Delivering Voice and Data: Comparing CDMA2000 and GSM/GPRS/EDGE/UMTS

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CDG

Executive Summary

Although voice continues to drive the lion's share of revenue for most wireless operators, data is emerging both as a key source of revenue and as a market differentiator. This trend means that operators must balance the unique needs of voice and data – particularly in terms of capacity – without overspending on spectrum and network infrastructure.

Regardless of the wireless technology used, the same rule applies: The more subscribers, minutes and megabytes that a cell site can handle, the lower the operator's cost to deliver those services. Lower overhead costs in turn determine the operator's ability to price voice and data services competitively and still turn a profit.

This white paper uses simulations to discuss how the evolution of the CDMA2000 and GSM families of technologies will affect their voice and data performance, including their spectral efficiency when delivering those services. While different technologies have distinct evolution strategies and different constraints, voice and data capacity will significantly improve with technology advancements in the coming years. CDMA technologies provide higher voice and data efficiencies than GSM, and the CDMA2000 evolution path offers a significant time-to-market advantage in enhanced capabilities compared to WCDMA.

Introduction

The CDMA2000 and GSM families of technologies are significantly different, yet they face the same marketplace realities:

- Although customers are talking more, declining prices – due largely to big "buckets" of minutes – are driving down voice revenues
- Data is emerging as an important way to offset declining voice revenue and as a market differentiator
- In a market as competitive as wireless, operators can't afford to overspend on spectrum and network infrastructure in order to accommodate growth in voice and data
- Efficiency – particularly in terms of spectrum – directly affects the economics for voice and data services
- Sector throughput is a useful way to determine the types of services that an operator can deliver

The relative performance of a technology is, therefore, an important consideration for an operator in a technology decision. The industry and media often use the theoretical peak rates that various wireless technologies can achieve, but these seldom represent the performance that operators and users will experience in real networks. Furthermore, often when comparing technologies, the bandwidth in which each operates is not being considered, providing a distorted view of the relative performance of the technology. Figure 1, on the next page, shows the theoretical peak rates for leading technologies in the bandwidths in which they typically operate.

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Figure 1: Peak data rates for CDMA and GSM technologies

	System	Theory	
		FL	RL
CDMA	1X (1.25 MHz)	614	614
	1xEV-DO Rev. 0 (1.25 MHz)	2458	153
	1xEV-DO Rev. A (2006) (1.25 MHz)	3072	1800
	1xEV-DO Rev. B (2007) (5 MHz)	14745	5400
GSM WCDMA	GPRS (200 kHz)	163	163
	EDGE (200 kHz)	474	474
	W-CDMA Rel. 99 (5 MHz)	2688	2304
	HSDPA Rel. 5 (2005) (5MHz)	14400	2304
	HSDPA Rel. 6 (2007) (5MHz)	14400	5000

This white paper uses simulations to discuss how the evolution of the CDMA2000 and GSM families of technologies will affect their voice and data performance, including their spectral efficiency when delivering those services in normalized 5 MHz and 10 MHz of bandwidth. The goal is to provide a fair and realistic assessment of the relative evolution of the voice and data capacity offered by the worldwide wireless market's dominant technologies.

The performance data are based on 3G evolution paths through 2007. This information was provided by CDMA Development Group members, which obtained the performance information from simulations and/or field tests. In each section, footnotes provide details about the technical assumptions used to calculate the performance figures.

It's important to note that for any wireless technology, voice capacity is determined partly by the handsets in use. For example, if an operator's entire customer base has upgraded to 1X handsets, the network and spectrum can accommodate more calls than if some customers are still using older, less efficient technologies, such as IS-95A. As a result, all of the data in this paper are based on the assumption that the comparisons are made between networks where 100 percent of the customer bases are using a particular technology rather than a mix.

Average Voice Capacity

Voice capacity directly affects a wireless operator's competitive position. Expanding the network to accommodate more calls requires an investment in additional radio infrastructure, spectrum or both – assuming that spectrum is even available. The more that an operator spends on expanding voice capacity, the less able it is to price its services competitively and still turn a profit. Although data usage is growing for most operators, voice continues to drive the lion's share of revenue. So for the foreseeable future, increased data usage will not reduce the importance of voice capacity.

Hence the value of a wireless technology that uses spectrum as efficiently as possible. Regardless of the technology, efficiency usually is measured in terms of "Erlangs," which is an average number of users arriving randomly at the network. The higher the Erlang score, the more simultaneous calls that a cell site sector can handle.

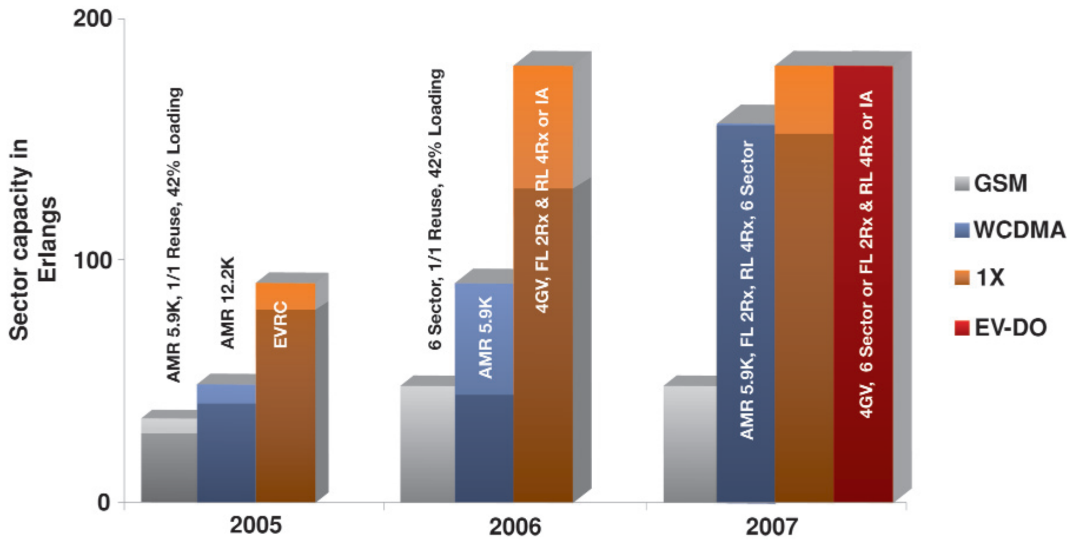
Figures 2 and 3 compare GSM, 1X, WCDMA and 1xEV-DO voice over IP (VoIP) in terms of the amount of calls that each technology can handle in a 5-MHz block of spectrum. (EV-DO supports only packet data, but it can carry voice calls, too, through the addition of VoIP.) The data show that the CDMA2000 family of technologies currently has a significant advantage over GSM and WCDMA in terms of voice capacity.

Figure 2: Average Voice Capacity – 5 MHz

	2005	2006	2007
GSM	33 – 36 (AMR 5.9K, 1/1 reuse, 42% fractional loading)	50 (6 sector)	
WCDMA	48 – 50 (AMR 12.2K)	69 – 93 (AMR 5.9K	117 – 128 (FL 2Rx, RL 4Rx) 160 (6 sector)
1X	79 – 93 (EVRC)	93 – 134 (4GV various COPs*) 158 – 184 (6 sector or FL 2Rx & RL 4Rx or IA***)	
EV-DO (VoIP)			105 – 116 (EVRC, FL & RL 2Rx) 115 – 134 (EVRC RL PIC**) 130 – 154 (4GV various COPs & PIC) 184 (6 sector or RL 4Rx or IA)

Footnotes:
100% loading of voice traffic
2% blocking
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
*COPs: Capacity Operating Points
**PIC: Pilot Interference Cancellation
***IA: Intelligent Antenna

Figure 3: Voice Capacity Evolution – 5 MHz



Footnotes:
Graph represents lower and upper range for each technology
100% loading of voice traffic
2% blocking
100% of subscribers using latest technology
Actual gains would depend on handset penetration
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For example, a 1X network using the Enhanced Variable Rate Codec (EVRC) can support at least twice as many voice calls (79-93 Erlangs per sector) as a GSM network using the Adaptive Multi-Rate (AMR) codec (33-36 Erlangs). This advantage continues through at least 2007, based on assumptions about upgrades to 1X and GSM.

Compared to WCDMA, 1X offers at least comparable voice capacity through 2007, based on the technologies' planned evolutionary paths. With the addition of EV-DO VoIP, the CDMA2000 network's capacity can run as high as 184 Erlangs per sector compared to WCDMA's 160 Erlangs, based on a comparison using 6-sector base stations. The bottom line is that under most usage scenarios, CDMA2000-based networks have a competitive advantage over those using GSM or WCDMA because they can fit more callers in a 5-MHz block of spectrum.

One fact that shouldn't be overlooked is that the GSM family of technologies is able to narrow the voice-capacity gap only by deploying a CDMA-based technology: WCDMA. That gain highlights one of the inherent benefits of CDMA.

Similar comparisons can be made using a 10-MHz block of spectrum. Figures 4 and 5 show that the CDMA2000 family of technologies maintains its significant edge over GSM and WCDMA in terms of voice capacity. For example, in 10 MHz, a 1X network using the EVRC codec supports 185-231 Erlangs per sector, while GSM and WCDMA never approach even the low end of this range.

Figure 4: Average Voice Capacity – 10 MHz

	2005	2006	2007
GSM	90 - 101 (AMR 5.9K, 1/1 reuse, 42% fractional loading)	171 (6 sector)	
WCDMA	95 – 107 (AMR 12.2K)	147 – 186 (AMR 5.9K)	246 – 256 (FL 2Rx, RL 4Rx) 320 (6 sector)
1X	185 – 231 (EVRC)	217 – 329 (4GV various COPs*) 368 – 448 (6 sector or FL 2Rx & RL 4Rx or IA***)	
EV-DO (VoIP)			245 – 287 (EVRC, FL&RL 2Rx) 270 – 329 (EVRC RL PIC**) 305 – 378 (4GV various COPs & PIC) 448 (6 sector or RL 4Rx or IA)

Footnotes:
100% loading of voice traffic
2% blocking
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
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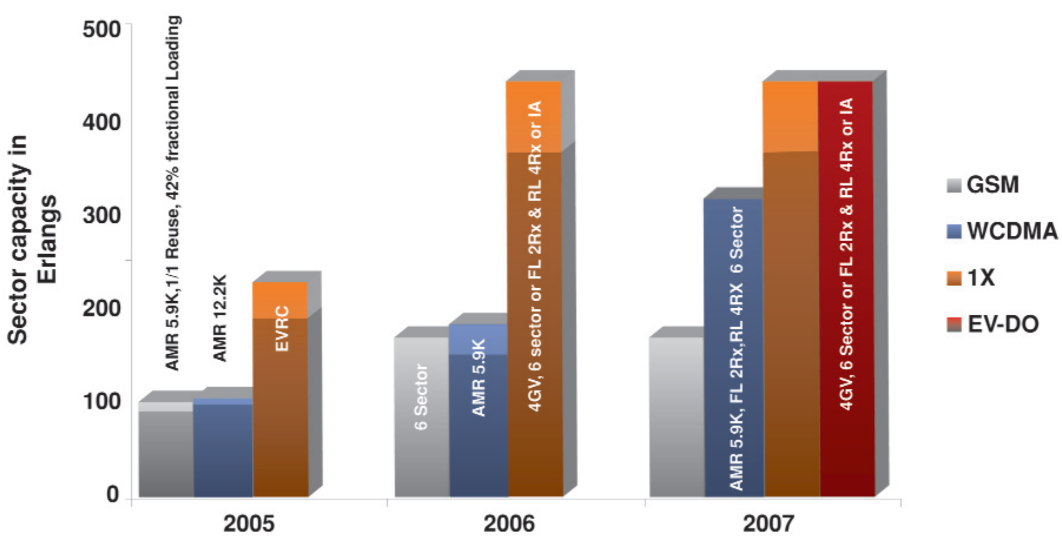
Figure 5: Voice Capacity Evolution – 10 MHz



Footnotes:
Graph represents lower and upper range for each technology
100% loading of voice traffic
2% blocking
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
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This advantage continues through at least 2007. For example, 1X's voice capacity evolves to 217-448 Erlangs per sector, depending on configuration, while GSM improves to only 171 Erlangs. This difference is particularly important for operators in regions such as South America, where analog and TDMA networks are approaching the end of their useful lives. If the operator serves markets where voice is expected to continue to drive the vast majority of revenue for the foreseeable future, then 1X is an ideal choice because it offers maximum voice capacity while also supporting packet-data services.

Average Forward Link Sector Throughput

Data services are important for wireless operators because they provide a way to offset flat or declining voice revenue. Data also provides a way to offer a wider range of services, which help drive additional revenue and serve as market differentiators so that the operator can compete on services rather than on price alone.

Forward link throughput – also referred to as “download speed” – is important because support for faster data speeds means that the operator can offer more than just low-bandwidth services such as multimedia messaging and basic Web browsing. For example, a wireless technology that can deliver average download speeds of 500 kbps is well-positioned to support consumer services such as video on demand and music downloads, as well as enterprise applications.

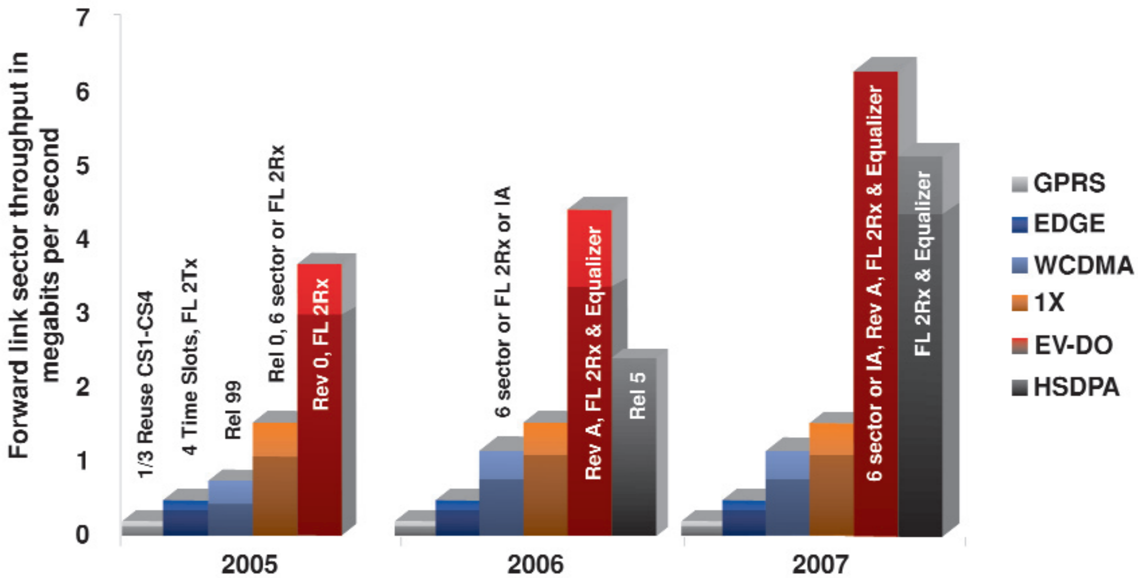
Figures 6 and 7 compare the CDMA2000 and GSM families of technologies in terms of forward link throughput in 5 MHz bandwidth. One key finding is that the two most widely available CDMA2000 technologies (1X and EV-DO Rel. 0) currently deliver significantly faster downloads than the three most widely available GSM technologies (GPRS, EDGE and WCDMA Release 99). This advantage increases in mid-2006, when EV-DO Rev. A becomes commercially available.

Figure 6: Average Forward Link Sector Throughput – 5 MHz

	2005	2006	2007
GPRS	140 – 230 (1/3 reuse, CS1-CS4)		
EDGE	430 – 506 (1/3 reuse, 4 time slots, FL 2Tx)		
WCDMA	495 – 800 (Rel 99)	840-1,200 (6 sector or FL 2Rx)	
1X	675 – 1,050 (Rel 0) 1,147.5 – 1,575 (6 sector or FL 2Rx or IA)		
EV-DO	1,800 – 2,610 (Rev 0) 3,000 – 3,720 (FL 2Rx)	3,750 – 4,500 (Rev A, FL 2Rx & Equalizer)	6375 (6 sector or IA)
HSDPA		~2,400 (Rel 5)	~3,600 (FL 2Rx) 4,356 – 5,200 (FL 2Rx & Equalizer)

Footnotes:
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
IA: Intelligent Antenna

Figure 7: Evolution of Forward Link Data Throughput – 5 MHz



Footnotes:
Graph represents lower and upper range for each technology
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
IA: Intelligent Antenna

Rev. A increases DO's forward link speeds to 3.75-4.5 Mbps per sector. That throughput is noteworthy for at least two reasons. First, it's significantly faster than HSDPA/UMTS Rel. 5, so CDMA2000 is better able to support bandwidth-intensive consumer and enterprise data services. Bandwidth is particularly important on the consumer side, where expectations about mobile data services are strongly influenced by user experiences with cable and DSL. In other words, dial-up speeds no longer are acceptable in a wired or wireless environment. Both EV-DO Rev. 0 and Rev. A acknowledge that reality by providing forward link throughput rates that any user would consider broadband.

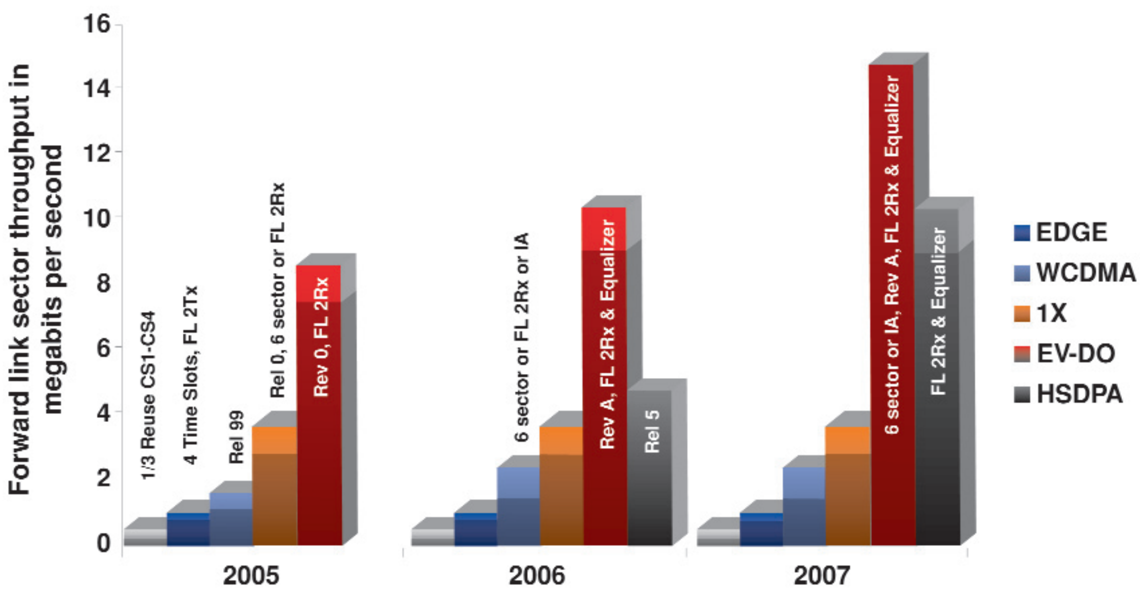
Figures 8 and 9 makes a similar comparison in 10 MHz of spectrum. In most scenarios, CDMA2000 maintains its forward link advantage at least through 2007.

Figure 8: Average Forward Link Sector Throughput – 10 MHz

	2005	2006	2007
GPRS	290 – 484 (1/3 reuse, CS1-CS4)		
EDGE	890 – 1,070 (1/3 reuse, 4 time slots, FL 2Tx)		
WCDMA	990 – 1,600 (Rel 99)	1,683-2,400 (6 sector or FL 2Rx)	
1X	1,575 – 2,450 (Rel 0) 2,677.5 – 3,675 (6 sector or FL 2Rx or IA)		
EV-DO	4,200 – 6,090 (Rev 0) 7,000 – 8,680 (FL 2Rx)	8,750 – 10,500 (Rev A, FL 2Rx & Equalizer)	14875 (6 sector or IA)
HSDPA		~4,800 (Rel 5)	~7,200 (FL 2Rx) 8,712 – 10,400 (FL 2Rx & Equalizer)

Footnotes:
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
IA: Intelligent Antenna

Figure 9: Evolution of Forward Link Data Throughput – 10 MHz



Footnotes:
Graph represents lower and upper range for each technology
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
IA: Intelligent Antenna

Average Reverse Link Sector Throughput

Reverse link throughput – also referred to as "upload speed" – is similar to forward link throughput in the sense that support for faster data speeds means that the operator can offer a wider range of data services. Although users tend to pay the most attention to a technology's download speeds, the reverse link shouldn't be overlooked. For example, as camera phones support resolutions of two megapixels or higher, the image files become larger. That increase requires a faster reverse link in order to share images. Another example is that business customers who use laptops with 3G PC card modems to download large files will find equal value in upload speeds because they can send attachments just as quickly as they receive them. For bandwidth-intensive consumers and enterprise applications, a 3G service with symmetrical broadband speeds is better able to compete with public Wi-Fi "hot spot" services.

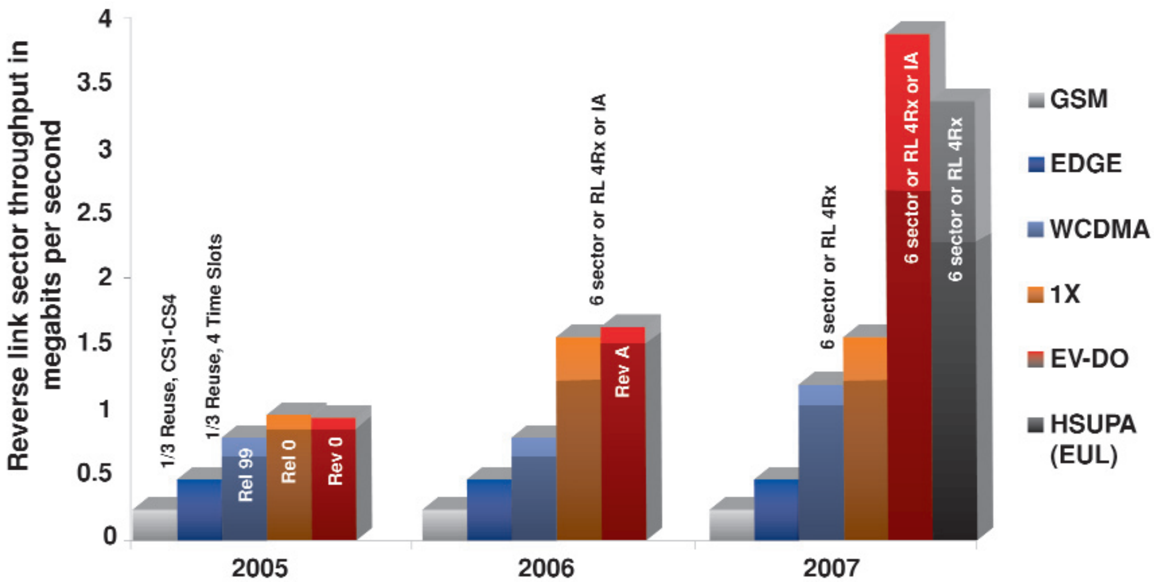
Figures 10 and 11 compare the CDMA2000 and GSM families of technologies in terms of reverse link throughput. One key finding is that 1X and EV-DO Rev. 0 support upload speeds that are comparable to that of WCDMA Rel. 99 – and are even faster, depending on the assumptions used to calculate the throughput scenarios. This advantage continues with EV-DO Rev. A, which supports upload speeds of 1.5-1.6 Mbps, compared to WCDMA's 1-1.2 Mbps.

Figure 10: Average Reverse Link Sector Throughput – 5 MHz

	2005	2006	2007
GPRS	230 (1/3 reuse, CS1-CS4)		
EDGE	475 (1/3 reuse, 4 time slots)		
WCDMA	605 – 800 (Rel 99)		1,028 – 1,200 (6 Sector or RL 4Rx)
1X	750 – 975 (Rel 0)	1,275 – 1,575 (6 Sector or RL 4Rx or IA)	
EV-DO	750 – 948 (Rev 0)	1,500 – 1,617 (Rev A)	2,700 – 3,924 (6 Sector or RL 4Rx or IA)
HSDPA			1,320 – 1,400 (Rel 6) 2,244 – 3,400 (6 Sector or RL 4 Rx)

Footnotes:
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
IA: Intelligent Antenna

Figure 11: Evolution of Reverse Link Data Throughput – 5 MHz



Footnotes:
Graph represents lower and upper range for each technology
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
IA: Intelligent Antenna

Another key finding is that EV-DO Rev. A will outperform UMTS/HSUPA through at least 2007. The latter is expected to support upload speeds of 1.3-3.4 Mbps, depending on the configuration, while EV-DO Rev. A is capable of delivering reverse link throughput of 2.7-3.9 Mbps per sector.

Figures 12 and 13 make similar comparisons using a 10 MHz block of spectrum. One finding is that EV-DO Rev. 0 remains competitive with WCDMA and HSDPA through 2007. If a WCDMA operator deploys HSUPA, an EV-DO Rev. 0 network can be competitive, depending on how the HSUPA network is configured. If the EV-DO network is upgraded to Rev. A, its reverse link throughput is as fast, or faster, than HSUPA, depending on how the networks are configured.

Figure 12: Average Reverse Link Sector Throughput – 10 MHz

	2005	2006	2007
GPRS	485 (1/3 reuse, CS1-CS4)		
EDGE	1,200 (1/3 reuse, 4 time slots)		
WCDMA	1,210 – 1,600 (Rel 99)		2,057 – 2,400 (6 Sector or RL 4Rx)
1X	1,750 – 2,275 (Rel 0)	2,975 – 3,675 (6 Sector or RL 4Rx or IA)	
EV-DO	1,750 – 2,212 (Rev 0)	3,500 – 3,773 (Rev A)	6,300 – 9,156 (6 Sector or RL 4Rx or IA)
HSUPA (EUL)			2,640 – 2,800 (Rel 6) 4,488 – 6,800 (6 Sector or RL 4 Rx)

Footnotes:
Full buffer, physical layer throughput
100% of subscribers using latest technology
Actual gains would depend on handset penetration
6 Sector sites: cover the same area as 3-sector sites. Capacity quoted for 2 adjacent sectors or 120 Degree arc
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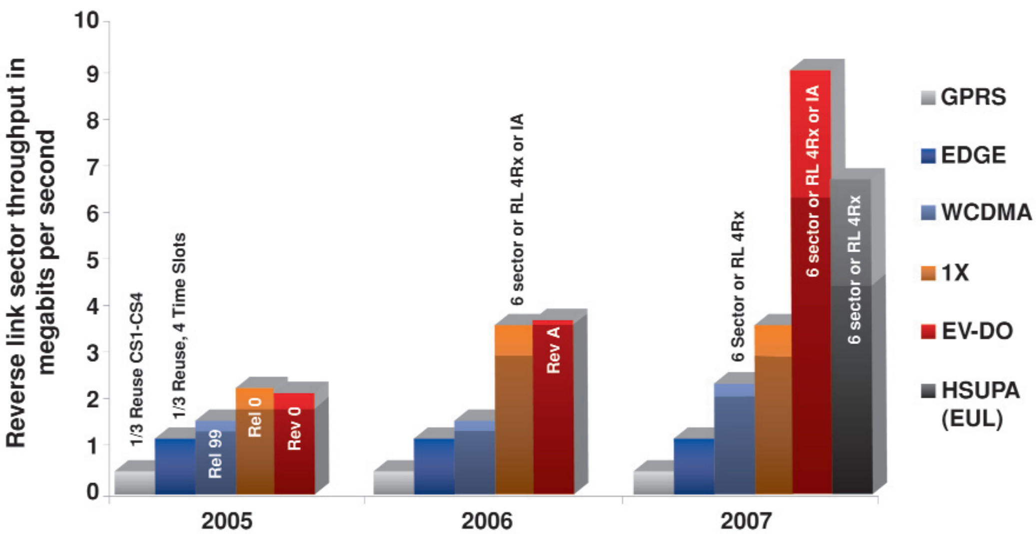
Figure 13: Evolution of Reverse Link Data Throughput – 10 MHz



Footnotes:
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Conclusion

Although the simulations discussed in this paper involve a variety of services and environments, there are several key findings that apply across the board:

- Growing demand for advanced services will drive the need for wireless capacity improvements
- Voice and data capacity will significantly improve with technology advancements over time
- Different technologies have distinct evolution strategies and different constraints
- CDMA systems provide the most spectrally efficient voice and data solutions

In terms of voice capacity, the key findings are:

- CDMA technologies deliver a higher Erlang capacity than GSM for any given time interval
  - CDMA2000 delivers 3-times as much voice capacity as GSM
  - WCDMA offers 2-times as much voice capacity as GSM
- CDMA2000 1X voice capacity will nearly double by 2006
  - 4G Vocoder will boost 1X & DOrA VoIP network voice capacity by up to 40 and 14 percent respectively
  - Receive Diversity and/or Intelligent Antenna techniques will further improve CDMA2000 1X and CDMA2000 1xEV-DO (VoIP) voice capacity

For data performance, the key findings are:

- Data throughput will significantly increase for all technologies
- CDMA2000 and WCDMA deliver higher throughput than other technologies for any given time interval

This analysis looks at the technology evolution through 2007 and it indicates that in the next two years, 3G networks will be able to handle more calls and support higher data rates, significantly lowering cost of delivery and enabling operators to offer increasingly more bandwidth-intensive services. Not part of this study, but important to mention, is the fact that there are a number of additional enhancements already planned to be introduced as early as 2008. CDMA2000 1xEV-DO Revision B, for example, a further enhancement to the CDMA2000 standard, significantly increases the data throughput up to 73.5 Mbps in the forward link and 27 Mbps in the reverse link by dynamically allocating multiple radio frequency (RF) carriers across wider frequency blocks.

CDMA technologies are very well positioned to meet the evolving needs of the wireless market and to compete with any other wireless solutions today and in the future.

Terminology

4GV	4G Vocoder
CDMA2000	Third Generation CDMA2000 System
AMR	Adaptive Multi-Rate Vocoder
CDMA	Code Division Multiple Access
Code Limit	UMTS has only 256 orthogonal codes per sector in 5 MHz
CS1 – CS4	GPRS Modulation Schemes
DPC	Dynamic Power Control
DSCH	Downlink Shared Channel
DTX	Discontinuous Transmission
EDGE	Enhanced Data for GSM Evolution
EFR	Enhanced Full Rate Vocoder
EVRC	Enhanced Variable Rate Coder
FH	Frequency Hopping
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HSDPA	High Speed Downlink Packet Access
HWFL	Hardware Fractional Loading
IC	Interference Cancellation
Rel. A	Release A of CDMA2000 1X
RxD	Receive Diversity
SAIC	Single Antenna Interference Cancellation
SMV	Selective Mode Vocoder
TD	Transmit Diversity
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access