest that technology has to offer in order to remain competitive and be able to attract new subscribers and retain existing ones. Although recent history has demonstrated that subscribers do not necessarily care whether they use 3G or 2G, let alone "2.5G," they do care about the inherent features that their mobile service has to offer. Such desired 3G features include broadband wireless access for demanding [and high ARPU-generating] corporate subscribers, as well as multimedia applications, gaming and lower cost voice services for consumers. In that regard, the CDMA2000 technologies give operators a first-mover advantage which they can use to their benefit if so desired.

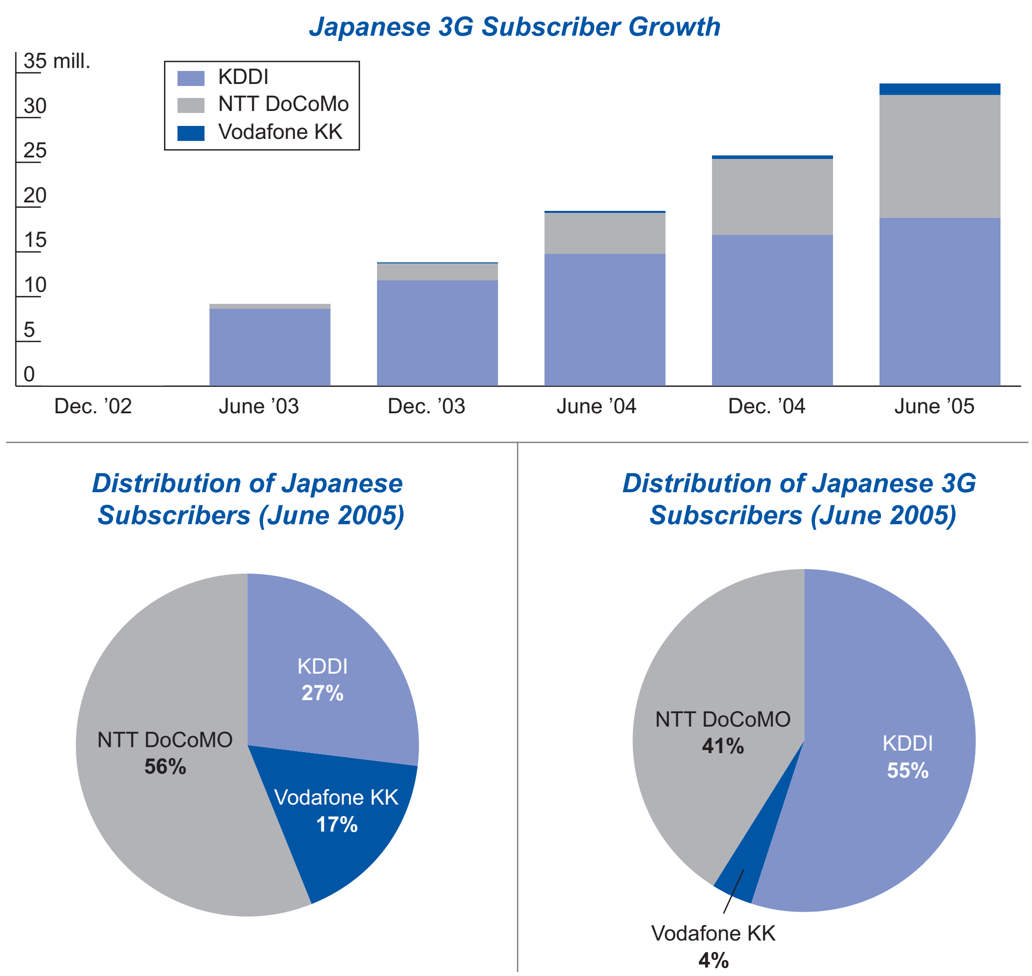
SK Telecom (SKT) launched the world's first 1X network in South Korea in October 2000. SKT also launched the world's first commercial EV-DO service in January 2002, followed by KT Freetel in May of that year. Since those initial deployments, the ecosystem has not only had time to develop, but the CDMA2000 technologies have had time to fully mature, prove themselves over a multi-year period, and introduce more optimized solutions that can drive down costs and improve the user experience (e.g., reduce power consumption).

Conversely, NTT DoCoMo was the first operator in the world to launch a WCDMA system using a pre-release [proprietary] version of WCDMA when it launched its FOMA (Freedom of Mobile Multimedia Access) service in October 2001. In December 2002, Vodafone KK (J-Phone) launched the world's first standards-based implementation of WCDMA when it began offering commercial 3G services in Japan.

In Japan, KDDI, which is the second largest operator with over 20 million subscribers, is the only carrier that is following the CDMA2000 evolutionary path. KDDI launched 1X in April 2002 and EV-DO in October 2003, with plans to begin deploying EV-DO Revision A hardware by the end of 2005 and upgrading the hardware with Revision A software once it is available. In response, NTT DoCoMo (and possibly Vodafone KK) could begin deploying HSDPA in 2006, although no official date has been set for commercial availability; HSUPA probably won't be a viable alternative until the 2008 time frame. Based on these dates and assumed future deployment plans, KDDI has at least a 1-2 year time advantage in its market, plus it can benefit from the incremental performance gains of 1X/EV-DO Release 0 and Revision A versus UMTS/HSDPA and HSUPA.

This time to market advantage is further demonstrated in the Japanese subscriber figures. By the end of June 2005, KDDI had 55% of the 3G subscriber base in Japan, versus 41% for NTT DoCoMo and only 4% for Vodafone KK. Worth noting, KDDI's total

Figure 3. KDDI's Time to Market Advantage



Source: Telecommunications Carriers Association (TCA)

subscriber base is 27% of the total number of Japanese mobile subscribers, meaning that its success rate in capturing new 3G subscribers is even more impressive.
Insert Figure 3

Subscribers are not necessarily gravitating to KDDI because it had 3G first. However, because 1X and EV-DO are well-established technologies with compelling performance characteristics, KDDI is able to offer its subscribers very attractive handsets with an attractive form factor and a rich portfolio of multimedia services that are made possible by the 3G network.

This time to market advantage is also prevalent in other regions, most notably North America and Brazil, where WCDMA/HSDPA commercial services are not yet available, while 1X and EV-DO have been deployed since 2002 and 2003, respectively. By being first to market with 1X and EV-DO services, CDMA2000 operators, such as Verizon Wireless, Sprint Nextel, Bell Mobility, and Vivo, have been able to provide their subscribers with feature-rich multimedia content (e.g., VCAST from Verizon Wireless) and offer mobile broadband access to the most lucrative subscribers – the mobile professional. The advantages of mobile data are discussed in the next section.

3.3 Making the Case for Mobile Data

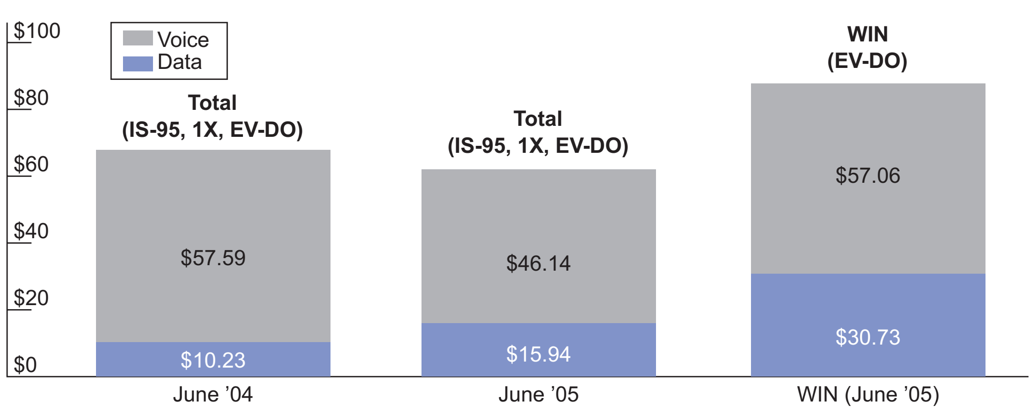
Deploying 3G does not in and of itself mean that an operator will have a rewarding experience with a commercial mobile data service. However, in the absence of a mobile data offering, the operator will be challenged to grow ARPU (average revenue per user), let alone sustain it. In most regions of the world the competition for new subscribers is very fierce, in particular in those markets where penetration rates are approaching their practical limit due to the regional demographics.

In response, operators are lowering their subscription rates for voice services and/or increasing the number of minutes available with so-called “bucket plans” in order to attract and/or retain subscribers. The net effect of these actions is lower ARPU, higher churn and reduced profitability. As an alternative, mobile operators are recognizing that a compelling mobile data service on their 3G network can attract/retain subscribers, increase data revenues, and even increase voice revenues.

Having been the first operators to launch 3G networks, CDMA2000 operators in South Korea and Japan are frequently in the spotlight for the success that they have had with mobile data.

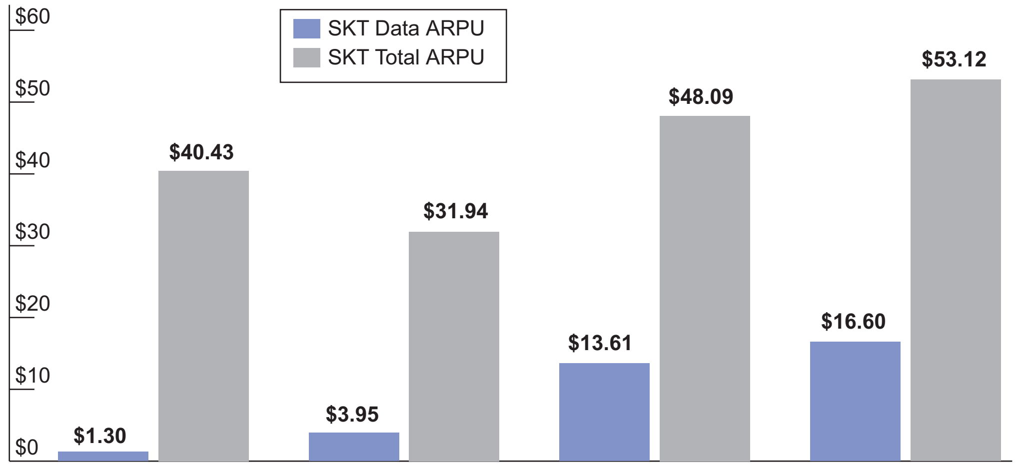
Between June 2004 and June 2005, KDDI’s voice ARPU declined by 32% to $46.14. However, during that same period ARPU from data services increased by 56% to

Figure 4. Mobile Data Drives Higher ARPU



Source: KDDI

Figure 5. Mobile Data Drives Higher Voice Usage



Source: SK Telecom

$15.94 across its entire subscriber base, thus stemming some of the overall decline. The contribution from its mobile data service is even more impressive when the results from KDDI's EV-DO service are isolated from its overall results. Subscribers to KDDI's EV-DO service, WIN, had an ARPU of $87.79 during June 2005, which is 41% higher than the ARPU across its entire base of subscribers. Further, the distribution between voice and data revenues indicates that as these WIN subscribers increase their EV-DO mobile data usage, their desire to place more voice calls, as reflected in the higher voice ARPU, also increases.

A mobile data offering can drive higher revenues, indirectly increase voice usage and help attract and retain subscribers.

Results in South Korea also suggest that mobile data usage can drive overall ARPU and help stem the decline in voice ARPU. ARPU for subscribers that used SK Telecom's June service, a multimedia service for high-end EV-DO handsets, was $53.12, or 66% higher than its ARPU for 1X subscribers. Within those ARPU figures, voice ARPU for its June service was 30.5% higher than voice ARPU with its 1X service. As was the case in Japan, higher data usage can lead to an increase in voice usage.

Put another way, operators with an aggressive mobile data service offering can benefit in several ways:

- Mobile data usage can drive higher ARPU;
- Mobile data usage can indirectly result in higher voice usage; and
- An attractive mobile data service offering, with compelling devices, can attract and retain subscribers

3.3.1 Broadband Wireless Access Using EV-DO

While 3G multimedia content and services represents the more appealing side of 3G, EV-DO, and even 1X, can provide a very basic, albeit critical function – wireless Internet connectivity.

In developing markets where wireline penetration rates are low or where DSL service is very limited, operators are offering EV-DO broadband access for the sole purpose of connecting their subscribers to the Internet.

In 2004, Eurotel launched an EV-DO network in the Czech Republic using its 450MHz spectrum. In the first two months, the operator was able to capture nearly 10% of the country's broadband market. The operator's success has since continued, with Eurotel having more than 50,000 subscribers on its near-nationwide network.

In North America, Verizon Wireless and Sprint Nextel are offering "all-you-can-eat" data plans on their EV-DO and 1X networks. These operators recognize that, although there is an abundance of wireline access to the Internet, access is not always readily available where its targeted subscribers need it the most – in airports, hotels and other areas where business travelers congregate.

In this case, EV-DO is not intended to replace wireline access. Instead, employees of large and small corporations can use EV-DO to remain in contact with the office while they are physically outside of the office – accessing their email, uploading and downloading files through a VPN, etc.

From the corporation's perspective, an EV-DO broadband service increases the productivity of its workforce for a modest cost while at the same time it likely reduces the costs that the corporation would have to pay if they used other access technologies. Although free in some instances, broadband access in hotels can cost $10-$15 per night. Unlimited Wi-Fi service is currently available for $30 per month, versus $59.99 for EV-DO, but with very limited coverage, subscribers would likely have to supplement their Wi-Fi plan with other subscription-based services where Wi-Fi coverage is not available.

From an operator's perspective, an EV-DO broadband access service can meaningfully boost its ARPU. Equally important, it creates another layer of stickiness that compels its most lucrative subscribers to remain loyal customers.

3.3.2 Gold and Platinum Multicast Drive Network Efficiencies

With the introduction of EV-DO Release 0, and followed by EV-DO Revision A, EV-DO operators have the ability to offer multicast services to their subscribers.

As the name implies, multicast is a "one to many" delivery mechanism that significantly enhances the capabilities of an EV-DO network. With multicast, all participating subscribers can simultaneously receive the same information that is being transmitted by the base station(s), much in the same way TV or radio signals can simultaneously provide the same information to an unlimited number of TVs or radios without the need to rebroadcast the information multiple times – one transmission supports an unlimited number of TV viewers or radio listeners.

The "one to one" equivalent to multicast is generally referred to as unicast. At a superficial level, unicast can offer subscribers the same type of content with the same video

A multicast service makes more efficient use of network resources while still allowing operators to offer a vast array of multimedia content to a virtually unlimited number of subscribers.

and audio quality that is possible with a multicast service – with one notable exception: in a unicast system, the network would have to individually send each subscriber its requested programming.

For a hypothetical 1MB video file and 5 active subscribers in the same cell, a unicast network would have to send 5MB of data. In a multicast network, the 1MB file is only transmitted once – simultaneously to all five users. At the same time, the value of that content, as measured by what the subscribers are willing to pay for it, remains unchanged. Put another way, with a multicast service, the data revenues flowing to the operator's coffers increase as the number of subscribers to the multimedia service increases, yet the impact on the network resources (e.g., the cost to deliver the content) remains virtually unchanged. The real efficiency of the multicast system is therefore a function of the number of subscribers that are using it in a given sector – the higher the number of subscribers, the higher the efficiency and vice versa.

A multicast system, through the use of program delivery software, can also take advantage of off-peak hours to transmit content, in particular, content that is not time sensitive. This feature can be extremely advantageous since network usage is widely variable with typically little or no traffic being sent during the late night and early morning hours.

The advantages of a multicast data service can be significant. From an operator's perspective, a multicast service makes more efficient use of its network resources and limited spectrum, while at the same time still allows it to offer a vast array of ARPU-generating multimedia content and programming to its subscribers. For subscribers, a multicast service means that the selection of multimedia content can be significantly increased, thus catering to those subscribers that are interested in these types of services.

Multimedia content that is well-suited for a multicast service include:

- Music video clips
- MP3 audio files
- Sports highlights
- Movie trailers
- Top news stories

For EV-DO Release 0, the multicast functionality is referred to as Gold Multicast, which can be implemented via a software upgrade in the RAN and handsets (chipsets), plus some modest changes in the core network, including software and increased backhaul capacity. In terms of performance, Gold Multicast can reportedly support sector throughput rates of up to 409.6kbps in the forward link across 99% of the targeted sector using a dedicated EV-DO carrier.

Platinum Multicast, which is available with EV-DO Revision A, is reportedly able to deliver sector throughput rates of up to 1.5Mbps (>98% coverage) in the forward link, or almost a 4x improvement over Gold Multicast. The dramatic improvement is due to the use of OFDM (Orthogonal Frequency Division Multiplexing). Since EV-DO is a TDM-based (time division multiplexing) technology, it is possible to interleave OFDM- and CDMA-generated signals in the same radio carrier, albeit separated in time (e.g., different time slots).

WCDMA incorporates a multicast service that is referred to as MBMS (Multimedia Broadcast Multicast Service). Although the evolution of WCDMA (HSDPA) is also a TDM-based system, it is not using OFDM to provide MBMS functionality.

3.3.3 VoIP and Multimedia Applications

CDMA2000 operators are able to offer a rich array of integrated voice and data services. Initially, these applications can include a more advanced, low-latency services, such as Push-to-Talk, Instant Messaging and Instant Multimedia, in which subscribers can combine text, audio and even video content within a single multimedia message.

With the introduction of EV-DO Revision A and further enhancements to the Core Network, operators can begin offering conversational VoIP (Voice over Internet Protocol) services, leading into video telephony services and multi-party video conferences. As discussed in more detail in Section 6.3.5, VoIP (along with receive diversity and pilot interference cancellation) may also increase voice capacity over 1X and lead to a more effective use of network resources, thus reducing an operator's capital expenditures and ongoing operating expenses.

3.4 CDMA2000 Targets the Underserved Markets

With a smooth migration path from 2G to 3G that features backward and forward compatibility, and minimizes new hardware requirements, the CDMA2000 technologies are well-suited for developing markets. In fact, CDMA2000 subscriber growth in developing markets over the last few years is actually higher than it is in more established markets. In many of these markets WCDMA is not even available, and may not be for the next few years (even then on a very limited scale).

The CDMA2000 community is working together to reduce costs and make it easier for operators to introduce mobile devices that target the very low end (VLE) market.

In order to maintain its competitive advantage as a 3G technology in these regions, the CDMA2000 community is working together to reduce costs and make it easier for operators to introduce mobile devices that target the very low end (VLE) market.

There are a number of activities that specifically address this issue, with four of these initiatives highlighted below.

VLE Handsets – In order to lower the cost of CDMA2000 handsets, a less expensive semiconductor technology (RF-CMOS) is being used today in the transceiver portion of the handset in place of an older and more expensive technology (Silicon Germanium). These transceivers can also be limited to a single frequency band, which reduces the complexity, size, and ultimately, the cost of the transceiver even more.

Early 2006, three different chipset solutions will be available that combine the baseband, RF and power management onto a single chip. These single-chip solutions will also take advantage of an ARM-9 processor using a more advanced processing node, which can reduce the footprint (cost) of the CPU and DSP functionality while also improving the performance level over an ARM-7 processor – the processor that is used on today's VLE handsets.

This family of single-chip solutions is also fully compatible with each other, with the most basic chipset being limited to voice and SMS, the middle chip including 1X data, and the most advanced chip also supporting a megapixel camera. A handset manufacturer can then use one basic handset design and subsequently make modest adjustments in order to offer a portfolio of very low cost 3G handsets with varying degrees of features. By taking this approach, operators will have the flexibility of being able to target the VLE market without having to sacrifice the ability to offer a modest data solution (e.g., downloadable ring tones).

Global Handset Requirements for CDMA (GHRC) Initiative – The CDG is working with its members to define a common set of handset requirements that will be applicable to all CDMA2000 operators. With a common set of requirements, the degree of operator-defined customization that was used in the past by some of the larger and more influential operators will be largely removed. This initiative will make it easier for handset manufacturers to support smaller operators, which, in turn, will allow smaller operators to introduce new handsets more rapidly, increase the portfolio of handsets that they offer, and lead to lower wholesale handset prices.

Supply and Demand Aggregation – With a few notable exceptions, operators in VLE markets generally lack the buying power which larger operators in developed markets possess. By aggregating the volumes (orders) of these operators, economies of scale can be achieved, which ultimately leads to more attractive prices.

CDMA Certification Forum (CCF) – Like all handsets, CDMA2000 handsets must be approved by the operator before they are allowed into an operator's network. To significantly reduce the time and cost of bringing CDMA devices to market, the CDG created the CDMA Certification Forum (CCF), a collaboration of operators and device suppliers, to develop and implement a global standardized certification process. Once this initiative is activated, device suppliers will be able to "pre-certify" a majority of the communications portion of the device for all potential market opportunities, thus eliminating the duplicative testing that occurs today. By optimizing the testing and certification process, the time and cost associated with device testing will be significantly reduced.

4.0 The Smooth Transition from 2G to 3G and Beyond

For CDMA operators, the transition from IS-95 to 1X and EV-DO is a relatively smooth process, with the technologies designed from the start to maximize the reuse of existing hardware. In so doing, operators can quickly roll out new technologies without disrupting their existing services and minimize their capital expenditures. There are several attributes which make this smooth transition possible.

4.1 An "In-Band" Evolution

As discussed in an earlier section, 1X is sometimes [incorrectly] referred to as a "2.5G" technology. At least part of the confusion has more to do with the outwardly subtle differences between 1X and IS-95 than with the underlying performance characteristics such as increased voice capacity and sector throughput.

From its inception the CDMA2000 evolution path was designed for "in-band" migration, meaning that operators could deploy the technology in their existing spectrum.

From its inception, the CDMA2000 evolution path was designed for "in-band" migration, meaning that operators could deploy the technology within their existing spectrum – spectrum that was likely being used to deliver 2G voice services. Therefore, if the working assumption was that new "3G spectrum" was required in order to deploy 3G, one might be able to understand how this misconception developed, even in advance of the first 1X network being deployed. As discussed earlier, the ITU did not explicitly require that 3G must be deployed in new spectrum.

The ITU did, however, identify a wide range of spectrum bands, including those that were already being used for 2G technologies, which operators around the world could use to deploy and offer 3G services. These frequency bands include:

- 806-960 MHz
- 1710-2025 MHz
- 2110-2200 MHz
- 2500-2690 MHz

Further, the ITU recommendation also allows governments to deploy 3G in bands other than those identified above.

There are a number of advantages to having an "in-band" evolutionary path:

Hardware Reuse. RF equipment, such as amplifiers, transmitters, receivers and filters, has to be customized for the frequency band in which it operates. By using the same spectrum that supports 2G services to deploy 3G, a large portion of an operator's 2G equipment can be reused. Major CDMA infrastructure suppliers offer multi-carrier RF solutions, which means that a given piece of hardware (e.g., an amplifier) can support several RF carriers, even if one carrier is 1X and another carrier is EV-DO. If 2G and 3G were deployed in different frequency bands, it would not be feasible to reuse the equipment, let alone use the equipment to simultaneously support 2G and 3G services. This attribute is discussed in more detail in an upcoming section.

Ease of Network Engineering. Due to the laws of physics, wireless technologies that are deployed in higher frequency bands (UMTS bands) cannot transmit as far as wireless technologies deployed in lower frequency bands (2G bands). Although 3G technologies, including WCDMA, have more advanced features that can extend the coverage (e.g., improve the "link budget"), these enhancements are not enough to allow an operator to simply deploy its 3G sites where its existing 2G cell sites are located. Instead, an operator would have to deploy additional cells to fill in coverage gaps that would exist due to higher frequencies being used by its 3G than 2G networks. These coverage gaps would be most noticeable as 3G traffic increases due to the phenomenon called "cell breathing," in which the coverage offered by a CDMA2000 or WCDMA-based cell site actually shrinks as the network traffic increases. In addition to increasing an operator's capital expenditures, the requirement for more cell sites in the new frequency band also makes network engineering and optimization more challenging and time consuming, while ongoing operating expenses will also be higher due to the larger number of cell sites in the network.

No Mandatory Auctions. European operators spent in aggregate more than $130 billion during the "3G Bubble" in order to acquire spectrum to deploy 3G services. Although some operators may have needed the spectrum to deploy 3G, other operators with unused spectrum were not given the flexibility of using their 2G spectrum for 3G services. By taking this approach, governments benefited from 3G in the form of a tax boon even before the networks were deployed. As a result, a number of operators were several billion dollars in the red before a single base station was ever deployed.

Beginning in 2005 and continuing into 2006, "in-band" WCDMA infrastructure and devices will be coming available. As the market for these solutions develops over the next few years, and as governments relax their requirements and allow 3G to be deployed in "2G spectrum," these operators will eventually be able to recognize similar advantages that CDMA operators have been experiencing since the inception of 3G. These operators, however, will still require entirely new RAN infrastructure since legacy GSM base stations cannot be retrofitted for WCDMA.

4.2 Maintaining the 1.25MHz Carrier

Beginning with IS-95 and continuing through at least Revision B, 1X and EV-DO utilize a 1.25MHz radio channel to send voice and data traffic from the base station to a mobile device and a separate 1.25MHz radio channel to send voice and data traffic from the mobile device to the base station. The path from the base station to the mobile device is referred to as the forward link or down link, while the path from the mobile device to the base station is referred to as the reverse link or uplink. The term used to describe traffic that requires separate frequencies for the forward link and reverse link is FDD (Frequency Division Duplexing), while in a TDD-based system (Time Division Duplexing), the same radio carrier supports the forward link and the reverse link traffic, with a short time interval used to separate the transmissions in each direction.

While the advantages of retaining a 1.25MHz carrier may not seem obvious and noteworthy, from an operator's perspective, the advantages are actually quite profound. Spectrum is a limited resource and it becomes even scarcer as network usage increases, *Spectrum is a limited resource and as network usage increases it becomes even more difficult to free up spectrum for a new technology, hence maintaining a 1.25MHz carrier when migrating from IS-95 to 1X and EV-DO is advantageous.*

which in turn means that an operator is committing most, if not all, of its spectrum to supporting existing services.

When an operator deploys a new technology (e.g., 3G) it must free up some of its spectrum and dedicate it to the new technology, unless it happens to have some unused spectrum available. The challenge, of course, is that by freeing up spectrum that is already being used, it places an even greater burden on its remaining 2G spectrum, which ultimately can lead to higher dropped call rates, network busy signals, and customer dissatisfaction. This occurrence is particularly prevalent when backward compatibility does not exist between the two technologies.

When the new technology requires a different [wider] amount of spectrum, the problem becomes even more challenging since it requires an operator to free up more spectrum and displace several RF carriers. For GSM operators migrating to WCDMA, it is somewhat of a Catch 22 situation since, although WCDMA supports more voice capacity than GSM, operators may not have enough spectrum to free up without severely degrading its 2G network; WCDMA utilizes a 5MHz FDD channel and GSM utilizes a 200kHz FDD channel, which equates to approximately 25 GSM radio carriers in a single WCDMA radio carrier. Further, even if the spectrum is available, the operator may have to reassign frequencies across its network of base stations in order to assemble 5MHz of contiguous spectrum.

In this case the problem is magnified since WCDMA is not backward compatible with GSM without the use of multi-mode WCDMA/GSM mobile devices. This means that unless the operator is able to rapidly increase its 3G subscriber base, for example through the use of large handset subsidies, the additional voice capacity that is possible on its 3G [WCDMA] network would not be realized since its subscribers would still be using the 2G [GSM] network. Recall that with 1X, the handsets are forward and backward compatible with IS-95, which is not the case with WCDMA and GSM.

As previously noted, IS-95, 1X and EV-DO all use 1.25MHz of FDD spectrum. Further, given the special characteristics of CDMA-based systems, including WCDMA, each active frequency can potentially be assigned to every single cell site in an operator's network. This frequency reuse scheme (N=1) is not easily achieved with TDMA-based systems, such as GSM. Thus, a CDMA operator only has to free up one RF carrier to deploy a new technology (e.g., EV-DO). Conversely, GSM operators who are deploying an "in-band" WCDMA system would have to not only find and allocate 5MHz of contiguous spectrum, it would also have to design an entirely new frequency reuse scheme with its remaining RF carriers in order to ensure that inter-cell interference in its GSM network does not develop. As discussed in the next section, backward compatibility makes the 3G transition even simpler.

4.3 Backward and Forward Compatibility

Perhaps the most compelling feature of the CDMA2000 evolution is that, in addition to increasing voice capacity and supporting mobile data applications, it is largely backward and forward compatible. So what is backward and forward compatibility and why is it advantageous for an operator?

With backward and forward compatibility intact, CDMA operators have flexibility to choose how, when, and where they evolve their network without any concerns about disrupting services.

Forward compatibility means that a new technology can be deployed in an operator's network and mobile devices that are based on an "old technology" would still operate with the new technology as if nothing had ever happened. Conversely, mobile devices that are based on a new technology would still work on networks that are based on an old technology – this is referred to as backward compatibility. This bi-directional compatibility feature is highly attractive for an operator that is spectrum constrained, or for an operator that wants to take a phased approach to evolving from 2G to 3G services.

Case in point, Sprint Nextel (Sprint PCS at the time) began selling 1X phones in late 2002, but it didn't launch nationwide CDMA2000 services until the early fall of 2003. By taking this approach, Sprint Nextel was able to seed the market with 3G phones, thus when it launched 3G services it was immediately able to reap the voice capacity benefits that CDMA2000 offers. Equally important, when Sprint Nextel launched 1X, existing IS-95 phones that were already on its network were fully operational on a 3G radio carrier, even though those phones were based on a 2G technology. As a result, the 1X radio carrier did not go unused if there were not any 3G phones present.

It should be noted that EV-DO Release 0 is not backward compatible with 1X or IS-95. This approach was taken in order to take advantage of an all-IP network and to maximize the performance of an all data network without having to support circuit switch voice services (e.g., 1xEV-DV). However, EV-DO does maintain backward compatibility through the use of multi-mode devices that support EV-DO, 1X and IS-95. As a result, an EV-DO mobile device can seamlessly roam between EV-DO, where it can take advantage of the technology's enhanced data capabilities, and 1X, where the EV-DO services and applications are still available, albeit with 1X performance characteristics.

In that regard, WCDMA is largely comparable from a device point of view since multi-mode WEDGE (WCDMA + EDGE/GPRS/GSM) devices support continuity of services between 3G and 2G network boundaries. The primary difference, however, is from a network infrastructure perspective since WCDMA and EDGE/GPRS/GSM potentially require different spectrum blocks and may require standalone RAN equipment, thus increasing the cost and complexity of the networks(s).

Once an operator has deployed EV-DO Release 0, the evolution to EV-DO Revision A and Revision B is fully backward and forward compatible, with a large amount of hardware reuse within the network infrastructure. With backward and forward compatibility intact, CDMA operators have flexibility to choose how, when, and where they evolve their network without concerns about disrupting services for existing subscribers. With this flexibility, an operator could upgrade its entire EV-DO Release 0 network to Revision A (Revision B), thus allowing it to take advantage of the enhanced features associated with the later revisions while at the same time still supporting existing Release 0 mobile devices. Alternatively, the operator could migrate portions of its EV-DO network to Revision A (Revision B) based on its own particular requirements and provide seamless roaming for EV-DO devices between Revision A (Revision B), EV-DO Release 0, and even to 1X/IS-95 with the use of multi-mode devices.

5.0 The Impact on the Network Infrastructure

In the previous section, the advantages of backward and forward compatibility from a network services and mobile device point of view were highlighted. In this section, we'll examine the impact of the evolution on an operator's existing CDMA network infrastructure.

5.1 Radio Access Network

For each step in the migration, there is a large amount of hardware reuse in the RAN, with only modest hardware additions (largely channel cards) and/or new software.

5.1.1 1X to EV-DO Release 0

The degree to which an operator decides to replace versus reuse existing hardware is based on a number of factors, including the equipment's longevity. However, the 1X and EV-DO evolution supports a very high degree of hardware reuse and flexibility on how that hardware can be employed.

The 1X and EV-DO evolution supports a very high degree of hardware reuse and flexibility on how existing hardware can be employed.

For example, in order to complete the upgrade from 1X to EV-DO Release 0, the only modification to the 1X base station is the addition of a new EV-DO channel card, which is responsible for processing the EV-DO signal. Since most OEMs offer multi-carrier power amplifiers (MCPAs) and multi-carrier radios that simultaneously support 1X and EV-DO, new RF subsystems and MCPAs may not be required unless the existing RF/PA subsystem in the legacy base station is already fully utilized. In addition to a new channel card in each base station, a new RNC (Radio Network Controller) is required for EV-DO call control and managing cell handoffs between EV-DO base stations. Typically, a single RNC can support up to several hundred base stations, meaning that it is highly scalable.

Although most CDMA operators have already begun, or have even completed, the evolution to 3G, it is worth highlighting that the transition from 2G (IS-95) to 3G (1X) is equally simplistic with the only requirement in the RAN being a new 1X channel card that can sit alongside an existing IS-95A/B card. In fact, it is even conceivable that IS-95A/B, 1X and EV-DO channel cards could sit adjacent to one another within the same base station and simultaneously share many elements within the base station.

5.1.2 EV-DO Release 0 to Revision A

For those CDMA operators that have already committed to or have already deployed EV-DO, their focus is on the impact to their networks when they move to Revision A. Again, the migration is relatively simplistic and arguably even easier than the migration from 1X to EV-DO Release 0.

Starting with KDDI in late 2005 and continuing in 2006 in other countries, operators will begin seeding their networks with EV-DO Revision A channel cards. As was the case in the migration from 1X to Release 0, these new cards can be inserted alongside 1X and EV-DO Release 0 cards and can share many of the same base station elements.

Initially, these new channel cards will only support Release 0 functionality, but when the Revision A software becomes available later in 2006, operators will be able to update these cards with the new software and begin taking advantage of the rich features and applications that are made possible by Revision A. This strategy allows operators to continue with their EV-DO plans without having to wait for Revision A software and then quickly switch to the later revision – literally overnight if desired. Again, this rapid transition would only be possible with seamless backward and forward compatibilities between Revision A and Release 0 in which the mobile devices are not impacted by the transition.

5.1.3 EV-DO Revision A to EV-DO Revision B

At first glance the performance characteristics of Revision B, including the ability to support up to 46.5Mbps in the forward link (73.5Mbps with 64-QAM), would suggest that a major hardware change would be required and that existing EV-DO mobile devices would not function in a Revision B network. This, however, is not the case.

The upgrade from Revision A to Revision B may require a new channel card, or it could be as simple as a software upgrade, meaning that from a network perspective, Revision A channel cards can be reused, albeit with new software installed. Revision B logically combines up to fifteen EV-DO Revision A carriers above the PHY layer via software; however, it does not physically combine them so the integrity of each 1.25MHz carrier is preserved. By taking this approach, an operator can combine two to three Revision A carriers [channel cards] to create a Revision B solution that supports up to 9.3Mbps (14.7Mbps with 64-QAM) and at the same time use each carrier [channel card] to provide Revision A and Release 0 services via three discrete 1.25MHz carriers; note that a 64-QAM-based system would require a hardware upgrade. Forward and backward compatibility at the infrastructure level is preserved.

There is another subtle, albeit critical, near-term advantage gained by not physically combining RF carriers to create “super channels.” By not physically combining these channels, the targeted 1.25MHz radio carriers do not have to be adjacent to one another in the spectrum band. For operators with a scarcity of spectrum, this can be a tremendous advantage as these operators would not have to re-band their existing 1X and EV-DO RF carriers in order to group the EV-DO carriers together.

Revision B does require new mobile devices with multiple transmit and/or receive paths in order to achieve the higher data rates. However, Revision A and Release 0 mobile devices would still be fully compatible with the new revision while Revision B mobile devices would also work in a Revision A or Release 0 network. Forward and backward compatibility from the mobile device perspective is preserved.

5.2 The Core Network Evolution

It is important to realize that the RAN and CN (core network) do not have to evolve together, with separate standards used to define the RAN and the CN requirements and technical specifications. Like the 1X and EV-DO RAN migration, the CN migration is relatively straightforward with a clear migration path to an all-IP core transport and switching architecture that supports MMD applications and services.

The WCDMA core network and its migration path are very comparable with new network elements required to support packet services (e.g., GPRS and then WCDMA). In fact, the 3GPP2 (Third Generation Partnership Project 2) has recognized the work that the 3GPP (Third Generation Partnership Project) has done with IMS (IP Multimedia Subsystem) and has adopted it in large part, albeit with modest modifications to support specific needs.

5.2.1 IS-95 to 1X and EV-DO

In the core network, new hardware elements, including the PDSN (Packet Data Server Node), FA (Foreign Agent), AAA (Authentication, Authorization and Accounting server) and a HA (Home Agent) (HA), are required when migrating from IS-95 to 1X to support 1X data services. However, in their absence an operator could still utilize 1X for voice capacity gains and then deploy the packet core network when it is ready to begin offering data services. When an operator deploys EV-DO, the same core network elements are reused, although the operator will likely increase its backhaul capacity to coincide with the capabilities of the higher throughput air link.

5.2.2 The Transition to IP Multimedia Domain

Until recently, mobile communications systems (e.g., 1G, 2G and 3G) lacked the capabilities to support a full end-to-end IP core network. As a result, real-time services such as voice were handled by a circuit switch network, while less time sensitive applications were handled by a packet data core network (e.g., IP routing and transport). As an example, the video telephony feature of WCDMA is actually a 64kbps circuit switch connection, even though the video telephony application is considered to be a "data application."

With the introduction of EV-DO Revision A and its inherent ability to support QoS (Quality of Service) and low latency applications on an IP RAN, it is now possible to extend IP throughout the radio access and core network and offer non-realtime and time sensitive applications on the same packet network.

From an operator's point of view, this is a very attractive proposition since over time it can migrate its voice and data traffic to a more scalable [all-IP] network and effectively "turn off," or at least scale down, its circuit switch network. In addition to reducing capital expenditures and operating expenses, it is possible to seamlessly integrate voice and data services to provide subscribers with a more compelling multimedia experience.

The 1X and EV-DO evolution is largely comparable to the 3GPP evolution within the core network.

Over the last eighteen months, there has been a lot of focus, and rightly so, on IMS, which is a feature of Release 5 within the 3GPP [WCDMA] standard. With many of the 3GPP2 members also supporting the development of the 3GPP standards and the work within the IETF (Internet Engineering Task Force), the decision was made to leverage this work and adopt it within 3GPP2, albeit with subtle differences. Thus the 1X and EV-DO evolution is largely comparable to the 3GPP evolution within the core network.

In addition to a network architecture that is SIP (Session Initiation Protocol) based, and in which the signaling and bearer traffic are separated for a more effective use of network resources, MMD supports convergence across multiple access technologies, including WLAN (wireless local area network), WWAN (wireless wide area network), and fixed line. Operators can also leverage MMD to offer new services, including:

- Push-to-talk/see
- Video telephony
- Multimedia conferencing
- Person-to-person gaming
- Interactive shows and events

MMD is not a requirement, and operators could upgrade the RAN to EV-DO Revision A in order to take advantage of its improvements without fully realizing its capabilities throughout the network. However, it is likely that operators will eventually move toward an all-IP core network that supports MMD.

6.0 The Technical and Performance Characteristics of 1X and EV-DO

Until now, the focus of this white paper has been on the ease of migration between IS-95, 1X and subsequent revisions of EV-DO. In this section, the performance characteristics of CDMA2000 will be described and compared to other widely available 3G technologies.

6.1 1X

1X is the most spectrally efficient 3G technology for circuit switch voice, and provides a near doubling in voice capacity over IS-95. Yet, the transition from IS-95 to 1X can be as easy as inserting a new channel card into an existing base station and installing new software in the BSC (base station controller).

Based on readily available information from a large number of CDMA operators, IS-95 can support approximately 20 voice calls per sector in a 1.25MHz FDD radio channel. There is data to suggest that the actual number is modestly higher, but for conservative reasons a lower number is being used. In the same amount of spectrum, 1X can readily support 33-35 simultaneous voice calls, with some operators claiming the actual number is closer to 38-40 voice calls per 1.25MHz; much depends on how the network is deployed and optimized, as well as the distribution of the voice traffic within the cell.

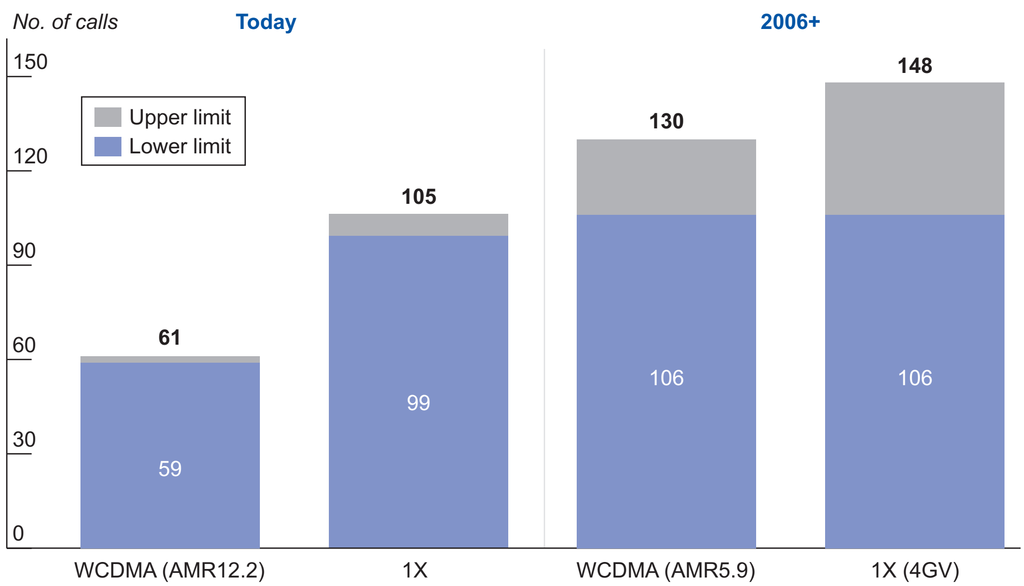
Using 34 voice calls as a conservative estimate, 1X increases voice capacity by 70% over IS-95, with most of that gain attributed to improvements in power control that reduces the noise floor and increases the capacity in a CDMA-based network. The increase in voice capacity, in and of itself, is compelling for an operator that is looking to minimize its capital expenditures, yet meet the demands of increasing network usage. A new codec, called 4GV, can reportedly increase voice capacity by another 40%.

For comparison purposes, simulations suggest that WCDMA can support approximately 60 voice calls in a 5MHz channel with a standard 12.2kbps codec rate, and 106 to 130 voice calls with AMR5.9 (a 5.9kbps codec). The AMR5.9 codec is not widely used at this time, and it isn't clear whether the impact on voice quality will be acceptable to subscribers. Operator-provided figures, however, place the actual number of simultaneous voice calls in a real world WCDMA network as being almost 50% lower. It isn't clear why this is the case, but for argument's sake, the theoretical numbers are assumed to be achievable over time, perhaps via network optimization.

In the following figure, WCDMA and 1X voice capacity are compared side-by-side. In order to normalize the data, it was assumed that three 1.25MHz 1X carriers and a 1.25MHz guard band are deployed in the 5MHz channel. This comparison, which discounts the disparity between the real-world performance of WCDMA and simulations, suggests that 1X voice capacity exceeds that of WCDMA. Signals Research Group, LLC validated the data presented in figure 6 through conversations with operators and with organizations that are exclusively aligned with WCDMA.

Most operators, however, are also using 1X to offer basic data services. In that regard, 1X supports bi-directional peak data rates of 153kbps at the PHY layer, with operators

FIGURE 6. 1X and WCDMA Voice Capacity in a 5MHz Channel



Source: Signals Research Group, LLC, and CDG

advertising typical data rates of 40-60kbps. While these advertised rates are almost always achievable, average data rates of 100-120kbps are very probable in a commercial network (note: theoretical data rates are at the PHY layer while measured/advertised data rates are at the application layer).

Although 1X is more than acceptable for basic data usage, including Verizon's BREW service and SK Telecom's NATE service, it was not designed to support the higher data rates that are normally associated with a broadband wireless service. Enter EV-DO Release 0.

6.2 EV-DO Release 0

EV-DO Release 0 supports peak data rates of 2.4Mbps in the forward link and 153kbps in the reverse link. In terms of sector throughput, this equates to theoretical estimates of up to 870kbps and 325kbps, respectively, in 1.25MHz. Data from operators who have already deployed EV-DO suggest that these numbers are achievable, with 730kbps at the low end of results while other operators are achieving more than 800kbps of average throughput in the forward link.

EV-DO Release 0 introduces an entirely new air interface with technical features that are specifically designed to enhance the performance of the all data network.

EV-DO Release 0 introduces an entirely new air interface with technical features that are specifically designed to enhance the performance of the all-data network. These features, which are exclusive to the forward link of the air interface, include:

Time Division Multiplexing (TDM) – Only one user is accessing the network at any given time, meaning that the full power from the base station can be dedicated to one user. Due to the rapid switching between active users (~1.6ms), the TDM feature is impossible to detect, even with real-time applications. By dedicating the power to a single user, the C/I (carrier/interference) level is improved, with a higher C/I equating to a higher quality signal and faster data rates.

Higher Modulation Schemes – EV-DO supports up to 16-QAM (16-Quadrature Amplitude Modulation) in the forward link, meaning that up to 16 bits of information can be encoded in the same time/space. 1X is limited to BPSK (Binary Phase Shift Key) which only supports 2 bits of information within the same time/space boundaries.

Adaptive Modulation and Coding – In addition to supporting a higher modulation scheme, the EV-DO air link can rapidly change between modulation schemes, thus maximizing the throughput for a given air link quality (C/I). This feature is particularly important since the quality of the air link is constantly changing due to fading and multipath effects, as well as the presence of other users.

Hybrid ARQ – Hybrid ARQ (Automatic Repeat reQuest), or HARQ, is a process that is used to limit the retransmission of data packets. Specifically, the EV-DO system tries to provide the highest possible data rate for a given C/I ratio. Since the C/I could get worse between the time of the measurement and the time the packet is supposed to arrive at the device, redundancy of the data is also transmitted. While this redundancy ensures that the data arrives at the receiving end, it can also create some network inefficiencies, specifically when the redundancy isn't needed. With HARQ, the base station can stop transmitting redundant information once the mobile device has successfully decoded the packet (e.g., it doesn't need the redundant information). In the absence of HARQ, the entire packet would have to be transmitted, even if the packet had already been successfully decoded. HSDPA also uses HARQ in the forward link.

Virtual Soft Handoffs – Typically, in a CDMA-based network a mobile device simultaneously communicates with multiple cell sites when it moves from cell to cell. Although this process, called soft handoffs, ensures a smooth and seamless handoff, it also creates some network inefficiencies as multiple network resources are being used to support the same user traffic. With EV-DO, soft handoffs are not used in the forward link, although they are still used in the reverse link. Instead, there is a mechanism where the device measures the C/I for each of the sectors that it sees and determines which is the best sector to serve it at any instant. At the point where the device detects that there is another sector that has a higher C/I, it tells the network that it wants to be served by the sector with the higher C/I.

Receive Diversity – While not a requirement, EV-DO mobile devices can use receive diversity (two separate receive chains with associated antennas) to boost the signal and therefore improve the C/I (and the data rates). By using receive diversity in the forward link, the sector throughput can be increased to 1.24Mbps, assuming that all devices in that sector support it. Receive diversity is not specific to EV-DO; however, it was first introduced with Release 0 and will also be introduced with WCDMA and 1X. Receive diversity is already implemented in all EV-DO handsets sold in Japan and most EV-DO data cards support it as well.

As suggested above, the Release 0 air interface in the reverse link is largely unchanged from 1X. As a result, there is very little difference in performance relative to 1X. That said, user experience has found that EV-DO data rates in the reverse link are generally much better than 1X data rates with network loading likely to be the best explanation for the phenomenon.

WCDMA peak data rates, based on a Release '99 implementation, are 384kbps in the forward link and 64-128kbps in the reverse link, depending on the capabilities of the mobile device and chipset. From a subscriber's perspective, this equates to average data rates of around 200kbps and 60kbps, respectively. Overall network performance, as determined by forward link sector throughput, is currently around 750kbps in a 5MHz FDD channel, although it could improve over time with network optimization. HSDPA, which should be introduced in late 2005 in North America and in other regions in 2006-2007, reportedly provides an increase in network efficiency by two to three times.

From a performance perspective, EV-DO is far superior to that of 1X and much better than WCDMA. Still, there are limitations associated with EV-DO that would preclude it from being suitable for real-time applications, such as VoIP, and for applications that require meaningful bandwidth in the reverse link (e.g., transmitting a large file). Enter Revision A.

6.3 EV-DO Revision A

EV-DO Revision A (TIA-856-A) is the first in a series of planned upgrades for EV-DO Release 0. In summary, Revision A introduces modest improvements in forward link capacity, full support for real-time applications and QoS, and a vastly improved reverse link.

The primary differences between EV-DO Revision A and Release 0 include:

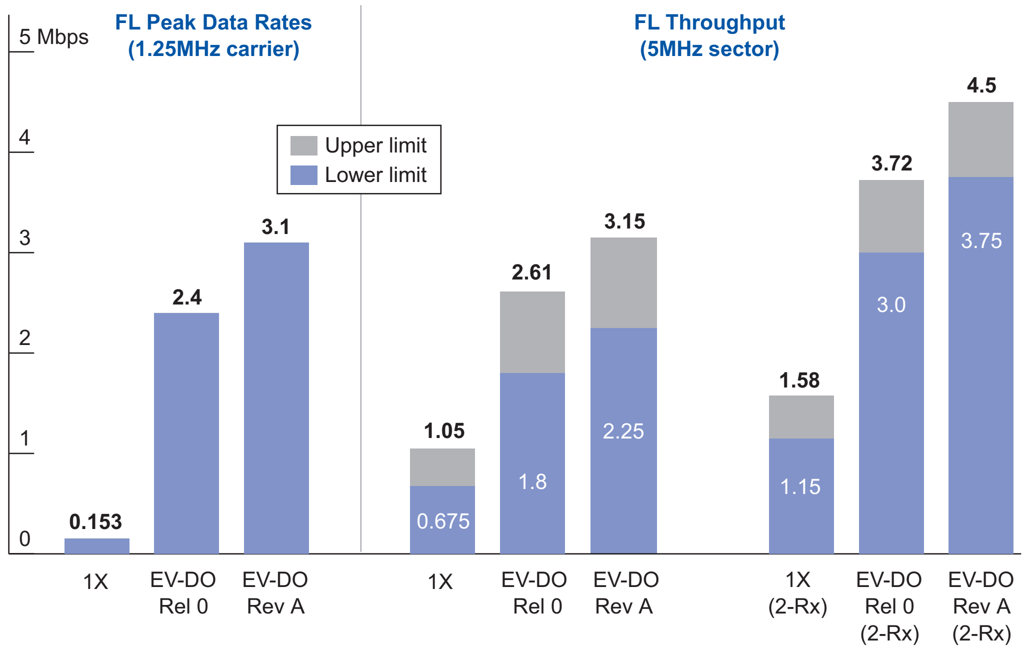
- Improved reverse link (peak rate and sector throughput)
- Advanced QoS mechanisms
- Platinum multicast

6.3.1 The EV-DO Revision A Forward Link

The improvements in the forward link include an increase in the peak data rate from 2.4Mbps (Release 0) to 3.1Mbps and an increase in sector throughput from 2.61Mbps to up to 3.15Mbps in 5MHz. With 2-Rx (2-way receive) diversity, which requires two receive chains in the mobile devices, forward link throughput in a 5MHz sector, based on simulations, should increase from 3.7Mbps to up to 4.5Mbps. This information is presented in Figure 7.

The improvements in the Revision A forward link are primarily achieved through better rate and packet quantization and equalization, which improves the C/I ratio, as well as the introduction of a new packet type with a transmission format that supports the 3.1Mbps peak data rate. Additionally, the higher throughput capabilities in the reverse link indirectly improve the forward link data rates by reducing the response time of the acknowledgement messages for packets that are sent in the forward link. The upper

Figure 7. 1X and EV-DO Comparisons (FL)



Source: CDG

and lower limits in Figure 7 and in subsequent figures are based on input from the CDG members.

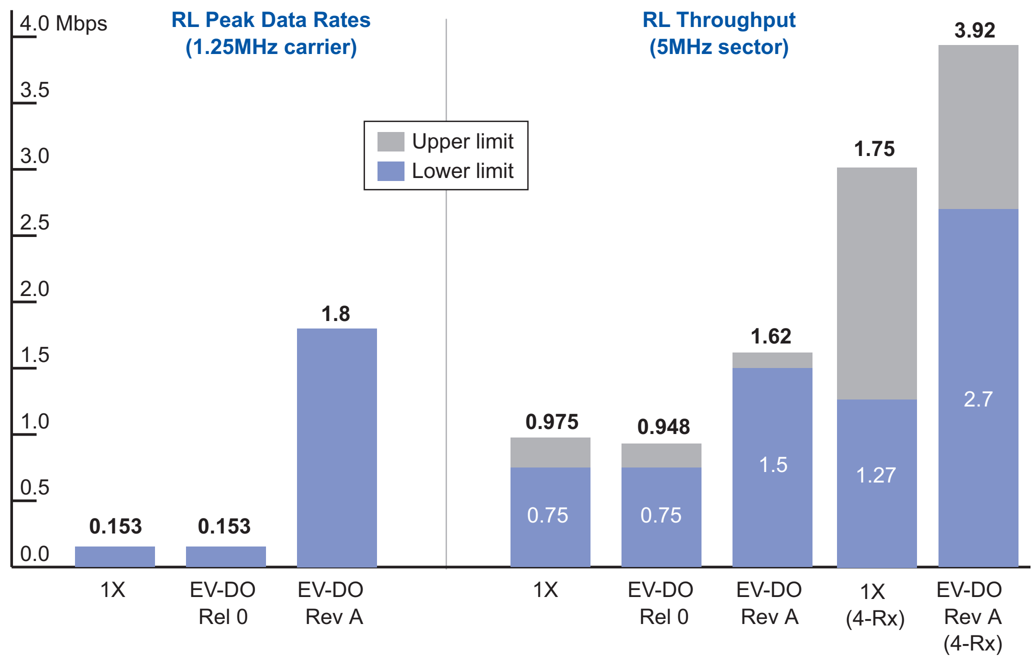
6.3.2 The EV-DO Revision A Reverse Link

Revision A offers a significant boost in sector throughput, peak and expected average user data rates in the reverse link. Based on modeling, which is supported by the 3GPP2 constituents, Revision A boosts the RL peak data rate from 153kbps to 1.8Mbps, and sector throughput from 0.948Mbps to 1.62Mbps in 5MHz. With 4-Rx diversity, which requires four Rx chains and associated antennas at the base station, the RL sector throughput is estimated to be as high as 3.92Mbps. 4-Rx diversity is not specifically tied to Revision A, but it is being implemented for the first time with this revision.

The equivalent technology on the WCDMA migration path is HSUPA. Depending on infrastructure and device/chipset availability, the technology could be ready as early as 2008.

The improvement in the RL performance is achieved through the use of higher modulation schemes and larger packet sizes, 4-branch receive diversity, Hybrid ARQ, smaller packet sizes, PIC (pilot interference cancellation) and, eventually, TIC (traffic interference cancellation).

Figure 8. 1X and EV-DO comparisons (RL)



Source: CDG

Higher Modulation Schemes – Revision A introduces the QPSK (Quadrature Phase Shift Key) and 8-PSK (Eight Phase Shift Key) modulation schemes in the reverse link. Previously, the reverse link only used BPSK. Both newly introduced modulation schemes were already present in the EV-DO Release 0 forward link and are also prevalent in other wireless standards, such as EDGE, meaning that they are not necessarily unique to CDMA-based systems.

Like all technologies, the challenge is being able to support the higher modulation schemes. If the air link is not of sufficient quality, the higher number of bits cannot be supported without retransmissions or error correction bits, which increases overhead and reduces the "real" data rates that users observe. Put another way, unless other changes are introduced, the use of a higher modulation scheme in and of itself will only have a modest impact on network performance. The changes to the air link that will result in an improved RL, and thus the ability to support the higher modulation schemes, are addressed by other RL enhancements (see next).

Receive Diversity – Revision A base stations support four-way, or four-branch, receive diversity in the reverse link. Four-branch receive diversity requires four receive chains and associated antennas per sector in 1.25MHz, although the use of cross-polarized antennas can reduce the number of antennas needed to two, although four antenna cables would still be required. Since there are four antennas receiving the signal, the ability of the system to extract out the signal from the noise is enhanced, in particular when fading and multi-path are present. The net result is an improved C/I (carrier/interference ratio) and a doubling in RL sector throughput.

Hybrid ARQ – With Revision A, Hybrid ARQ is used in the forward link and in the reverse link (see previous section). The same basic principles on how HARQ works apply in the reverse link as well. HSUPA also uses HARQ.

Packet Quantization – Revision A uses twelve different "types" of packets in the reverse link, with a packet type being characterized by its payload (# of data bits) and the modulation scheme that is applied. Therefore, the system allows for numerous options of available data rates (4.8kbps to 1.8Mbps), thus ensuring that the highest data rate is available to the user for a given air link (C/I) quality. Release 0 was limited to only 5 available data rates (9.6kbps to 153.6kbps).

Pilot Interference Cancellation – When there are a large number of users in a CDMA-based network, including WCDMA, each subscriber's pilot signal contributes to interference, which in turn reduces the capacity in the network. PIC reduces the interference from the mobile device's pilot signal and can increase network capacity by up to 20%. Since pilot interference is the result of a number of users and not the amount of traffic in a network, PIC is most effective when there are a large number of users transmitting relatively low amounts of data (e.g., VoIP).

6.3.3 QoS Mechanisms

6.3.3.1 Packet Prioritization

Revision A allows the network to prioritize traffic (data packets) based on the profile of the subscriber and/or the type of packet that is being sent. For example, high data users could pay a premium and receive preferential treatment over other subscribers, thus meeting their more demanding requirements, while providing an incremental revenue stream for the operator. Packets can also be prioritized based on the application being used. For example, packets that are flagged as carrying latency sensitive bits, such as those for VoIP, could be given priority over non-critical packets, such as a packet that is containing a portion of an MMS message. This degree of QoS capability is also available for Release 0 via a software upgrade.

QoS mechanisms, such as reduced latency and flow-based QoS, are probably the most important features of EV-DO Revision A.

While user-based and application-based QoS are noteworthy, flow-based QoS, in which the packets within an application are prioritized, is even more beneficial. For example, with flow-based QoS, video and audio packets could be prioritized differently, with the preference likely given to the audio packets since video applications can use buffering for modest amounts of jitter and delays. This is perhaps one of the most important features of Release A since it allows for multimedia services, such as video telephony, while providing the utmost in efficient and flexible control of how packets are sent in the network, thus maximizing network efficiency.

6.3.3.2 Reduced Latency

Latency on Release 0, as measured as the round trip time between a handset and the PDSN, is greater than 100ms, with the latency to external sites even higher once transport and router delays are factored into the equation. Although this is adequate for non-real-time applications, it is not generally considered acceptable for real-time services such as VoIP and video teleconferences, and can also impact the user experience for non-real-time applications such as Internet browsing. In contrast, latency between a mobile phone in circuit switch mode and a landline phone (e.g., including transport/switching time) is around 125ms.

Revision A reduces the latency by introducing improvements in the reverse link. Specifically, the use of smaller size packets (fewer time slots per packet), combined with HARQ, reduces the transmission time of an individual packet. The net effect is that RL latency can be reduced by 50% under a wide variety of usage scenarios, while maintaining Release 0 capacity. Alternatively, the RL latency can be reduced substantially when only small packets are used (e.g., VoIP) with the tradeoff being lower network capacity.

HSDPA also introduces improvements in latency relative to WCDMA. In this case, the improvement is due, in part, to moving the packet scheduler from deep within the core network (RNC) to the base station. A packet scheduler determines how/when to send packets to users, thus by moving it closer to the air interface, versus locating it deep in the core network, the response time is improved.

6.3.3.3 Multi Flow Packet Application
Multi Flow Packet Application is the ability to support multiple data sessions involving different applications on the same device. For example, if a subscriber is downloading email using Outlook, he/she does not have to terminate the connection to answer an incoming VoIP phone call. Another example is a video telephony call in which the voice and video packets are treated differently, with the higher QoS given to the more demanding voice packets while the video packets can stand some degree of delay due to buffering.

6.3.4 Other Enhanced Capabilities
Revision A also introduces several features that allow data applications to make more efficient use of an operator's network and make them more appealing and compelling for subscribers to use.

6.3.4.1 Support for More Users
In EV-DO systems, the theoretical maximum number of users is based on the number of power control bits that are available. With Revision A, the number of power control bits is increased from 59 in Release 0 to 114, with each power control bit associated with an individual user. Under normal conditions other limiting factors would take precedence, thus the 114 figure may not necessarily be achievable.

6.3.4.2 Platinum Multicast – Incorporating OFDM
Platinum Multicast is a one-to-many solution that enables operators to deliver multiple content streams to many subscribers by dedicating any fraction of a 1.25 MHz carrier to multicast services. Platinum Multicast, which is now going through the standardization

process (TIA-1006-A), takes advantage of the TDM-nature of EV-DO by interleaving OFDM tones into certain time slots to provide a more efficient multicast service

Based on modeling, it is reportedly able to deliver sector throughput rates of up to 1.5Mbps (>98% coverage) in the forward link – since it is a multicast service, there is very little traffic in the reverse link. From an operator's perspective (network efficiency) a multicast service has its clear advantages since the number of users being served is virtually unlimited for a given amount of committed network resources (bandwidth), thus the revenue-generating opportunity is far greater for a given amount of multicast (versus unicast) throughput. The real efficiency of the multicast system is therefore also a function of the number of subscribers that are using it in a given sector – the higher the number of subscribers the higher the efficiency and vice versa.

The Platinum Multicast system, through the use of program scheduling software, can also take advantage of off-peak hours to transmit its content, in particular content that is not time sensitive. This feature can be extremely advantageous since network usage is widely variable with typically little or no traffic being sent during the late night and early morning hours.

6.3.5 Voice over Internet Protocol (VoIP)

Voice over Internet Protocol (VoIP) is not a Revision A technical enhancement, per se, but an application that is enabled by the aforementioned features of the latest release: specifically, QoS and an improved reverse link. Additionally, Revision A shortens the time required to complete a cell handover in packet mode to around 40ms versus >100ms with Release 0 – a necessity for carrier-grade VoIP calls.

Based on simulations, Revision A (w/2-Rx diversity and PIC) can support close to 50 simultaneous voice calls per sector in a 1.25MHz FDD radio channel, which compares with 33-40 simultaneous voice calls using 1X (no receive diversity or PIC).

The potential for increased voice capacity relative to 1X is of high interest to operators, but VoIP on Revision A offers other advantages as well. In particular, voice and data can be combined to create a seamless multi-media experience, with applications including video telephony and "see what I see" – a great tool for real estate agents, insurance claim examiners, and tourists.

Longer term, VoIP can help an operator reduce its capital expenditures and subsequent operating expenses as it is able to leverage the advantages of an all-IP network, both in the RAN and in the core network. For example, operators are already moving toward adopting softswitches and a distributed switch architecture, which among other things reduces transport costs and minimizes their dependence on MSCs (mobile switching centers). This migration will be a very long process, however, since operators are not necessarily willing to throw out multi-million dollar circuit switches.

As VoIP is an end-to-end service, CDMA operators will also have to upgrade their core networks in advance of launching the service. Additionally, there is some more work required within the standards body to ensure full-interoperability with 1X circuit switch voice. In all likelihood, conversational VoIP that is suitable to replace 1X circuit switch voice calls will not become a commercial reality until 2008, although it could be used for Push-To-Talk services once Revision A has been deployed in the RAN.

6.4 Revision B – Scalable Bandwidth EV-DO

Although Revision A is not yet a reality in a commercial sense, efforts are already underway within the 3GPP2 to develop and standardize the next revision, which is Revision B.

Revision B, which could be adopted as a standard in Q1/06 and commercially available in late 2007, literally builds on the efficiencies contained within Revision A by introducing the concept of dynamically scalable bandwidth. Scalable bandwidth can theoretically combine up to fifteen 1.25MHz carriers (20MHz) in the forward link and/or the reverse link to increase available bandwidth. For example, if three 1.25MHz carriers are combined, the theoretical peak data rate would be three times that available with Revision A, or 9.3Mbps. Should all fifteen carriers be used, the peak data rate would be 46.5Mbps (RL = 27Mbps). Recently, there was a proposal to introduce 64-QAM into the standard. Should this occur, the peak data rate per 1.25MHz carrier would be 4.9Mbps, which equates to 14.7Mbps with three carriers and 73.5Mbps with all fifteen carriers; note that a 64-QAM-based system would require a hardware upgrade.

It is important to note that these carriers are not physically combined together (e.g., the spreading of the signal is not across a 20MHz carrier). Instead, each 1.25MHz carrier remains its own entity, so there is no loss in spectral efficiency. This also means that the carriers do not have to be directly adjacent to one another in the spectrum band, thus giving the operator flexibility in determining which carriers to use.

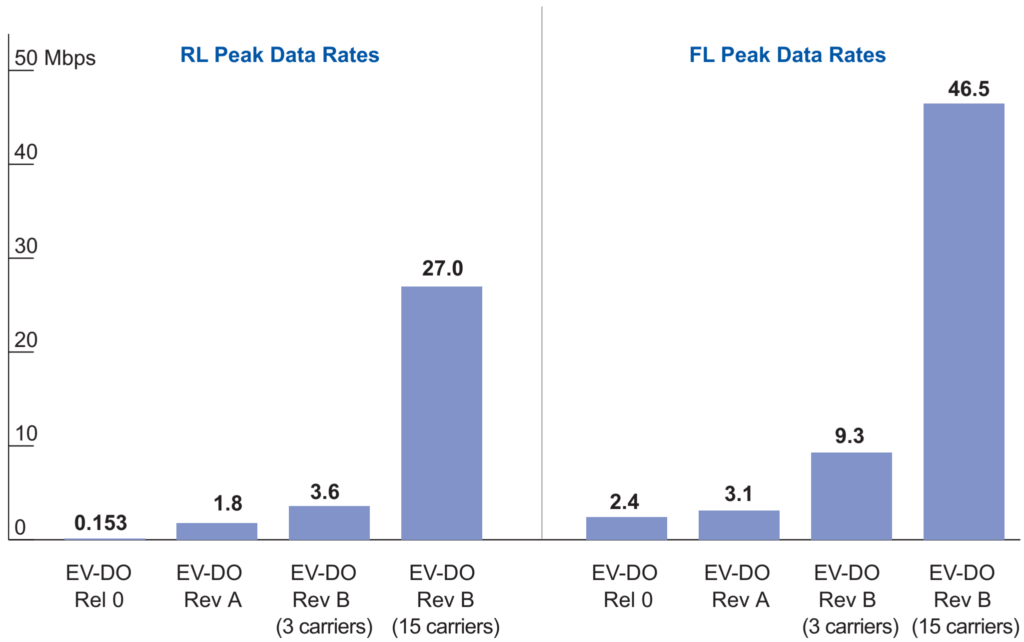
Latency and QoS can also be improved since the system can dynamically switch between EV-DO carriers based on the channel quality and traffic load. Put another way, packets can be sent to [received from] a mobile device using, for example, three carriers, or the packets can be sent to [received from] a mobile on only one carrier, but the active carrier constantly changes in order to provide the best possible throughput and lowest latency.

As carriers are not physically combined, and since there are no changes to the lower OSI layers relative to Revision A, Revision B is fully backward and forward compatible with Revision A (and Release 0). Therefore, Revision A mobile devices do not require hardware and software changes to function in a Revision B network, although they would only have Revision A functionality. Likewise, network infrastructure could only require software changes since the existing hardware (channel cards) can be reused.

On the device side, new chipsets would be required that had multiple RF chains that could be simultaneously transmitting and/or receiving on multiple RF carriers.

From a Revision B device perspective, it isn't practical to have fifteen transmit and/or receive chains due to cost, size and battery life considerations. Revision B does not have to symmetrically allocate carriers in the FL and RL. Instead, it is likely that Revi-

Figure 9. A Comparison of EV-DO Technologies



Source: Signals Research Group, LLC

sion B devices only support two to three EV-DO carriers and perhaps modestly higher for PDAs and data cards. Telematics or wireless DSL replacement are examples of potential applications where higher data rates (>10Mbps) are desirable and where cost and battery life considerations are less of an issue. However, operators would have to balance the ability to deliver these types of services with the economics of delivering these high bandwidth-consuming applications.

6.5 Revision C

The exact features of Revision C are still being discussed; however, there is a good probability that this revision could include the use of smart antenna technologies (SDMA or MIMO). Additionally, there is a lot of discussion about physically combining the carriers to create channel bandwidths in excess of 1.25MHz. In such a scenario, a 5MHz, 10MHz or even 20MHz super channel would be possible.

Revision C could also be the first opportunity for the more aggressive use of OFDM in 3GPP2. Depending on engineering analyses, OFDM could be limited to the forward link with CDMA still used in the reverse link or it could be used bi-directionally. The jury is still out. Nonetheless, Revision C and whatever follows will propel CDMA2000 and EV-DO well into the next decade.

7.0 Conclusions

CDMA2000 1X and EV-DO provide a compelling "one-two punch" that combines the most spectrally-efficient 3G technology for voice capacity along with a data optimized solution that can provide broadband wireless access in a mobile environment.

There are a number of factors that an operator must take into consideration when selecting a wireless technology, just as there are many factors that a consumer must take into consideration when selecting a wireless service provider and a mobile device. However, historical and fact-based data, performance characteristics, and the planned evolution of the CDMA2000 family of technologies are very compelling and worthy of consideration.

The success of 1X and EV-DO over the last few years did not happen by chance. Its success is largely due to the smooth migration process from 2G to 3G, which does not require an operator to purchase additional spectrum and deploy an entirely new RAN. As important, since forward and backward capability is an inherent feature, CDMA operators do not have to unduly worry about the impact on their network or on their subscribers.

The relatively smooth migration from IS-95 to 1X and EV-DO has also given CDMA2000 operators a time to market advantage which they can capitalize on if they so choose. From a technology perspective, 1X, EV-DO Revision 0, and its future revisions have at least a one to two year lead over their comparative technologies on the 3GPP evolutionary path. Furthermore, while EV-DO Revision A will not be commercial reality until mid-2006, work within the standards body on the next revision is almost completed – a software upgrade that will increase data rates by two to three times , depending on the number of carriers that are supported (2 carriers doubles the data rate, etc).

CDMA operators who have launched EV-DO services are already witnessing a favorable impact on their ARPU, both from the increase in data revenues as well as from an increase in voice usage. Although it is difficult to quantify, these operators are also attracting new subscribers and increasing subscriber loyalty because of their mobile data offering, including both broadband wireless access and multimedia services.

With the introduction of QoS mechanisms that support the prioritization of individual packets and a dramatic reduction in latency, combined with the potential for multi-megabit-per-second average data rates, the CDMA2000 family is well positioned to take the industry into the next decade.