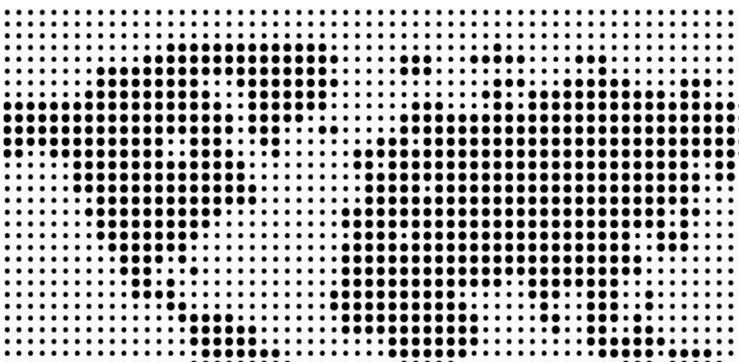
QUALCOMM

EV-DO Rev. A and B: Wireless Broadband for the Masses



Qualcomm Incorporated
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Table of Contents

[1] Introduction

Wireless phones are found in virtually every corner of the planet. The mass adoption of wireless technology has brought voice communication to more than 2.5 billion people around the world. This near-ubiquitous access to voice communication has changed the way people interact. It has become easier to keep in touch with family and friends across town or across continents. Wireless communication has also changed the way business is conducted. Productivity has improved as employees can stay connected anywhere and anytime. Businessmen can strike deals, service customers, and order supplies from just about anywhere. Small-scale farmers and fishermen can call ahead to find the best market for their goods and are not wholly reliant on a single wholesaler. Wireless telephony has helped make the world a smaller place.

The next great paradigm shift is now occurring as people are increasingly using wireless data networks to connect to the Internet and to each other. On mobile terminals, SMS has been an unqualified success, and wireless e-mail and location-based services are becoming increasingly popular. Mobile gaming has been very been popular and mobile music downloads are expected to surpass wireline downloads in the near future. Wireless networks are also providing connectivity for PCs and desktops. Mobile professionals are buying notebook PCs with built-in Wide Area Network (WAN) connectivity or are purchasing PC cards with the same. In developing countries, wireless is being used to provide DSL-like connectivity to the emerging middle class. As with wireless voice, wireless data is quickly becoming an indispensable part of our daily lives.

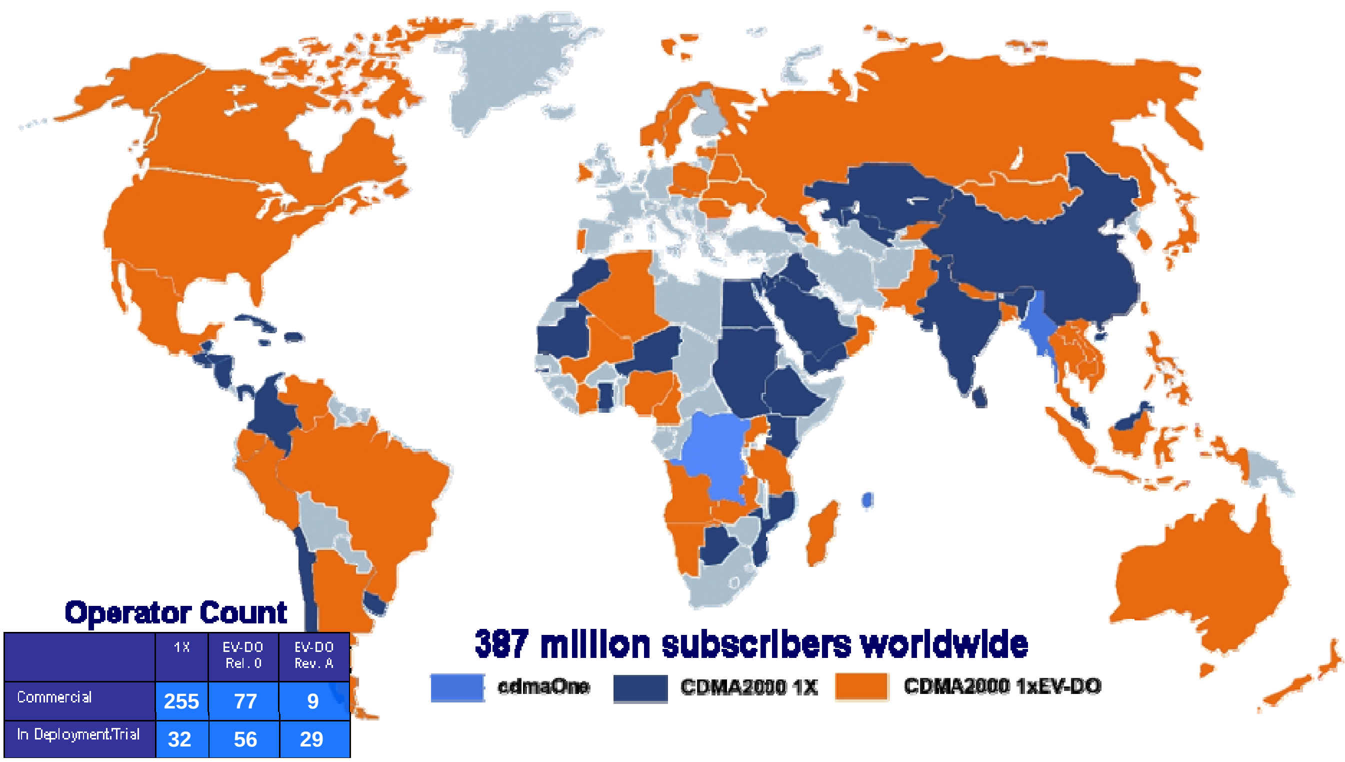
More than five years ago, EV-DO was commercially launched as the world's first high speed mobile broadband technology. The success of EV-DO Release 0 led to the development of EV-DO Revision A (Rev. A) and Revision B (Rev. B). These standards include innovative features for providing ubiquitous broadband coverage over a wide area. Rev. A improves uplink (also referred to as reverse link) and downlink (also referred to as forward link) performance, increases capacity, and adds support for low-latency applications such as VoIP, video telephony, and low-latency gaming. EV-DO Rev. B adds higher rates, multicarrier support, and better cell-edge performance to provide wireline-like performance across the entire coverage area. This paper describes the enhancements included in Rev. A and Rev. B that enable fast and efficient broadband wireless access in WAN deployments.

[2] The History of Mobile Broadband

When EV-DO Release 0 was first launched in 2002, it brought broadband wireless connectivity to mobile terminals. With EV-DO, consumers experienced 400-600 Kbps of average downlink throughput with bursts up to 2.4 Mbps - 4 to 10 times faster than data over CDMA2000® 1X (also referred to as 1xRTT) or UMTS networks.

EV-DO was designed to co-exist with CDMA2000 1X. Because the coverage area and frequency plans are the same, EV-DO was deployed in the same cell sites as 1X, using the same antenna. Also, the EV-DO channel cards fit in the 1X channel card enclosures. Other competing technologies were limited in performance and were more costly to deploy.

As the first mass market mobile broadband technology, EV-DO blazed a trail for the rest of the industry. With its head start, EV-DO quickly became the most widely deployed wireless broadband standard in the world. As of August 2007, the EV-DO Release 0 networks of 77 operators served more than 65 million subscribers in 46 countries worldwide. Figure 1 shows the worldwide coverage of EV-DO.



	1X	EV-DO Rel. 0	EV-DO Rev. A
Commercial	255	77	9
In Deployment/Trial	32	56	29

Figure 1. Worldwide Coverage of EV-DO

Shortly after the launch of EV-DO Release 0, work began on improving the user experience even further. The efficient downlink design was used as a reference to create a highly efficient uplink. Quality of Service (QoS) and other features were added to create a flexible and versatile solution. These enhancements were standardized in 2004 as EV-DO Rev. A, which was commercially deployed in 2006. As of September 2007, Rev. A was available on five continents, with nationwide footprints of Rev. A in the U.S., Japan and Korea.

The strength and flexibility of Rev. A has since been evolved to Rev. B, which adds multicarrier support. Rev. B also increases the single carrier peak rates of EV-DO and provides wireline-like performance across a large coverage area.

As EV-DO continues to evolve, networks and devices will provide increasingly enhanced levels of performance. Because of the forward and backward compatibility of EV-DO, users will benefit from the wide array of existing networks and devices. Rev. B devices will seamlessly roam onto Rev. A and Release 0 networks. Similarly, Release 0 and Rev. A devices will continue to be supported on Rev. B networks, allowing operators to gradually roll out Rev. B and benefit from the increased performance without impacting existing subscribers. Consumers and operators will both benefit from the large and established ecosystem of device and infrastructure vendors who are creating exciting and innovative solutions around EV-DO.

[3] EV-DO Rev. A – Downlink, Uplink, VoIP and More

Rev. A introduces a number of significant changes to improve airlink performance of EV-DO. Key aspects of Rev. A are:

- Peak rates of 3.1 Mbps on the downlink and 1.8 Mbps on the uplink
- Sector capacity of 1.5 Mbps downlink and 1.2 Mbps uplink
- Enhanced QoS capabilities, improving the connection setup time and lowering end-to-end delays
- VoIP capacity of up to 49 calls per sector

Major features such as QoS provide greater flexibility for supporting a whole new class of applications that were not previously possible on wireless networks. Some of the key applications enabled include:

- Voice over IP (VoIP)
- Push To Talk/Push To Media
- Video Telephony
- Multimedia Upload/Exchange
- Low-Latency Gaming
- High-Speed Web Browsing
- Large E-mail Attachments
- Video/Music Streaming/Downloads
- Multicasting

Most importantly, Rev. A provides a significant improvement to the user experience of the wireless consumer.

3.1 New Class of Applications

3.1.1 Uplink-Centric Applications

The enhanced Reverse Link capability of Rev. A improves the performance of uploads. Current trends in the Internet show more emphasis being placed on user created content.

Mobile phones now have cameras to capture photos and videos. Events are now captured on phones and then uploaded or blogged directly from the phones. Storage has increased on mobile devices, and users are carrying their media libraries with them. Web 2.0 services increase interaction between users, encouraging exchange of content.

Rev. A reduces the upload time and improves the overall user experience when interacting with other users. This enables users to express themselves anytime and anywhere, allowing operators greater opportunity to better monetize their networks.

3.1.2 Rich Media Experience

The mechanisms in Rev. A that support both VoIP and data enable a multitude of applications that support simultaneous VoIP and data. One classic example of a mixed VoIP and data application is Video Telephony (VT), however this is only one of a spectrum of solutions. Applications such as Video Share and Picture Share allow two or more users to simultaneously view and discuss the same video or picture. The QoS and low-latency capabilities of Rev. A support prioritization of the VoIP/video/picture flows to provide a richer media experience than offered by voice alone.

Another benefit of low-latency packet transport is the ability to support the gradual introduction of new media and voice services. One example of this is the EVRC Wide-Band (EVRC-WB) codec available with Rev. A VoIP. The EVRC-WB codec has 16 kHz of frequency response and provides improved audio quality over standard 8k codecs. Because of the packet transport of Rev. A, EVRC-WB can be gradually introduced by adding new handsets, downloading the new codec into the audio gateway, and updating the IMS server to support the negotiation of the new codec.

The flexibility to quickly and easily roll out new applications and services means it is less costly to introduce these to the market. This provides a substantial advantage to operators by allowing them to monetize their network quicker. Users benefit from having access to the latest services, including the popular applications of today and the applications and services that haven’t even been conceived.

3.1.3 Low-latency Gaming

As mobile devices have become more powerful, the gaming experience once reserved for high-end desktop machines is now available on mobile terminals. Features such as Digital Signal Processors (DSPs) and 3D graphics are commonplace in mobile platforms. These hardware components now enable support for First Person Shooter (FPS) and Massively Multi-player Online (MMO) games. These games require both fast processors and fast connections to the game server. Packets representing bullets in FPS can arrive every 30 ms, acting much like voice packet. The low-latency performance of Rev. A can handle these packets along with the half-duplex VoIP communication that is being introduced in MMO platforms. In addition, the high-bandwidth capability of Rev. A can easily support the high throughputs of MMOs.

3.2 Rev. A Enhancements

Rev. A provides a number of enhancements over EV-DO Release 0 that improve the performance of the network and increase the spectral efficiency. These improvements include changes to the Reverse Link (RL) and Forward Link (FL), as well as improved handoff and enhanced quality of service, enabling multiple content flows to be prioritized based on performance requirements.

Optimized Reverse Link

One of the most significant changes Rev. A brings is the improved RL. The redesigned link provides a significant speed and capacity improvement, and is designed to support low latency applications such as VoIP.

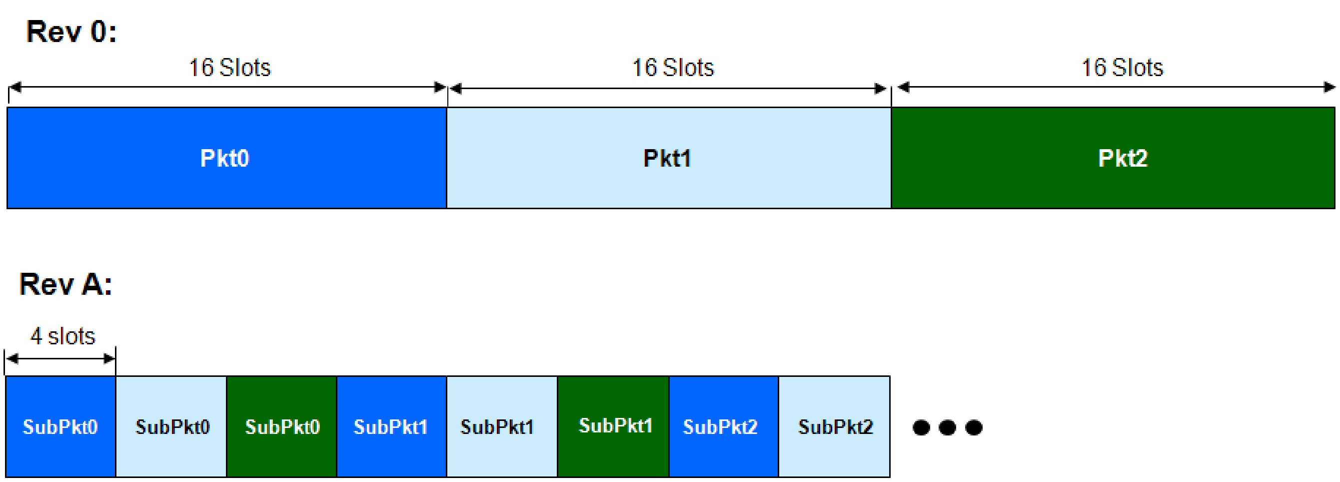


Figure 2. Optimized Reverse Link

New to the Rev. A RL are QPSK and 8-PSK modulation, and a host of physical layer packet sizes. Also supported is a four-slot sub-packet transmission format, a 3 sub-packet interlace, and Hybrid ARQ. This new physical layer architecture brought over from the FL improves the efficiency of the air-link.

In Release 0, RL frames were transmitted over 26.6 ms, or 16 FL slots. An equivalent Rev. A transmission is a four-slot subframe transmitted four times as shown in Figure 2. The total transmission time is the same, however interspersing the subframes with other packets provides time for the Access Network to attempt a decode of the received frame and relay the result back to the Mobile Terminal. If the frame is successfully decoded before the 4th subframe, the transmission of remaining subframes is discontinued or 'early-terminated'.

Additional techniques can be employed to reduce packet latency. Because the subframes are sent at different times, algorithms can be used to selectively boost the transmit power of individual subframes to improve the probability of an early decode.

These improvements combine to improve the RL sector throughput of Rev. A by 70% over EV-DO Release 0 as shown in Figure 3. Adding Successive Interference Calculation (SIC) and 4-way Receive Diversity at the access network results in an 7x user experience improvement over EV-DO Release 0. The improved link also supports low-latency applications such as VoIP, Push-To-Talk, and video telephony.

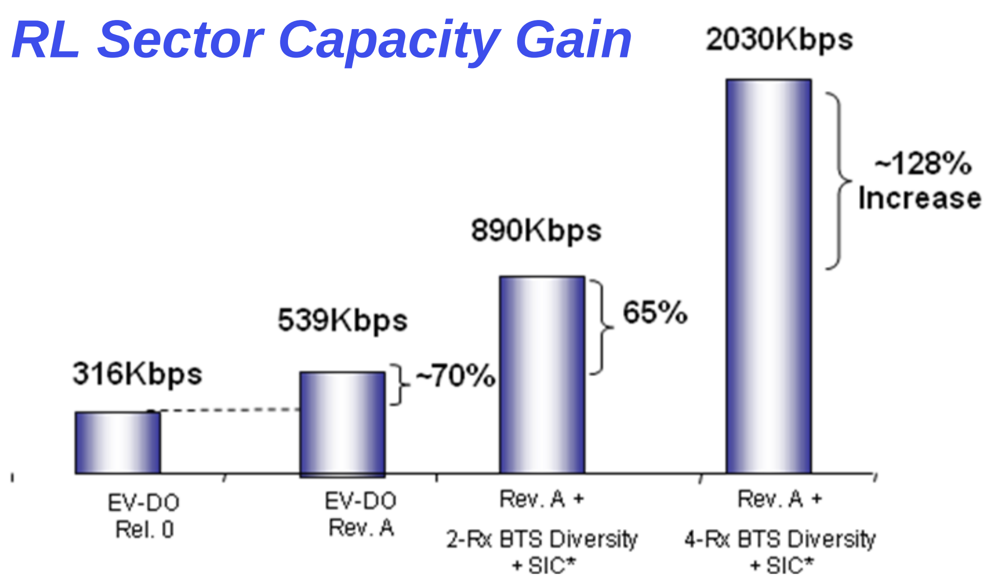


Figure 3. RL Sector Capacity Gain

3.2.1 Rev. A Forward Link Enhancements

Rev. A provides increased performance on the FL by adding new data rates of 1.5 Mbps and 3.1 Mbps.

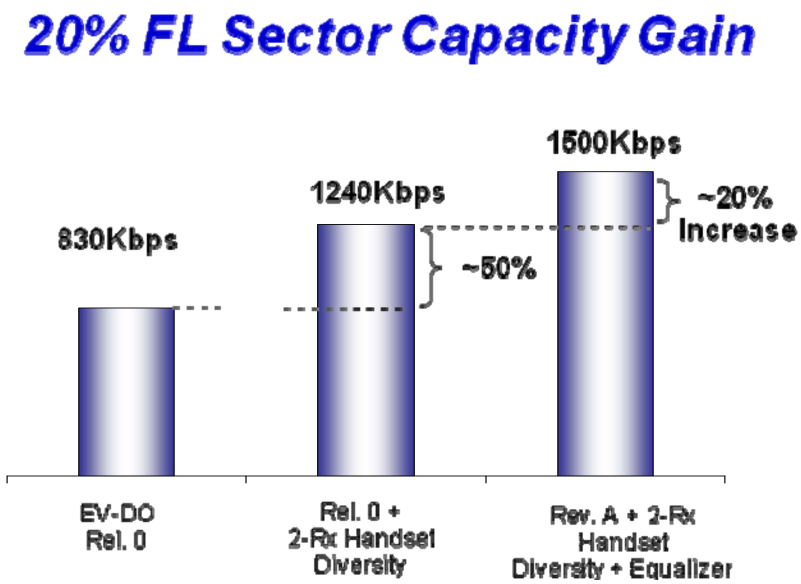


Figure 4. FL Sector Capacity Gain

Smaller packets have also been introduced to improve packing efficiency and reduce transmission times for small data-rate applications such as VoIP. Physical layer packets of 128, 256, and 512 bits are now possible. Multi-user packets have been introduced to take advantage of the small physical layer packets. Packets for different users are aggregated into a single physical layer packet. By combing smaller packets, the overall efficiency of the DL is improved by sending more payload and less overhead.

The improved rates result in a 20% sector capacity gain over EV-DO Release 0 as shown in Figure 4. More importantly; the changes increase the overall VoIP capacity of the network.

3.2.2 Faster Handoff

A key feature in Rev. A is the improved handoff performance over EV-DO Release 0. The handoff improvements were necessary to support applications that require continuous delivery of packets such as VoIP.

The Data Source Channel (DSC) is a new physical layer channel from the mobile that provides an early indication of handoff to the access network. When the mobile decides to handoff to a new Base Station Transceiver (BTS), it signals the network by changing the DSC 64 slots before formalizing the handoff. This advance notice allows the network to queue data at the new BTS while continuing to serve the mobile from the original BTS. When the handoff is triggered, the mobile is not served for 16 slots in a typical configuration. However, as soon as the mobile initiates a connection with the new BTS, there is data waiting to be delivered to the mobile.

The outage during handoff of a little more than 16 slots results in an outage of about 27 ms. Since the VoIP implementation within Rev. A terminals can handle 40-60 ms of jitter, this outage is well within the tolerable range of VoIP and other low-latency applications.

3.2.3 Enhanced Multi-Flow Packet App

Coupled with the physical layer improvements in Rev. A is support for multiple application layer flows. This is enabled through the Enhanced Multi-Flow Packet App (EMPA) which provides the mechanisms for the network to assign separate Radio Link Protocol (RLP) instances per flow to a single user. EMPA is a feature of Rev. A that differentiates flows, allowing Quality of Service (QoS). Another key aspect of EMPA is the integration of Robust Header Compression (RoHC) which allows efficient VoIP transmission. QoS and VoIP are discussed below.

3.3 End-To-End Quality of Service

With Rev. A, QoS is used to prioritize data delivery to devices and individual applications. Both user-based and flow-based QoS are supported. With user-based QoS, premium users receive prioritized service in a proportional manner and experience greater data rates than non-premium users. Flow-based QoS goes a step further and differentiates between flows to different applications on the same device. This allows a network to simultaneously support premium services such as VoIP & PTT, and non-premium services such as web browsing and file download. Premium services can be billed at a higher rate, while the system still supports best-effort services.

Rev. A networks provide true end-to-end quality of service by utilizing the IS-835D standard to negotiate QoS on a per-application basis. Premium applications such as VoIP, Video Telephony, PTT and low-latency gaming can negotiate priority service from the network. With flow-based QoS, best-effort services can also be offered at a flat rate, allowing operators to generate incremental revenue from spare system capacity.

3.4 Optimized VoIP

Even as data usage is growing significantly, voice is currently the most widely used application for wireless. Networks have been deployed worldwide to provide voice access, and voice subscribers are still growing at a rapid pace. Operators are interested in utilizing a single core network to service both voice and data networks at a reduced cost. Providing both voice and data on the same wireless network can lead to greater economies of scale, and lower CAPEX and OPEX. Operators are also interested in better monetizing their networks, and adding VoIP to data applications provides an enhanced user experience for consumers and drives revenue increases. Trends show interest by users in fixed mobile convergence and rich media applications.

The key difference between Circuit-Switched (CS) Voice and VoIP is in the overhead associated with each solution. With CS Voice, the Radio Access Network (RAN) assigns a circuit to the mobile and voice packets are continuously exchanged on this circuit. With VoIP, each voice packet is packaged into an IP packet. Packet exchange between the mobile and the RAN is not governed by a strict timeline and packets can therefore be opportunistically delivered over a small window of time.

The additional IP overhead used for addressing of VoIP packets can represent a substantial overhead when compared to a CS Voice solution. Rev. A solves this by integrating Robust Header Compression (RoHC) into the RAN and the mobile.

3.4.1 Robust Header Compression

Rev. A addresses the overhead issue of VoIP by integrating support for Robust Header Compression (RoHC) directly into the device and the RAN. An IETF protocol developed for VoIP header compression, RoHC compresses the IP/UDP/RTP header from 40 bytes down to as little as 3 bytes. Considering that the payload for EVRC Voice is only 22 bytes, a VoIP packet is reduced from 62 bytes to 25 bytes—a significant reduction.

Figure 5 shows the RoHC compressor/decompressor relationship and the integration with the EV-DO Rev. A RAN.

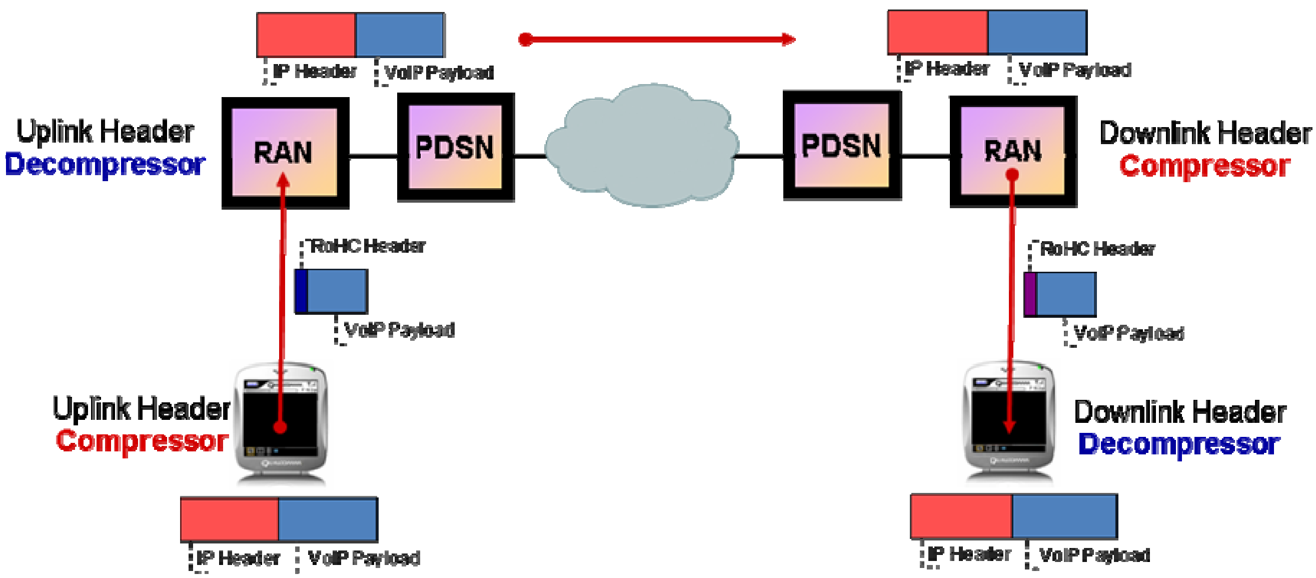


Figure 5. RoHC compressor/decompressor

Compressed packets are sent over the airlink. This reduction of payload bytes provides a direct increase in the VoIP capacity of the network.

3.4.2 Telco-Quality VoIP

Rev. A VoIP does not compromise on voice quality and is indistinguishable from CS Voice. EV-DO VoIP utilizes the same EVRC voice codec as 1X CS voice to maintain the same audio fidelity. Recovery from air link errors is identical because voice packets are unbundled at the physical layer, and therefore only one voice frame is lost if a physical layer packet is lost. In addition, the low-latency support in Rev. A ensures that voice packets are delivered with similar latency as CS voice, with 95% of the packets arriving before 280 ms. As a result, Rev. A VoIP provides all the advantages of VoIP while maintaining the CS Voice user experience.

The enhanced features of Rev. A including multi-user packets, small packet sizes, EMPA and RoHC result in a capacity of 42 VoIP calls per sector, which is slightly higher than current CDMA2000 1xRTT CS voice capacity. However, additional improvements available with Rev. A equipment such as Pilot Interference Cancellation (PIC) increase the VoIP capacity of Rev. A to 49 calls per sector. The telco-quality performance of Rev. A VoIP along with the ability to support mixed VoIP and data on the same network are significant incentives for operators to consider Rev. A VoIP. Table 1 below shows the performance of Rev. A VoIP using various voice codecs, including Markov Service Option (MSO), the random voice traffic generator used in the 3GPP2 simulation environment

	Rev. A VoIP Calls/Sector	
	No IC	**PIC**
MSO	**42**	**49**
EVRC	**41**	**48**
EVRC-WB	**41**	**48**
EVRC-B op2	**45**	**54**
Assumptions	*1 slot pilot filter* *Setpoint range: [-22dB, -18dB]* *Overhead Gains: [RRI: -8dB , DRC: -8/-6dB, DSC:-9 dB]*	

Table 1: Performance of Rev. A VoIP Using Various Codes

[4] Rev. B – Enhanced Mobile Broadband

The next step in the EV-DO evolution path, Rev. B, allows mobile terminals to use multiple RF carriers to communicate with the Access Network.

Rev. B improves the performance of all Rev. A data applications, and provides an enhanced user experience across the entire coverage area. With consistently higher data rates, Rev. B enables higher streaming rates for video and audio; faster upload of pictures, videos, and audio files; and faster mobile broadband for laptops.

4.1 Key Benefits of Rev. B

4.1.1 Enhanced Experience for Broadband Apps

The improvements in Rev. B provide a significantly improved experience for mobile broadband applications.

Rev. B enables higher streaming rates of audio and video. As mobile screens improve in quality and resolution, users will demand higher quality and higher resolution video streaming. With Rev. B, video downloads can be offered at higher resolutions and more users can be served. Similarly, more channels of Internet radio and on-demand music can be simultaneously streamed.

The Internet user experience is noticeably improved. Pictures, videos, and audio files can now be uploaded or downloaded much faster. Web surfing is noticeably faster as RF carriers are added. HTTP page response times decrease by 38% with a two-carrier Rev. B deployment, and up to 50% with three carriers. Table 2 shows the peak, average, and cell edge data rate improvements as RF carriers are added.

	Rev A	2 X Rev B	3 X Rev B
FL Peak Data Rate	3.1 Mbps	6.2 Mbps	9.3 Mbps
FL Avg Data Rate	1.25 Mbps	2.5 Mbps	3.75 Mbps
FL Cell Edge Data Rate	0.5 Mbps	1.0 Mbps	1.5 Mbps
Web Page Response Time	Baseline	38% reduction	50% reduction

Table 2: Peak, Average, and Cell Edge Data Rate Improvements

Applications such as video surveillance and video conferencing can now be offered to a larger number of users. In addition, by adding bundled services and combined billing, operators can now offer Fixed Mobile Convergence (FMC) solutions to the consumer.

The enhanced data rates of Rev. B allow operators to offer it as the primary broadband connection in under-served markets, while QoS ensures the high revenue services such as VoIP are concurrently supported.

4.1.2 Increased VoIP Performance

As operators migrate voice services to Rev. A VoIP, the need for additional capacity will necessitate the deployment of additional carriers. As these carriers get deployed with Rev. B, users will benefit from the additional enhancements within Rev. B that improve VoIP performance. Total Interference Cancellation (TIC) is an optional feature with Rev. B that reduces the interference received from other devices, allowing them to transmit at a lower power. This increases the capacity of the network while also improving the talk time of the devices. Enhancements to paging algorithms also improve stand-by times.

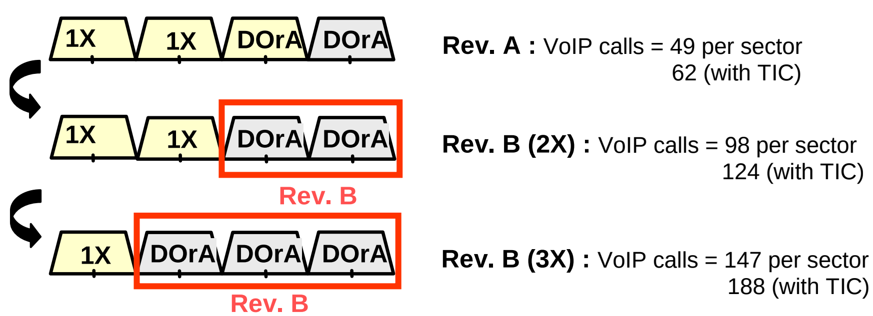


Figure 6. Increased VoIP Performance

The increased VoIP performance with Rev. A will drive the replacement of 1xRTT carriers with Rev. A, and Rev. B is the logical choice to take advantage of the multiple carriers. Figure 6 shows how VoIP capacity scales by adding Rev B carriers.

4.1.3 Selective Deployment in High Demand Areas

A key advantage available with Rev. B is the ability to selectively upgrade areas of the network that need higher capacity or greater performance. Because of the backward compatibility and seamless roaming across Rev. A networks, Rev. B can be gracefully rolled-out across a network. As Rev. B gets deployed, users in those areas will immediately experience improved performance, while continuing to benefit from the availability of Rev. A across the wider coverage area.

Figure 7 shows a possible deployment scenario. Operators may choose to deploy three carriers in dense urban areas to provide greater capacity, two carriers in suburban areas, and one carrier in rural areas to provide continuity of coverage across the entire region.

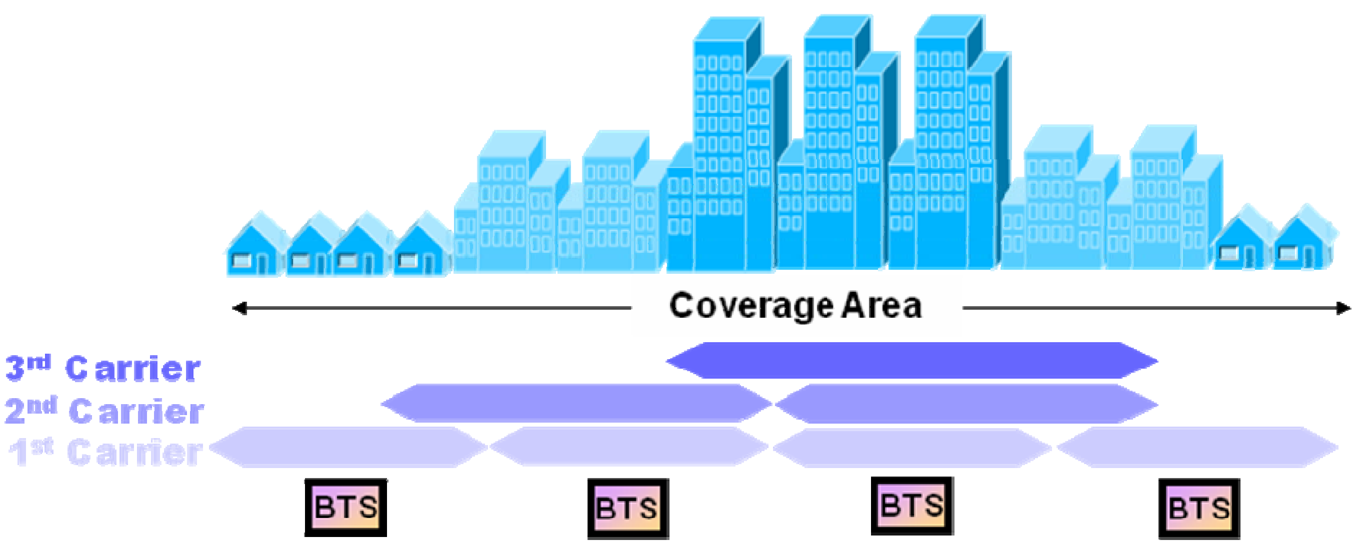


Figure 7. Possible Deployment Scenario

4.2 Software Upgrade to Existing Rev. A Equipment

Rev. B allows operators to leverage their Rev. A network equipment by adding Rev. B functionality to existing channel cards through a software upgrade. Multilink RLP and multicarrier operation can be added, allowing aggregation of carriers for Rev. B devices.

Operators around the world are currently deploying Rev. A across new or existing EV-DO Release 0 networks. In a short time, the continued traction of data services will necessitate the deployment of multiple Rev. A carriers. With the software upgrade option, up to three Rev. A carriers can be aggregated to provide 9.3 Mbps of peak throughput in 5 MHz. This provides a significant network enhancement for operators.

Backward compatibility and seamless roaming across Rev. A, Release 0, and even 1xRTT data networks, ensures that Rev. B devices are able to work with existing networks across the world. In addition, Rev. B network support for existing devices allows consumers to benefit from greater economies of scale. Low-cost Release 0 devices will still allow users to participate in the mobile broadband experience at entry-level prices while Rev. B terminals will provide a wireline-like experience on the same network.

4.3 Rev. B Enhancements

4.3.1 Multicarrier Operation

Rev. B enables mobile terminals to communicate with the access network across multiple carriers at once. By utilizing more than one carrier to transmit data, Rev. B terminal users enjoy higher throughputs and lower latency. Bundling two or more carriers together results in two or more times the data rate of a Rev. A device. Similarly, lower latency is achieved by reducing the transmit time of each packet.

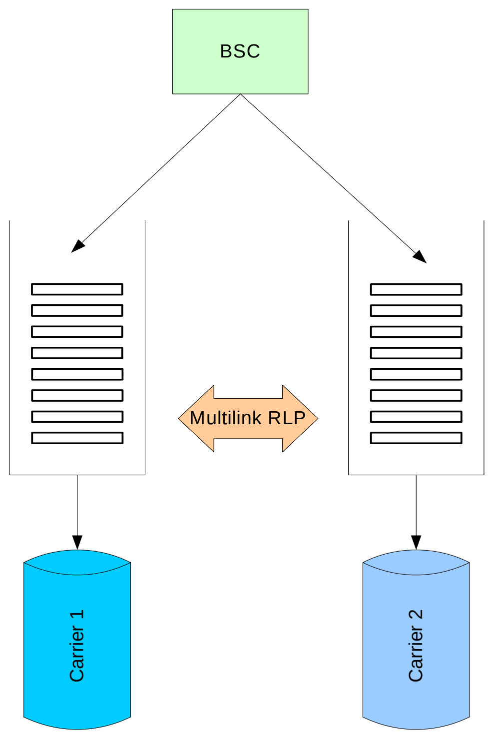


Figure 8. Multilink RLP Operation

Multilink Radio-Link-Protocol (RLP) is used to deliver data across the two carriers. The queue of each carrier is monitored and as each queue depletes, it is replenished by the access network. Since each carrier is a separate physical path, the performance across it is independent of the other carrier. By ensuring the queues for each carrier are carrying data, Multilink RLP maximizes the availability of the two air links.

4.3.2 Higher Order Modulation

Rev. B introduces new physical layer rates by adding 64-QAM. This increases the single carrier Rev. B physical layer peak rate to 4.9 Mbps, a 58% improvement over the Rev. A physical layer peak rate. In a typical 3 carrier deployment, Rev. B will support a peak rate of 14.4 Mbps.

In a mobile environment, as users move across a coverage area, mobile terminals encounter varied signal conditions. As such, periods of high signal strength can be capitalized upon to deliver a burst of data, resulting in greater availability of system resources for future needs. Implementing the Rev. B physical layer requires a hardware upgrade of the channel cards at the base station.

[5] Summary

EV-DO Release 0 introduced the world to mobile broadband and established itself as a benchmark standard. Using EV-DO, operators were able to better monetize their networks by providing rich multimedia content, leading to differentiated services. These services are now a mainstay of wireless networks and are a fast growing revenue segment.

The enhancements included in Rev. A improve the uplink performance of EV-DO and allow low-latency applications such as VoIP and low-delay gaming. Rev. A improves the performance of social networking and Web 2.0 applications—the enhanced services that users are becoming accustomed to on their mobile platforms. The ability to support telco-quality VoIP, enhanced rich media applications, and broadband data connectivity on the same network provides a competitive advantage over competing networks. This allows greater monetization of spectrum, and is a key incentive for operators to deploy Rev. A.

Finally, as broadband data applications continue to grow in popularity, the increase in data adoption necessitates the deployment of multiple carriers of Rev. A. Rev. B allows higher data rates by aggregating Rev. A carriers, allowing applications such as high-def video conferencing and streaming video. Rev. B improves the user experience for all applications available over Rev. A, and provides a cost-effective way to achieve high data rates while leveraging the installed base of EV-DO users.